Appendix E  Self-Test Solutions and Answers to Even-Numbered Problems

Chapter 1

2. Define the problem; identify the alternatives; determine the criteria; evaluate the alternatives; choose an alternative.

4. A quantitative approach should be considered because the problem is large, complex, important, new, and repetitive.

6. Quicker to formulate, easier to solve, and/or more easily understood.

8. a. Max $10x + 5y$
   s.t.
   $5x + 2y \leq 40$
   $x \geq 0, y \geq 0$
   b. Controllable inputs: $x$ and $y$
   Uncontrollable inputs: profit (10, 5), labor-hours (5, 2), and labor-hour availability (40)
   c. See Figure 1.8c.
   d. $x = 0, y = 20$; Profit = $100$ (solution by trial and error)
   e. Deterministic

10. a. Total units received = $x + y$
    b. Total cost = $0.20x + 0.25y$
    c. $x + y = 5000$
    d. $x \leq 4000$ Kansas City
       $y \leq 3000$ Minneapolis
    e. Min $0.20x + 0.25y$
       s.t.
       $x + y = 5000$
       $x \leq 4000$
       $y \leq 3000$
       $x, y \geq 0$

FIGURE 1.8C  SOLUTION

12. a. $7C = 2000 + 60x$
    b. $P = 80x - (2000 + 60x) = 20x - 2000$
    c. Break even when $P = 0$
       Thus, $20x - 2000 = 0$
       $20x = 2000$
       $x = 100$

14. a. 4000
    b. Loss of $8000
    c. $48.11$
    d. $10,810$ profit

16. a. Max $6x + 4y$
    b. $50x + 30y \leq 800,000$
       $50x \leq 500,000$
       $30y \leq 450,000$

18. a. Max $2.80x_1 + 2.90y_1 + 2.70x_2 + 2.80y_2 + 2.62x_3 + 2.72y_3$
    b. (1) $x_1 + y_1 \leq 12,000$
       (2) $x_2 + y_2 \leq 20,000$
       (3) $x_3 + y_3 \leq 24,000$
    c. $.65x_1 - .35x_2 - .35x_3 \geq 0$
       $.50x_1 + .50x_2 - .50x_3 \leq 0$
       $- .15x_1 - .15x_2 + .85x_3 \geq 0$
       $.80y_1 - .20y_2 - .20y_3 \leq 0$
       $- .30y_1 + .70y_2 - .30y_3 \leq 0$
       $- .40y_1 - .40y_2 + .60y_3 \leq 0$
       $x_1 + x_2 + x_3 \geq 20,000$
       $y_1 + y_2 + y_3 \geq 20,000$

20. a. Max $7000x + 4000y$
    b. $500x + 250y \leq 100,000$
    c. $x \leq 20$
    d. $y \geq 50$
    e. $2/3x - 1/3y \geq 0$
    f. If the number of television ads purchased ($x$) must be less than or equal to 20 and the number of Internet ads purchased ($y$) must be at least 50, the producers’ desire that at least one-third of all ads will be placed on television cannot be satisfied.

Chapter 2

1. Parts (a), (b), and (e) are acceptable linear programming relationships.
   Part (c) is not acceptable because of $-2x_1^2$.
   Part (d) is not acceptable because of $3\sqrt{x_1}$.
   Part (f) is not acceptable because of $1x_1x_2$.
   Parts (c), (d), and (f) could not be found in a linear programming model because they contain nonlinear terms.
10. **Optimal solution**

\[ A = \frac{12}{7}, \quad B = \frac{15}{7} \]

**Value of Objective Function**

\[ 2\left(\frac{12}{7}\right) + 3\left(\frac{15}{7}\right) = \frac{69}{7} \]

**Equation (1)**

\[ A + 2B = 6 \quad (1) \]

**Equation (2)**

\[ 5A + 3B = 15 \quad (2) \]

**Equation (3)**

\[ -7B = -15 \]

**From equation (1):**

\[ A = 6 - 2\left(\frac{15}{7}\right) \]

\[ = 6 - \frac{30}{7} = \frac{12}{7} \]

12. **a.** \( A = 3, \ B = 1.5; \) value of optimal solution = 13.5

**b.** \( A = 0, \ B = 3; \) value of optimal solution = 18

**c.** Four: \( (0, 0), (4, 0), (3, 1.5), \) and \( (0.3) \)

13. **a.** Feasible region consists of this line segment only
b. The extreme points are (5, 1) and (2, 4).

c. 

\[
\begin{array}{c}
0 & 2 & 4 & 6 & 8 \\
A & 2 & 4 \quad \text{B = 4} & 2B + A & 10 \\
\end{array}
\]

14. a. Let \( F \) = number of tons of fuel additive
\( S \) = number of tons of solvent base
Max \( 40F + 30S \)
s.t.
\[
\begin{align*}
\%F + \frac{1}{2} S & \leq 20 & \text{Material 1} \\
\frac{1}{2} S & \leq 5 & \text{Material 2} \\
\%F + \frac{1}{10} S & \leq 21 & \text{Material 3} \\
F, S & \geq 0 
\end{align*}
\]

b. \( F = 25, S = 20 \)

c. Material 2: 4 tons are used; 1 ton is unused.

d. No redundant constraints

16. a. \( 3S + 9D \)

b. \( (0, 540) \)

c. \( 90, 150, 348, 0 \)

17. Max \( 5A + 2B + 0x_1 + 0x_2 + 0x_3 \)
s.t.
\[
\begin{align*}
1A - 2B + 1x_1 & = 420 \\
2A + 3B - & + 1x_2 = 610 \\
6A - 1B + & + 1x_3 = 125 \\
A, B, s_1, s_2, s_3 & \geq 0 
\end{align*}
\]

b. \( A = 18/7, B = 15/7 \)

c. \( 0, 0, 4/7 \)

20. a. \( A = 3.43, B = 3.43 \)

c. \( 2.86, 0, 1.43, 0 \)

22. b. 

<table>
<thead>
<tr>
<th>Extreme Point</th>
<th>Coordinates</th>
<th>Profit ($)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>(0, 0)</td>
<td>0</td>
</tr>
<tr>
<td>2</td>
<td>(1700, 0)</td>
<td>8500</td>
</tr>
<tr>
<td>3</td>
<td>(1400, 600)</td>
<td>9400</td>
</tr>
<tr>
<td>4</td>
<td>(800, 1200)</td>
<td>8800</td>
</tr>
<tr>
<td>5</td>
<td>(0, 1680)</td>
<td>6720</td>
</tr>
</tbody>
</table>

Extreme point 3 generates the highest profit.

c. \( A = 1400, C = 600 \)

d. Cutting and dyeing constraint and the packaging constraint

e. \( A = 800, C = 1200; \) profit = $9200

24. a. Let \( R \) = number of units of regular model
\( C \) = number of units of catcher’s model
Max \( 5R + 8C \)

\[
\begin{align*}
& 1R + \frac{1}{2}C \leq 900 & \text{Cutting and sewing} \\
& \frac{1}{2}R + \frac{1}{10}C \leq 300 & \text{Finishing} \\
& \frac{1}{4}R + \frac{1}{10}C \leq 100 & \text{Packaging and shipping} \\
& R, C \geq 0 
\end{align*}
\]

b. \( R = 500, C = 150 \)

c. \( 5(500) + 8(150) = 3700 \)

d. \( 1C \) & \( S \) \( 1(500) + \frac{1}{2}(150) = 725 \)

\( F \) \( \frac{1}{4}(500) + \frac{1}{10}(150) = 300 \)

\( P \) & \( S \) \( \frac{1}{8}(500) + \frac{1}{4}(150) = 100 \)

e. 

<table>
<thead>
<tr>
<th>Department</th>
<th>Capacity</th>
<th>Usage</th>
<th>Slack</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cutting and sewing</td>
<td>900</td>
<td>725</td>
<td>175 hours</td>
</tr>
<tr>
<td>Finishing</td>
<td>300</td>
<td>300</td>
<td>0 hours</td>
</tr>
<tr>
<td>Packaging and shipping</td>
<td>100</td>
<td>100</td>
<td>0 hours</td>
</tr>
</tbody>
</table>

26. a. Max \( 50N + 80R \)
s.t.
\[
\begin{align*}
N + R & = 1000 \\
N & \geq 250 \\
R & \geq 250 \\
N - 2R & = 0 \\
N, R & \geq 0 
\end{align*}
\]

b. \( N = 666.67, R = 333.33; \) Audience exposure = 60,000

28. a. Max \( 1W + 1.25M \)
s.t.
\[
\begin{align*}
5W + 7M & \leq 4480 \\
3W + 1M & \leq 2080 \\
2W + 2M & \leq 1600 \\
W, M & \geq 0 
\end{align*}
\]

b. \( W = 560, M = 240; \) Profit = 860
30. a. Max 15E + 18C
   s.t.
   40E + 25C ≤ 50,000
   40E ≥ 15,000
   25C ≥ 10,000
   25C ≤ 25,000
   E, C ≥ 0
c. (375, 400); (1000, 400); (625, 1000); (375, 1000)
d. E = 625, C = 1000
   Total return = $27,375
31. B
   Feasible region
   Optimal solution
   A = 3, B = 1
   3A + 4B = 13
   Objective function value = 13
32.

<table>
<thead>
<tr>
<th>Extreme Points</th>
<th>Objective Function Value</th>
<th>Surplus Demand</th>
<th>Surplus Production</th>
<th>Slack Processing Time</th>
</tr>
</thead>
<tbody>
<tr>
<td>(250, 100)</td>
<td>800</td>
<td>125</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>(125, 225)</td>
<td>925</td>
<td>—</td>
<td>—</td>
<td>125</td>
</tr>
<tr>
<td>(125, 350)</td>
<td>1300</td>
<td>—</td>
<td>—</td>
<td>—</td>
</tr>
</tbody>
</table>
34. a. B
   Feasible region
   (21/4, 9/4)
   (4, 1)
b. The two extreme points are
   (A = 4, B = 1) and (A = 21/4, B = 9/4)
c. The optimal solution (see part (a)) is A = 4, B = 1.
35. a. Min 6A + 4B + 0x1 + 0x2 + 0x3
   s.t.
   2A + 1B - s1 = 12
   1A + 1B - s2 = 10
   1B + x3 = 4
   A, B, x1, s2, s3 ≥ 0
   b. The optimal solution is A = 6, B = 4.
   c. x1 = 4, s2 = 0, s3 = 0
36. a. Min 10,000T + 8,000P
   s.t.
   T ≥ 8
   P ≥ 10
   T + P ≥ 25
   3T + 2P ≤ 84
   c. (15, 10); (21.33, 10); (8, 30); (8, 17)
   d. T = 8, P = 17
   Total cost = $216,000
38. a. Min 7.50S + 9.00P
   s.t.
   0.10S + 0.30P ≤ 6
   0.06S + 0.12P ≤ 3
   S + P = 30
   S, P ≤ 0
   c. Optional solution is S = 15, P = 15.
   d. No
   e. Yes
40. P1 = 30, P2 = 25; Cost = $55
42. B
   Satisfies constraint #2
   Infeasibility
   Satisfies constraint #1
43. B
   Unbounded
44. a. $A = \frac{30}{14}, B = \frac{30}{14}$; Value of optimal solution = $\frac{50}{14}$
   b. $A = 0, B = 3$; Value of optimal solution = 6
46. a. 180, 20
   b. Alternative optimal solutions
   c. 120, 80
48. No feasible solution
50. $M = 65.45, R = 261.82$; Profit = $45,818$
52. $S = 384, O = 80$
54. a. Max $160M_1 + 345M_2$
    s.t.
    $M_1 \leq 15$
    $M_2 \leq 10$
    $M_1 \geq 5$
    $M_2 \geq 5$
    $40M_1 + 50M_2 \leq 1000$
    $M_1, M_2 \geq 0$
   b. $M_1 = 12.5, M_2 = 10$
56. No, this could not make the problem infeasible. Changing an equality constraint to an inequality constraint can only make the feasible region larger, not smaller. No solutions have been eliminated and anything that was feasible before is still feasible.
58. The statement by the boss shows a fundamental misunderstanding of optimization models. If there were an optimal solution with 15 or less products, the model would find it, because it is trying to minimize. If there is no solution with 15 or less, adding this constraint will make the model infeasible.

Chapter 3

1. a. 

   ![Graph](image)

   b. The same extreme point, $A = 7$ and $B = 3$, remains optimal; value of the objective function becomes $5(7) + 2(3) = 41$.
   c. A new extreme point, $A = 4$ and $B = 6$, becomes optimal; value of the objective function becomes $3(4) + 4(6) = 36$.
   d. The objective coefficient range for variable $A$ is 2 to 6; the optimal solution, $A = 7$ and $B = 3$, does not change. The objective coefficient range for variable $B$ is 1 to 3; re-solve the problem to find the new optimal solution.

2. a. The feasible region becomes larger with the new optimal solution of $A = 6.5$ and $B = 4.5$.
   b. Value of the optimal solution to the revised problem is $3(6.5) + 2(4.5) = 28.5$; the one-unit increase in the right-hand side of constraint 1 improves the value of the optimal solution by $28.5 - 27 = 1.5$; therefore, the dual value for constraint 1 is 1.5.
   c. The right-hand-side range for constraint 1 is 8 to 11.2; as long as the right-hand side stays within this range, the dual value of 1.5 is applicable.
   d. The improvement in the value of the optimal solution will be 0.5 for each unit increase in the right-hand side of constraint 2 as long as the right-hand side is between 18 and 30.

4. a. $X = 2.5, Y = 2.5$
   b. $-2$
   c. 5 to 11
   d. $-3$ between 9 and 18

5. a. Regular glove = 500; Catcher’s mitt = 150; Value = 3700
   b. The finishing, packaging, and shipping constraints are binding; there is no slack.
   c. Cutting and sewing = 0
      Finishing = 3
      Packaging and shipping = 28
      Additional finishing time is worth $3 per unit, and additional packaging and shipping time is worth $28 per unit.
   d. In the packaging and shipping department, each additional hour is worth $28.

6. a. 4 to 12
   b. As long as the profit contribution for the regular glove is between $4.00 and $12.00, the current solution is optimal; as long as the profit contribution for the catcher’s mitt stays between $3.33 and $10.00, the current solution is optimal; the optimal solution is not sensitive to small changes in the profit contributions for the gloves.
   c. The dual values for the resources are applicable over the following ranges:

<table>
<thead>
<tr>
<th>Constraint</th>
<th>Right-Hand-Side Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cutting and sewing</td>
<td>725 to No upper limit</td>
</tr>
<tr>
<td>Finishing</td>
<td>133.33 to 400</td>
</tr>
<tr>
<td>Packaging and shipping</td>
<td>75 to 135</td>
</tr>
<tr>
<td>d. Amount of increase</td>
<td>$(28)(20) = $560</td>
</tr>
</tbody>
</table>
Appendix E  Self-Test Solutions and Answers to Even-Numbered Problems

8. a. More than $7.00
b. More than $3.50
c. None

10. a. $S = 4000, \ M = 10,000; \ Total \ risk = 62,000$
b. 

<table>
<thead>
<tr>
<th>Variable</th>
<th>Objective Coefficient Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>$S$</td>
<td>3.75 to No upper limit</td>
</tr>
<tr>
<td>$M$</td>
<td>No lower limit to 6.4</td>
</tr>
</tbody>
</table>

c. $5(4000) + 4(10,000) = 60,000$
d. $60,000/1,200,000 = 0.05 \ or \ 5\%$
e. 0.057 risk units
f. 0.057(100) = 5.7\%

12. a. $E = 80, \ S = 120, \ D = 0$
Profit = $16,440$
b. Fan motors and cooling coils
c. Labor hours; 320 hours available
d. Objective function coefficient range of optimality
   No lower limit to 159
Because $150$ is in this range, the optimal solution
would not change.

13. a. Range of optimality
   $E$ 47.5 to 75
   $S$ 87 to 126
   $D$ No lower limit to 159
b. 

<table>
<thead>
<tr>
<th>Model</th>
<th>Profit</th>
<th>Change</th>
<th>Allowable Increase/Decrease</th>
<th>%</th>
</tr>
</thead>
</table>
| $E$   | $63$   | Increase 6$\times$100 | $75 - 63 - 12 = 50$  
| $S$   | $95$   | Decrease 2$\times$100 | $95 - 87 - 8 = 25$  
| $D$   | $135$  | Increase 4$\times$100 | $159 - 135 - 24 = 17$  |

Because changes are 92\% of allowable changes, the optimal solution of $E = 80, S = 120, D = 0$ will not change. The change in total profit will be

$E$ 80 units @ +$6 = $480
$S$ 120 units @ -$2 = -$240
$D$ 40 units @ +$6 = $240

\[ \therefore \text{Profit} = 16,440 + 240 = 16,680 \]

c. Range of feasibility
Constraint 1 160 to 280
Constraint 2 200 to 400
Constraint 3 2080 to No upper limit
d. Yes, Fan motors = 200 + 100 = 300 is outside the range of feasibility; the dual value will change.

14. a. Manufacture 100 cases of A and 60 cases of B, and purchase 90 cases of B; Total cost = $2170
b. Demand for A, demand for B, assembly time

c. $-12.25, -9.0, 0, 0.375$
d. Assembly time constraint

16. a. 100 suits, 150 sport coats
Profit = $40,900
40 hours of cutting overtime
b. Optimal solution will not change.
c. Consider ordering additional material $34.50 is the
maximum price.
d. Profit will improve by $875.

18. a. The linear programming model is as follows:
Min $30AN + 50AO + 25BN + 40BO$
s.t.

\[ AN + \ AO \geq 50,000 \]
\[ BN + BO \geq 70,000 \]
\[ AN + BN \leq 80,000 \]
\[ AO + BO \leq 60,000 \]

b. Optimal solution

<table>
<thead>
<tr>
<th>New Line</th>
<th>Old Line</th>
</tr>
</thead>
<tbody>
<tr>
<td>Model A</td>
<td>50,000</td>
</tr>
<tr>
<td>Model B</td>
<td>30,000</td>
</tr>
</tbody>
</table>

Total cost: $3,850,000

c. The first three constraints are binding.
d. Because the dual value is negative, increasing the right-hand side of constraint 3 will decrease (improve) the solution; thus, an increase in capacity for the new production line is desirable.
e. Because constraint 4 is not a binding constraint, any increase in the production line capacity of the old production line will have no effect on the optimal solution; thus, increasing the capacity of the old production line results in no benefit.
f. The reduced cost for model A made on the old production line is 5; thus, the cost would have to decrease by at least $5 before any units of model A would be produced on the old production line.
g. The right-hand-side range for constraint 2 shows a lower limit of 30,000; thus, if the minimum production requirement is reduced to 10,000 units to 60,000, the dual value of 40 is applicable; thus, total cost would decrease by 10,000(40) = $400,000.

20. a. Max $0.07H + 0.12P + 0.09A$
s.t.

\[ H + P + A = 1,000,000 \]
\[ 0.6H - 0.4P - 0.4A \geq 0 \]
\[ P - 0.6A \leq 0 \]
\[ H, P, A \geq 0 \]

b. $H = 400,000, P = 225,000, A = 375,000$
Total annual return = $88,750
Annual percentage return = 8.875\%
c. No change
d. Increase of $890
e. Increase of $312.50, or 0.031%

22. a. Min $30L + 25D + 18S$

s.t.

\[ L + D + S = 100 \]
\[ 0.6L - 0.4D \geq 0 \]
\[ -0.15L - 0.15D + 0.85S \geq 0 \]
\[ -0.25L - 0.25D + S \leq 0 \]
\[ L \leq 50 \]
\[ L, D, S \geq 0 \]

b. \( L = 48, D = 72, S = 50 \)

Total cost = $3780
c. No change
d. No change

24. Let \( A \) = number of shares of stock A
\( B \) = number of shares of stock B
\( C \) = number of shares of stock C
\( D \) = number of shares of stock D

a. To get data on a per share basis multiply price by rate of return or risk measure value.

Min \( 10A + 3.5B + 4C + 3.2D \)

s.t.

\[ 100A + 50B + 80C + 40D = 200,000 \]
\[ 12A + 4B + 4.8C + 4D \geq 18,000 \text{ (9\% of 200,00)} \]
\[ 100A \leq 100,000 \]
\[ 50B \leq 100,000 \]
\[ 80C \leq 100,000 \]
\[ 40D \leq 100,000 \]

\( A, B, C, D \geq 0 \)

Solution: \( A = 333.3, B = 0, C = 833.3, D = 2500 \)
Return: 18,000 (9\%) from constraint 2

b. 

<table>
<thead>
<tr>
<th>Variable</th>
<th>Objective Coefficient Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>9.5 to 11</td>
</tr>
<tr>
<td>B</td>
<td>3.33 to No Upper Limit</td>
</tr>
<tr>
<td>C</td>
<td>3.2 to 4.4</td>
</tr>
<tr>
<td>D</td>
<td>No Lower Limit to 3.33</td>
</tr>
</tbody>
</table>

Individual changes in the risk measure coefficients within these ranges will not cause a change in the optimal investment decisions.

c. The dual value associated with the rate of return constraint is 0.833. If the firm requires a 10\% rate of return, this will increase the right-hand side of this constraint to 0.1*200,000 = 20,000 which is an increase of 2000 units. Because this increase is within the right-hand-side range, this means that we would expect the objective function to increase by 2000*0.833 = 1666 units.

In other words, the increased rate of return would result in an increase in risk of 1660 units.

26. a. Let \( M_1 \) = units of component 1 manufactured
\( M_2 \) = units of component 2 manufactured
\( M_3 \) = units of component 3 manufactured
\( P_1 \) = units of component 1 purchased
\( P_2 \) = units of component 2 purchased
\( P_3 \) = units of component 3 purchased

Min \( 4.50M_1 + 5.00M_2 + 2.75M_3 + 6.50P_1 + 8.80P_2 + 7.00P_3 \)

s.t.

\[ 2M_1 + 3M_2 + 4M_3 \leq 21,600 \text{ Production} \]
\[ 1M_1 + 1.5M_2 + 3M_3 \leq 15,000 \text{ Assembly} \]
\[ 1.5M_1 + 2M_2 + 5M_3 \leq 18,000 \text{ Testing & Packaging} \]
\[ 1M_1 + 1P_1 \leq 6,000 \text{ Component 1} \]
\[ 1M_2 + 1P_2 \leq 4,000 \text{ Component 2} \]
\[ 1M_3 + 1P_3 \leq 3,500 \text{ Component 3} \]
\[ M_1, M_2, M_3, P_1, P_2, P_3 \geq 0 \]

b. 

<table>
<thead>
<tr>
<th>Component</th>
<th>Component</th>
<th>Component</th>
</tr>
</thead>
<tbody>
<tr>
<td>Source</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>Manufacture</td>
<td>2000</td>
<td>4000</td>
</tr>
<tr>
<td>Purchase</td>
<td>4000</td>
<td>2100</td>
</tr>
</tbody>
</table>

Total cost = $73,550

c. Production: $54.36 per hour
Testing & Packaging: $7.50 per hour
d. Dual values = $7.969; so it will cost Benson $7.969 to add a unit of component 2.

28. b. \( G = 120,000; S = 30,000; M = 150,000 \)
c. 0.15 to 0.60; No lower limit to 0.122; 0.02 to 0.20
d. 4668
e. \( G = 48,000; S = 192,000; M = 60,000 \)
f. The client’s risk index and the amount of funds available

30. a. \( L = 3, N = 7, W = 5, S = 5 \)
b. Each additional minute of broadcast time increases cost by $100.
c. If local coverage is increased by 1 minute, total cost will increase by $100.
d. If the time devoted to local and national news is increased by 1 minute, total cost will increase by $100.
e. Increasing the sports by 1 minute will have no effect because the dual value is 0.

32. a. Let \( P_1 \) = number of PT-100 battery packs produced at the Philippines plant
\( P_2 \) = number of PT-200 battery packs produced at the Philippines plant
\( P_3 \) = number of PT-300 battery packs produced at the Philippines plant
\( M_1 \) = number of PT-100 battery packs produced at the Mexico plant
Appendix E  Self-Test Solutions and Answers to Even-Numbered Problems

Chapter 4

1. Let $T$ = number of television advertisements
   $R$ = number of radio advertisements
   $N$ = number of newspaper advertisements

Max $100,000T + 18,000R + 40,000N$

s.t.

- $2000T + 300R + 600N \leq 18,200$  Budget
- $T \leq 10$  Max TV
- $R \leq 20$  Max radio
- $N \leq 10$  Max news
- $0.5T + 0.5R \leq 0.5N$  Max 50% radio
- $0.9T - 0.1R \leq 0.1N$  Min 10% TV
- $T, R, N \geq 0$

**Budget $**

Solution: $T = 4$  $\$ 8000
   $R = 14$  $\$ 4200
   $N = 10$  $\$ 6000

Audience = 1,052,000

b. The dual value for the budget constraint is 51.30, meaning a $100 increase in the budget should provide an increase in audience coverage of approximately 5130;

the right-hand-side range for the budget constraint will show that this interpretation is correct.

2. a. $x_1 = 77.89, x_2 = 63.16, x_3 = 52.39$
   b. Department A $\$15.79; Department B $\$47.37$
   c. $x_1 = 87.21, x_2 = 65.12, x_3 = 33.41$

Department A 10 hours; Department B 3.2 hours

4. a. $x_1 = 500, x_2 = 300, x_3 = 200, x_4 = 550$
   b. $0.55$
   c. Aroma, 75; Taste 84.4
   d. $-0.60$

6. 50 units of product 1; 0 units of product 2; 300 hours department A; 600 hours department B

8. Schedule 19 officers as follows:
   3 begin at 8:00 a.m.; 3 begin at noon; 7 begin at 4:00 p.m.;
   4 begin at midnight, 2 begin at 4:00 a.m.

9. Let $x_i$ = the number of call-center employees who start work on day $i$
   (i = 1 = Monday, i = 2 = Tuesday …)

Min $X_1 + X_2 + X_3 + X_4 + X_5 + X_6 + X_7$

s.t.

- $X_1 + X_4 + X_5 + X_6 + X_7 \geq 75$
- $X_1 + X_2 + X_5 + X_6 + X_7 \geq 50$
- $X_1 + X_2 + X_3 + X_6 + X_7 \geq 45$
- $X_1 + X_2 + X_3 + X_4 + X_7 \geq 60$
- $X_1 + X_2 + X_3 + X_4 + X_5 \geq 90$
- $X_3 + X_4 + X_5 + X_6 + X_7 \geq 75$
- $X_3 + X_4 + X_5 + X_6 + X_7 \geq 45$
- $X_1, X_2, X_3, X_4, X_5, X_6, X_7 \geq 0$

Solution: $X_1 = 20, X_2 = 20, X_3 = 0, X_4 = 45, X_5 = 5,$
   $X_6 = 5, X_7 = 0$

Total number of employees = 95

Excess employees: Thursday = 25, Sunday = 10, all others = 0.

10. a. 40.9%, 14.5%, 14.5%, 30.0%
    b. Annual return = 5.4%
    c. 0.0%, 36.0%, 36.0%, 28.0%
    d. Annual return = 2.52%
    e. 75.0%, 0.0%, 15.0%, 10.0%
    f. Annual return = 8.2%
    g. Yes

12.

<table>
<thead>
<tr>
<th>Week</th>
<th>Buy</th>
<th>Sell</th>
<th>Store</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>80,000</td>
<td>0</td>
<td>100,000</td>
</tr>
<tr>
<td>2</td>
<td>0</td>
<td>0</td>
<td>100,000</td>
</tr>
<tr>
<td>3</td>
<td>0</td>
<td>100,000</td>
<td>0</td>
</tr>
<tr>
<td>4</td>
<td>25,000</td>
<td>0</td>
<td>25,000</td>
</tr>
</tbody>
</table>
14. b.

<table>
<thead>
<tr>
<th>Quarter</th>
<th>Production</th>
<th>Ending Inventory</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>4000</td>
<td>2100</td>
</tr>
<tr>
<td>2</td>
<td>3000</td>
<td>1100</td>
</tr>
<tr>
<td>3</td>
<td>2000</td>
<td>100</td>
</tr>
<tr>
<td>4</td>
<td>1900</td>
<td>500</td>
</tr>
</tbody>
</table>

15. Let \( x_{11} \) = gallons of crude 1 used to produce regular
\( x_{12} \) = gallons of crude 1 used to produce high octane
\( x_{21} \) = gallons of crude 2 used to produce regular
\( x_{22} \) = gallons of crude 2 used to produce high octane

Min \( 0.10x_{11} + 0.10x_{12} + 0.15x_{21} + 0.15x_{22} \)

s.t.

Each gallon of regular must have at least 40% A.
\( x_{11} + x_{21} = \) amount of regular produced
\( 0.4(x_{11} + x_{21}) = \) amount of A required for regular
\( 0.2x_{11} + 0.50x_{21} = \) amount of A in \((x_{11} + x_{21})\) gallons of regular gas
\( 0.2x_{11} + 0.50x_{21} = \) amount of high octane
\( 0.2x_{11} + 0.10x_{21} = \) amount of B required for high octane

Each gallon of high octane can have at most 50% B.
\( x_{12} + x_{22} = \) amount high octane
\( 0.5(x_{12} + x_{22}) = \) amount of B required for high octane
\( 0.60x_{12} + 0.30x_{22} = \) amount of B in \((x_{12} + x_{22})\) gallons of high octane
\( 0.1x_{12} + 0.2x_{22} = \) amount of waste

Optimal solution: \( x_{11} = 266,667, x_{12} = 333,333, x_{21} = 533,333, x_{22} = 166,667 \)

Cost = $165,000

16. \( x_i \) = number of 10-inch rolls processed by cutting alternative \( i \)

17. \( x_1 = 0, x_2 = 125, x_3 = 500, x_4 = 1500, x_5 = 0, x_6 = 0, x_7 = 0; 2125 rolls with waste of 750 inches

18. a. 5 Super, 2 Regular, and 3 Econo-Tankers

Chapter 5

2. b. \( E = 0.924 \)
\( wa = 0.074 \)
\( wc = 0.436 \)
\( we = 0.489 \)

3. D is relatively inefficient.
Composite requires 92.4 of D’s resources.

4. b. \( E = 0.960 \)
\( wb = 0.074 \)
\( wc = 0.000 \)
\( wj = 0.436 \)
\( wn = 0.489 \)
\( ws = 0.000 \)

C. Yes; \( E = 0.960 \)
d. More: $220 profit per week
   Less: Hours of Operation 4.4 hours
   FTE Staff 2.6
   Supply Expense $185.61
   d. Bardstown, Jeffersonville, and New Albany

6. a. 19, 18, 12, 18
b. PCQ = 8 PMQ = 0 POQ = 27
   PCY = 4 PMY = 1 POY = 2
   NCQ = 6 NMQ = 23 NOQ = 2
   NCY = 4 NMY = 2 NOY = 1
   CMQ = 37 CMY = 2 COY = 3
   c. PCQ = 8 PMQ = 1 POQ = 3
   PCY = 4 PMY = 1 POY = 2
   NCQ = 6 NMQ = 3 NOQ = 2
   NCY = 4 NMY = 2 NOY = 1
   CMQ = 3 CMY = 2 COY = 3
   c. Defend with probability $2/3$ and Defend with probability $1/3$.
   b. Assume the Blue Army chooses Attack with probability $q$ and Defend with probability $1 − q$. If the Red Army chooses Attack, the expected payoff for the Blue Army is $30q + 50*(1 − q)$. If the Red Army chooses Defend, the expected payoff for the Blue Army is $40q + 0*(1 − q)$. Setting these equations equal to each other and solving for $q$, we get $q = 0.833$. Therefore the Blue Army should choose to Attack with probability $0.833$ and Defend with probability $1 − 0.833 = 0.167$.

8. b. 65.7% small-cap growth fund
   34.3% of the portfolio in a small-cap value
   Expected return = 18.5%
   c. 10% foreign stock
   50.8% small-cap growth fund
   39.2% of the portfolio in a small-cap value
   Expected return = 17.178%

10. The game has a pure strategy: Player A strategy $a_1$; Player B strategy $b_2$; and value of game = 5.

12. a. The payoff table is
   Setting these equations equal to each other and solving for $p$, we get $p = 2/3$. Red Army should choose to Attack with probability $2/3$ and Defend with probability $1/3$.
   b. Assume the Blue Army chooses Attack with probability $q$ and Defend with probability $1 − q$. If the Red Army chooses Attack, the expected payoff for the Blue Army is $30q + 50*(1 − q)$. If the Red Army chooses Defend, the expected payoff for the Blue Army is $40q + 0*(1 − q)$. Setting these equations equal to each other and solving for $q$ we get $q = 0.833$. Therefore the Blue Army should choose to Attack with probability $0.833$ and Defend with probability $1 − 0.833 = 0.167$.

Chapter 6

1. The network model is shown:

2. a. Let $x_{11}$ = amount shipped from Jefferson City to Des Moines
   $x_{12}$ = amount shipped from Jefferson City to Kansas City
   $x_{13}$ = amount shipped from Jefferson City to Phila.
   $x_{21}$ = amount shipped from Des Moines to Phila.
   $x_{22}$ = amount shipped from Des Moines to Dallas.
   $x_{23}$ = amount shipped from Des Moines to New Orleans.
   Min $14x_{11} + 9x_{12} + 7x_{13} + 8x_{21} + 10x_{22} + 5x_{23}$
   s.t.
   $x_{11} + x_{12} + x_{13} \leq 30$
   $x_{11} + x_{21} + x_{22} + x_{23} \leq 20$
   $x_{11} + x_{12} + x_{13} + x_{21} + x_{22} + x_{23} = 25$
   $x_{11} + x_{13} + x_{21} + x_{23} = 15$
   $x_{11}, x_{12}, x_{13}, x_{21}, x_{22}, x_{23} \geq 0$
b. Optimal Solution:

<table>
<thead>
<tr>
<th></th>
<th>Amount</th>
<th>Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Jefferson City–Des Moines</td>
<td>5</td>
<td>70</td>
</tr>
<tr>
<td>Jefferson City–Kansas City</td>
<td>15</td>
<td>135</td>
</tr>
<tr>
<td>Jefferson City–St. Louis</td>
<td>10</td>
<td>70</td>
</tr>
<tr>
<td>Omaha–Des Moines</td>
<td>20</td>
<td>160</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>435</strong></td>
<td></td>
</tr>
</tbody>
</table>

4. The optimization model can be written as

\[
x_y = \text{Red GloFish shipped from } i \text{ to } j = M \text{ for Michigan, } T \text{ for Texas}; j = 1, 2, 3.
\]

\[
y_y = \text{Blue GloFish shipped from } i \text{ to } j, i = M \text{ for Michigan, } T \text{ for Texas}; j = 1, 2, 3.
\]

Minimize \[x_M^1 + 2.50x_M^2 + 0.50x_M^3 + y_M^1 + 2.50y_M^2 + 0.50y_M^3 + 2.00y_T^1 + 1.50y_T^2 + 2.80y_T^3\]

subject to

\[
x_M^1 + x_M^2 + x_M^3 \leq 1,000,000
\]

\[
y_M^1 + y_M^2 + y_M^3 \leq 600,000
\]

\[
x_T^1 + x_T^2 + x_T^3 \leq 320,000
\]

\[
y_T^1 + y_T^2 + y_T^3 \leq 300,000
\]

\[
x_T^3 \geq 160,000
\]

\[
y_T^3 \geq 450,000
\]

\[
x_{ij} \geq 0
\]

Solving this linear program, we find that we should produce 780,000 red GloFish in Michigan, 670,000 blue GloFish in Michigan, and 450,000 blue GloFish in Texas.

Using the notation in the model, the number of GloFish shipped from each farm to each retailer can be expressed as follows:

\[
x_M^1 = 320,000
\]

\[
x_M^2 = 300,000
\]

\[
x_M^3 = 160,000
\]

\[
y_M^1 = 380,000
\]

\[
y_M^2 = 0
\]

\[
y_M^3 = 290,000
\]

\[
y_T^1 = 0
\]

\[
y_T^2 = 450,000
\]

\[
y_T^3 = 0
\]

a. The minimum transportation cost is $2.35 million.

b. We have to add variables \(x_T^1, x_T^2, \text{ and } x_T^3\) for Red GloFish shipped between Texas and Retailers 1, 2 and 3. The revised objective function is

Minimize \[x_M^1 + 2.50x_M^2 + 0.50x_M^3 + y_M^1 + 2.50y_M^2 + 0.50y_M^3 + 2.00y_T^1 + 1.50y_T^2 + 2.80y_T^3 + x_T^1 + 2.50x_T^2 + 0.50x_T^3\]

We replace the third constraint above with

\[x_T^1 + x_T^2 + x_T^3 + y_T^1 + y_T^2 + y_T^3 \leq 600,000\]

And we change the constraints

\[
x_M^1 \geq 320,000
\]

\[
x_M^2 \geq 300,000
\]

\[
x_M^3 \geq 160,000
\]

to

\[
x_M^1 + x_T^1 \geq 320,000
\]

\[
x_M^2 + x_T^2 \geq 300,000
\]

\[
x_M^3 + x_T^3 \geq 160,000
\]

Using this new objective function and constraint the optimal solution is $2.2 million, so the savings are $150,000.

6. The network model, the linear programming formulation, and the optimal solution are shown. Note that the third constraint corresponds to the dummy origin. The variables \(x_{31}, x_{32}, x_{33}, \text{ and } x_{34}\) are the amounts shipped out of the dummy origin; they do not appear in the objective function because they are given a coefficient of zero.
Max $32x_{11} + 34x_{12} + 32x_{13} + 40x_{14} + 34x_{21} + 30x_{22} + 28x_{23} + 38x_{24}$

s.t.

$\begin{align*}
    x_{11} + x_{12} + x_{13} + x_{14} & \leq 5000 \\
    x_{21} + x_{22} + x_{23} + x_{24} & \leq 4000 \\
    x_{31} + x_{32} + x_{33} + x_{34} & \leq 3000 \\
    x_{41} + x_{42} + x_{43} + x_{44} & \leq 2000 \\
    x_{i1} + x_{i2} + x_{i3} + x_{i4} & = 2000
\end{align*}$

$x_{ij} \geq 0$ for all $i, j$

### Optimal Solution

<table>
<thead>
<tr>
<th>Units</th>
<th>Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Clifton Springs–$D_2$</td>
<td>4000</td>
</tr>
<tr>
<td>Clifton Springs–$D_4$</td>
<td>1000</td>
</tr>
<tr>
<td>Danville–$D_1$</td>
<td>2000</td>
</tr>
<tr>
<td>Danville–$D_4$</td>
<td>1000</td>
</tr>
</tbody>
</table>

Total Cost: $282,000

Customer 2 demand has a shortfall of 1000.
Customer 3 demand of 3000 is not satisfied.

### 8. a.

If solution 1 is used, Forbelt should produce 10 motors at Denver, 100 motors at Atlanta, and 150 motors at Chicago. There will be idle capacity for 90 motors at Denver.

If solution 2 is used, Forbelt should adopt the same production schedule but a modified shipping schedule.

### 10. a.

The total cost is the sum of the purchase cost and the transportation cost. We show the calculation for Division 1–Supplier 1 and present the result for the other Division-Supplier combinations.

#### Division 1–Supplier 1

| Supplier 1–Division 2 | $603 |
| Supplier 2–Division 5 | 648 |
| Supplier 3–Division 3 | 775 |
| Supplier 5–Division 1 | 590 |
| Supplier 6–Division 4 | 553 |

Total $3169

#### Cost Matrix ($1000$s)

<table>
<thead>
<tr>
<th>Supplier</th>
<th>Division</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>614</td>
<td>660</td>
<td>534</td>
<td>680</td>
<td>590</td>
<td>630</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>603</td>
<td>639</td>
<td>702</td>
<td>693</td>
<td>693</td>
<td>630</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>865</td>
<td>830</td>
<td>775</td>
<td>850</td>
<td>900</td>
<td>930</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>532</td>
<td>553</td>
<td>511</td>
<td>581</td>
<td>595</td>
<td>553</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>720</td>
<td>648</td>
<td>684</td>
<td>693</td>
<td>657</td>
<td>747</td>
<td></td>
</tr>
</tbody>
</table>

### b. Optimal Solution:

<table>
<thead>
<tr>
<th>Supplier</th>
<th>Division</th>
</tr>
</thead>
<tbody>
<tr>
<td>Supplier 1–Division 2</td>
<td>$603</td>
</tr>
<tr>
<td>Supplier 2–Division 5</td>
<td>648</td>
</tr>
<tr>
<td>Supplier 3–Division 3</td>
<td>775</td>
</tr>
<tr>
<td>Supplier 5–Division 1</td>
<td>590</td>
</tr>
<tr>
<td>Supplier 6–Division 4</td>
<td>553</td>
</tr>
</tbody>
</table>

Total $3169
11. a. Network Model

There is an excess capacity of 130 units at plant 3.

12. a. Three arcs must be added to the network model in Problem 11a. The new network is shown:

b. & c. The linear programming formulation and optimal solution is shown below:

### Linear Programming Problem

**Objective Function Value** = 11850.000

<table>
<thead>
<tr>
<th>Variable</th>
<th>Value</th>
<th>Reduced Costs</th>
</tr>
</thead>
<tbody>
<tr>
<td>X14</td>
<td>450.000</td>
<td>0.000</td>
</tr>
<tr>
<td>X15</td>
<td>0.000</td>
<td>3.000</td>
</tr>
<tr>
<td>X24</td>
<td>0.000</td>
<td>3.000</td>
</tr>
<tr>
<td>X25</td>
<td>600.000</td>
<td>0.000</td>
</tr>
<tr>
<td>X34</td>
<td>250.000</td>
<td>0.000</td>
</tr>
<tr>
<td>X35</td>
<td>0.000</td>
<td>1.000</td>
</tr>
<tr>
<td>X46</td>
<td>0.000</td>
<td>3.000</td>
</tr>
<tr>
<td>X47</td>
<td>300.000</td>
<td>0.000</td>
</tr>
<tr>
<td>X48</td>
<td>0.000</td>
<td>1.000</td>
</tr>
<tr>
<td>X49</td>
<td>400.000</td>
<td>0.000</td>
</tr>
<tr>
<td>X56</td>
<td>300.000</td>
<td>0.000</td>
</tr>
<tr>
<td>X57</td>
<td>0.000</td>
<td>2.000</td>
</tr>
<tr>
<td>X58</td>
<td>600.000</td>
<td>0.000</td>
</tr>
<tr>
<td>X59</td>
<td>0.000</td>
<td>3.000</td>
</tr>
</tbody>
</table>
The value of the solution here is $630 less than the value of the solution for Problem 23. The new shipping route from plant 3 to customer 4 has helped ($x_{30} = 380$). There is now excess capacity of 130 units at plant 1.

**14.**

A linear programming model is

\[
\begin{align*}
\text{Min } & \ 8x_{14} + 6x_{15} + 3x_{24} + 8x_{25} + 9x_{34} + 3x_{35} + 44x_{45} + 34x_{46} + 32x_{49} + 57x_{59} + 35x_{57} + 28x_{69} + 24x_{79} \\
\text{s.t. } & \ x_{34} + x_{45} \leq 3 \\
& \ x_{24} + x_{25} \leq 6 \\
& \ x_{34} + x_{35} \leq 5 \\
& \ -x_{34} - x_{24} - x_{34} + 4x_{45} + 4x_{46} + 4x_{49} + 4x_{59} + 5x_{57} + 5x_{59} + 5x_{69} + 5x_{79} \leq 0 \\
& \ -x_{15} - x_{25} - x_{35} + x_{46} + x_{56} + x_{67} + x_{78} = 0 \\
& \ x_{47} + x_{48} + x_{49} = 4 \\
& \ x_{56} + x_{57} + x_{58} + x_{59} = 2 \\
& \ x_{48} + x_{56} + x_{57} + x_{58} + x_{59} = 3 \\
& \ x_{49} + x_{46} + x_{56} + x_{57} + x_{58} + x_{59} = 3 \\
& \ x_{34} = x_{35} = 5 \\
& \ x_{35} = 0 \\
& \ x_{34} = 0 \\
& \ x_{25} = 8 \\
& \ x_{36} = 5 \\
& \ x_{27} = 0 \\
& \ x_{34} = 0 \\
& \ x_{36} = 0 \\
& \ x_{36} = 5 \\
& \ x_{42} = 3 \\
\end{align*}
\]

Two rail cars must be held at Muncie until a buyer is found.

**16. a.**

\[
\begin{align*}
\text{Min } & \ 20x_{12} + 25x_{14} + 30x_{24} + 45x_{25} + 20x_{31} + 35x_{36} + 30x_{42} + 25x_{53} + 15x_{54} + 28x_{56} + 12x_{67} + 27x_{74} \\
\text{s.t. } & \ x_{31} - x_{12} - x_{15} = 8 \\
& \ x_{25} + x_{27} - x_{12} - x_{42} = 5 \\
& \ x_{31} + x_{36} - x_{53} = 3 \\
& \ x_{54} + x_{56} - x_{42} = 3 \\
& \ x_{33} + x_{34} + x_{36} - x_{15} - x_{25} - x_{36} - x_{42} = 2 \\
& \ x_{34} - x_{27} - x_{67} = 5 \\
& \ x_{47} = 6 \\
& \ x_{ij} \geq 0 \text{ for all } i, j
\end{align*}
\]

Total completion time = 64

**17. a.**

Total cost of redistributing cars = $917
18. **a.**

<table>
<thead>
<tr>
<th>Crews</th>
<th>Jobs</th>
</tr>
</thead>
<tbody>
<tr>
<td>Red</td>
<td>1</td>
</tr>
<tr>
<td>White</td>
<td>2</td>
</tr>
<tr>
<td>Blue</td>
<td>3</td>
</tr>
<tr>
<td>Green</td>
<td>4</td>
</tr>
<tr>
<td>Brown</td>
<td>5</td>
</tr>
</tbody>
</table>

The linear programming model of this problem has 23 variables (one for each combination of distribution center and customer zone). It has 13 constraints. There are five supply (≤3) constraints and eight demand (=1) constraints.

The optimal solution is as follows:

<table>
<thead>
<tr>
<th>Assignments</th>
<th>Cost (1000s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Plano</td>
<td>Kansas City, Dallas</td>
</tr>
<tr>
<td>Flagstaff</td>
<td>Los Angeles</td>
</tr>
<tr>
<td>Springfield</td>
<td>Chicago, Columbus, Atlanta</td>
</tr>
<tr>
<td>Boulder</td>
<td>Newark, Denver</td>
</tr>
</tbody>
</table>

Total Cost $216

**b.** The Nashville distribution center is not used.

**c.** All the distribution centers are used. Columbus is switched from Springfield to Nashville. Total cost increases by $11,000 to $227,000.

22. A linear programming formulation of this problem can be developed as follows. Let the first letter of each variable name represent the professor and the second two the course. Note that a $DPH$ variable is not created because the assignment is unacceptable.

Max $2.8AUG + 2.2AMB + 3.3AMS + 3.0APH + 3.2BUG + \cdots + 2.5DMS$

s.t.

$$
\begin{align*}
AUG + AMS + APH & \leq 1 \\
BUG + BMB + BMS + BPH & \leq 1 \\
CUG + CMR + CMS + CPH & \leq 1 \\
DUG + DMB + DMS & \leq 1 \\
AUG + BUG + CUG + DUG & = 1 \\
AMB + BMB + CMR + DMB & = 1 \\
AMS + BMS + CMS + DMS & = 1 \\
APH + BPH + CPH & = 1 \\
\text{All Variables} & \geq 0
\end{align*}
$$

**Optimal Solution**

<table>
<thead>
<tr>
<th>Assignments</th>
<th>Rating</th>
</tr>
</thead>
<tbody>
<tr>
<td>A to MS course</td>
<td>3.3</td>
</tr>
<tr>
<td>B to Ph.D. course</td>
<td>3.6</td>
</tr>
<tr>
<td>C to MBA course</td>
<td>3.2</td>
</tr>
<tr>
<td>D to Undergraduate course</td>
<td>3.2</td>
</tr>
</tbody>
</table>

Max Total Rating 13.3

23. **a.** This is the variation of the assignment problem in which multiple assignments are possible. Each distribution center may be assigned up to three customer zones.

The linear programming model of this problem has 40 variables (one for each combination of distribution center and customer zone) and 30 constraints. There are five supply (≤3) constraints and seven demand (=1) constraints.

The optimal solution is as follows:

Because the data are in hundreds of dollars, the total installation cost for the five contracts is $16,200.

20. **a.** This is the variation of the assignment problem in which multiple assignments are possible. Each distribution center may be assigned up to three customer zones.

The linear programming model of this problem has 40 variables (one for each combination of distribution center and customer zone). It has 13 constraints. There are five supply (≤3) constraints and eight demand (=1) constraints.

The optimal solution is as follows:

Because the data are in hundreds of dollars, the total installation cost for the five contracts is $16,200.
The linear program will have 10 variables for the arcs and 5 constraints for the nodes.

Let

\[ x_{ij} = \begin{cases} 
1 & \text{if the arc from node } i \text{ to node } j \text{ is on the shortest route} \\
0 & \text{otherwise}
\end{cases} \]

The system cannot accommodate a flow of 10,000 vehicles per hour.
32. a. 10,000 gallons per hour or 10 hours
   b. Flow reduced to 9000 gallons per hour; 11.1 hours.
34. Maximal Flow = 23 gallons/minute. Five gallons will flow from node 3 to node 5.
36. a. Let $R_1, R_2, R_3$ represent regular time production in months 1, 2, 3
   $O_1, O_2, O_3$ represent overtime production in months 1, 2, 3
   $D_1, D_2, D_3$ represent demand in months 1, 2, 3
Using these nine nodes, a network model is shown:

```
    275
    R1  \
     |   \
     |   \
     |   150
     |   D1

   100
   O1

   200
   R2

   50
   O2

   250
   D2

   50
   O3

   100
   R3

   300
   D3
```

b. Use the following notation to define the variables: The first two characters designate the “from node” and the second two characters designate the “to node” of the arc. For instance, $R_1D_1$ is amount of regular time production available to satisfy demand in month 1; $O_1D_1$ is amount of overtime production in month 1 available to satisfy demand in month 1; $D_1D_2$ is the amount of inventory carried over from month 1 to month 2; and so on.

Min $50R_1D_1 + 80O_1D_1 + 20D_1D_2 + 50R_2D_2 + 80O_2D_2 + 20D_2D_3 + 60R_3D_3 + 100O_3D_3$

S.T.

(1) $R_1D_1 \leq 275$
(2) $O_1D_1 \leq 100$
(3) $R_2D_2 \leq 200$
(4) $O_2D_2 \leq 50$
(5) $R_3D_3 \leq 100$
(6) $O_3D_3 \leq 50$
(7) $R_1D_1 + O_2D_2 - D_1D_2 = 150$
(8) $R_2D_2 + O_2D_3 + D_2D_3 - D_3D_3 = 250$
(9) $R_3D_3 + O_3D_3 + D_2D_3 = 300$

c. Optimal Solution:

<table>
<thead>
<tr>
<th>Variable</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>$R_1D_1$</td>
<td>275.000</td>
</tr>
<tr>
<td>$O_1D_1$</td>
<td>25.000</td>
</tr>
<tr>
<td>$D_1D_2$</td>
<td>150.000</td>
</tr>
<tr>
<td>$R_2D_2$</td>
<td>200.000</td>
</tr>
<tr>
<td>$O_2D_2$</td>
<td>50.000</td>
</tr>
<tr>
<td>$D_2D_3$</td>
<td>150.000</td>
</tr>
<tr>
<td>$R_3D_3$</td>
<td>100.000</td>
</tr>
<tr>
<td>$O_3D_3$</td>
<td>50.000</td>
</tr>
</tbody>
</table>

Value = $46,750

Note: Slack variable for constraint 2 = 75

d. The values of the slack variables for constraints 1 through 6 represent unused capacity. The only nonzero slack variable is for constraint 2; its value is 75. Thus, there are 75 units of unused overtime capacity in month 1.

Chapter 7

2. a. $x_2$

   Optimal solution to LP Relaxation (1.43, 4.29)

b. The optimal solution to the LP Relaxation is given by $x_1 = 1.43, x_2 = 4.29$, with an objective function value of 41.47. Rounding down gives the feasible integer solution $x_1 = 1, x_2 = 4$; its value is 37.
6. a. \( x_1 = 1.96, x_2 = 5.48; \) Value = 7.44
   Rounded: \( x_1 = 1.96, x_2 = 5; \) Value = 6.96
   Lower bound = 6.96; Upper bound = 7.44
   c. \( x_1 = 1.29, x_2 = 6; \) Value = 7.29

7. a. \( x_1 + x_3 + x_6 = 2 \)
   b. \( x_3 - x_5 = 0 \)
   c. \( x_1 + x_4 = 1 \)
   d. \( x_4 \leq x_1 \)
   e. \( x_4 \leq x_3 \)
   f. \( x_4 \geq x_1 \)
   g. \( x_4 \geq x_3 \)
   h. \( x_4 \geq x_1 + x_3 = 1 \)

8. a. \( x_3 = 1, x_4 = 1, x_6 = 1; \) Value = 17,500
   b. Add \( x_1 + x_2 \leq 1 \)
   c. Add \( x_3 - x_4 = 0 \)

10. b. Choose locations B and E.

12. a. Let \( y[i,j] = 1 \) if carrier \( j \) is selected, 0 if not \( j = 1, 2, \ldots, 7 \)
   \( x[i,j] = 1 \) if city \( i \) is assigned to carrier \( j \).
   0 if not \( i = 1, 2, \ldots, 20 \) \( j = 1, 2, \ldots, 7 \)

Minimize the cost of city-carrier assignments (note: for brevity, zeros are not shown).

Minimize
\[
\begin{align*}
\end{align*}
\]
x[18,1] + x[18,2] + x[18,3] + x[18,4] + x[18,5] + x[18,6] + x[18,7] = 1
x[2,7] + x[4,7] = 0
Solution: Total Cost = $436,512
Carrier 2: assigned cities 2, 3, 4, 5, 6, and 9
Carrier 5: assigned cities 7, 8, and 10–20
Carrier 6: assigned city 1

<table>
<thead>
<tr>
<th># Carriers</th>
<th>Cost</th>
<th>Carriers Chosen</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>$524,677</td>
<td>5</td>
</tr>
<tr>
<td>2</td>
<td>$452,172</td>
<td>2, 5</td>
</tr>
<tr>
<td>3</td>
<td>$436,512</td>
<td>2, 5, 6</td>
</tr>
<tr>
<td>4</td>
<td>$433,808</td>
<td>2, 4, 5, 6</td>
</tr>
<tr>
<td>5</td>
<td>$433,112</td>
<td>1, 2, 4, 5, 6</td>
</tr>
<tr>
<td>6</td>
<td>$432,832</td>
<td>1, 2, 3, 4, 5, 6, 7</td>
</tr>
<tr>
<td>7</td>
<td>$432,832</td>
<td>1, 2, 3, 4, 5, 6, 7</td>
</tr>
</tbody>
</table>

Given the incremental drop in cost, three seems like the correct number of carriers (the curve flattens considerably after three carriers).
13. a. Add the following multiple-choice constraint to the problem:

\[ y_1 + y_2 = 1 \]

New optimal solution: \( x_1 = 1, y_1 = 1, x_{12} = 10, x_{31} = 30, x_{32} = 10, x_{33} = 20 \)

Value = 940

b. Because one plant is already located in St. Louis, it is only necessary to add the following constraint to the model:

\[ y_3 = y_4 \leq 1 \]

New optimal solution: \( x_4 = 1, x_{42} = 20, x_{43} = 20, x_{51} = 30 \)

Value = 860

14. b. Modernize plants 1 and 3 or plants 4 and 5.

d. Modernize plants 1 and 3.

16. b. Use all part-time employees.

Bring on as follows: 9:00 a.m.–6, 11:00 a.m.–2, 12:00 noon–6, 1:00 p.m.–1, 3:00 p.m.–6

Cost = $672

c. Same as in part (b)

d. New solution is to bring on 1 full-time employee at 9:00 a.m., 4 more at 11:00 a.m., and part-time employees as follows:

9:00 a.m.–5, 12:00 noon–5, and 3:00 p.m.–2

18. a. 52, 49, 36, 83, 39, 70, 79, 59

b. Thick crust, cheese, blend, chunky sauce, medium sausage: Six of eight consumers will prefer this pizza (75%).

20. a. New objective function: Min 25x_1 + 40x_2 + 40x_3 + 40x_4 + 25x_5

b. \( x_4 = x_5 = 1 \); modernize the Ohio and California plants.

c. Add the constraint \( x_2 + x_3 = 1 \).

d. \( x_3 = x_4 \leq 1 \)

22. \( x_1 + x_2 + x_3 = 3y_1 + 5y_2 + 7y_3 \)

1. \( y_1 + y_2 + y_3 = 1 \)

24. Let \( x_i \) be the amount (dollars) to invest in alternative \( i \), \( i = 1, 2, \ldots, 10 \)

\( y_i = 1 \) if Dave invests in alternative \( i \), 0 if not \( i = 1, 2, \ldots, 10 \)

Max \( 0.067x_1 + 0.0765x_2 + 0.0755x_3 + 0.0745x_4 + 0.075x_5 + 0.0645x_6 + 0.0705x_7 + 0.069x_8 + 0.052x_9 + 0.059x_{10} \)

subject to

\( x_1 + x_2 + x_3 + x_4 + x_5 + x_6 + x_7 + x_8 + x_9 + x_{10} = 100,000 \)

Invest $100,000

\( x_i \leq 25,000y_i \) \( i = 1, 2, \ldots, 10 \)

Invest no more than $25,000 in any one fund

\( x_i \geq 10,000y_i \) \( i = 1, 2, \ldots, 10 \)

If invest in a fund, invest at least $10,000 in a fund

\( y_1 + y_2 + y_3 + y_4 \leq 2 \)

No more than 2 pure growth funds

\( y_9 + y_{10} \geq 1 \)

At least 1 must be a pure bond fund

Amount in pure bonds must be at least that invested in pure growth funds

\( x_i \geq 0 \) \( i = 1, 2, \ldots, 10 \)

The optimal solution follows: \( x_3 = x_{10} = 12,500, x_5 = x_7 = x_8 = 25,000 \);

Total return = $7,056.25

Assumptions: (1) the expected annual returns are valid for the future. (2) All $100,000 will be invested. (3) These are the only alternatives for this $100,000.

Since these are annual returns, we would expect to run this no more often than once per year.

Chapter 8

2. a. \( X = 4.32 \) and \( Y = 0.92 \), for an optimal solution value of 4.84.

b. The dual value on the constraint \( X + 4Y \leq 8 \) is 0.88, which is the decrease in the optimal objective function value if we increase the right-hand-side from 8 to 9.

c. The new optimal objective function value is 4.0, so the actual decrease is only 0.84 rather than 0.88.

4. a. \( q_1 = 2150 \)

\( q_2 = 100 \)

Gross profit = $1,235,000

b. \( G = -1.5p_1^2 - 0.5p_2^2 + p_1p_2 + 2000p_1 + 3450p_2 - 11,465,000 \)

c. \( p_1 = $2725 \) and \( p_2 = $6175; q_1 = 1185 \) and \( q_2 = 230; \)

\( G = $1,911,875 \)

d. Max \( p_1q_1 + p_2q_2 - c_1 - c_2 \)

s.t.

\( c_1 = 10000 + 1500q_1 \)

\( c_2 = 30000 + 4000q_2 \)

\( q_1 = 950 - 1.5p_1 + 0.7p_2 \)

\( q_2 = 2500 + 0.3p_1 - 0.5p_2 \)

5. a. If $1000 is spent on radio and $1000 is spent on direct mail, simply substitute those values into the sales function:

\[ S = -2R^2 - 10M^2 - 8RM + 18R + 34M = -2(2^2) - 10(1^2) - 8(2)(1) + 18(2) + 34(1) = 18 \]

Sales = $18,000

b. Max \(-2R^2 - 10M^2 - 8RM + 18R + 34M\)

s.t.

\[ R + M \leq 3 \]

c. The optimal solution is Radio = $2500 and Direct mail = $500

Total sales = $37,000

6. Substituting the given data into the model formulation gives us

\[ \text{Min} \left[ 100 \times 2000 + \frac{150 \times 2000}{Q_1} + 0.20 \times 100 \times \frac{Q_1}{2} + 50 \times 2000 + \frac{135 \times 2000}{Q_2} + 0.20 \times 50 \times \frac{Q_2}{2} + 80 \times 1000 + \frac{125 \times 1000}{Q_3} + 0.20 \times 80 \times \frac{Q_3}{2} \right] \]
14. Optimal solution:

Local optimal solution found.
Objective value: 0.1990478
Total solver iterations: 12
Model Title: MARKOWITZ

<table>
<thead>
<tr>
<th>Variable</th>
<th>Value</th>
<th>Reduced Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>R1</td>
<td>-0.1457056</td>
<td>0.0000000</td>
</tr>
<tr>
<td>RBAR</td>
<td>0.1518649</td>
<td>0.0000000</td>
</tr>
<tr>
<td>R2</td>
<td>0.7316081</td>
<td>0.0000000</td>
</tr>
<tr>
<td>R3</td>
<td>0.8905417</td>
<td>0.0000000</td>
</tr>
<tr>
<td>R4</td>
<td>-0.6823468E-02</td>
<td>0.0000000</td>
</tr>
<tr>
<td>R5</td>
<td>-0.3873745</td>
<td>0.0000000</td>
</tr>
<tr>
<td>R6</td>
<td>-0.5221017</td>
<td>0.0000000</td>
</tr>
<tr>
<td>R7</td>
<td>0.3499810</td>
<td>0.0000000</td>
</tr>
<tr>
<td>R8</td>
<td>0.2290317</td>
<td>0.0000000</td>
</tr>
<tr>
<td>R9</td>
<td>0.2276271</td>
<td>0.0000000</td>
</tr>
<tr>
<td>AAPL</td>
<td>0.1817734</td>
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</tr>
<tr>
<td>AMD</td>
<td>0.1687534</td>
<td>0.0000000</td>
</tr>
<tr>
<td>ORCL</td>
<td>0.6494732</td>
<td>0.0000000</td>
</tr>
</tbody>
</table>

(Excel Solver will produce the same optimal solution.)

15. MODEL TITLE: MARKOWITZ;
! MINIMIZE VARIANCE OF THE PORTFOLIO;
MIN = (1/9) * ((R1 - RBAR)^2 + (R2 - RBAR)^2 + (R3 - RBAR)^2 + (R4 - RBAR)^2 + (R5 - RBAR)^2;
1000*FS + 1764*IB + 3241*LG + 3256*LV + 3344*SG + 2346*SV = R1;
1312*FS + 0325*IB + 1871*LG + 2601*LV + 1904*SG + 2332*SV = R2;
1347*FS + 0751*IB + 3328*LG + 1293*LV + 0385*SG + 0670*SV = R3;
4542*FS + 0133*IB + 4146*LG + 0706*LV + 5868*SG + 0543*SV = R4;
-2193*FS + 0756*IB + 2326*LG + 0537*LV + 0002*SG + 1731*SV = R5;
R1 + R2 + R3 + R4 + R5 = RBAR;
RBAR > RMIN;
RMIN = 5000;
@FREE(R1);
@FREE(R2);
@FREE(R3);
@FREE(R4);
@FREE(R5);

Optimal solution:

Local optimal solution found.
Objective value: 6784038
Total solver iterations: 19
Model Title: MARKOWITZ

<table>
<thead>
<tr>
<th>Variable</th>
<th>Value</th>
<th>Reduced Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>R1</td>
<td>9478.492</td>
<td>0.0000000</td>
</tr>
<tr>
<td>RBAR</td>
<td>5000.000</td>
<td>0.0000000</td>
</tr>
<tr>
<td>R2</td>
<td>5756.023</td>
<td>0.0000000</td>
</tr>
<tr>
<td>R3</td>
<td>2821.951</td>
<td>0.0000000</td>
</tr>
<tr>
<td>R4</td>
<td>4864.037</td>
<td>0.0000000</td>
</tr>
<tr>
<td>R5</td>
<td>2079.496</td>
<td>0.0000000</td>
</tr>
<tr>
<td>FS</td>
<td>7920.372</td>
<td>0.0000000</td>
</tr>
<tr>
<td>IB</td>
<td>26273.98</td>
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<tr>
<td>LG</td>
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<tr>
<td>LV</td>
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<td>208.2068</td>
</tr>
<tr>
<td>SG</td>
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<tr>
<td>SV</td>
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</tr>
<tr>
<td>RMIN</td>
<td>5000.000</td>
<td>0.0000000</td>
</tr>
</tbody>
</table>

(Excel Solver will produce the same optimal solution.)

12. Optimal value of $\alpha = 0.1743882$
Sum of squared errors = 98.56
Appendix E  Self-Test Solutions and Answers to Even-Numbered Problems

Optimal solution:
Local optimal solution found.
Objective value:  0.4120213
Total solver iterations:  8
Model Title: MATCHING S&P INFO TECH RETURNS

<table>
<thead>
<tr>
<th>Variable</th>
<th>Value</th>
<th>Reduced Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>R1</td>
<td>0.5266475E-01</td>
<td>0.000000</td>
</tr>
<tr>
<td>R2</td>
<td>0.8458175</td>
<td>0.000000</td>
</tr>
<tr>
<td>R3</td>
<td>0.9716207</td>
<td>0.000000</td>
</tr>
<tr>
<td>R4</td>
<td>-0.1370104</td>
<td>0.000000</td>
</tr>
<tr>
<td>R5</td>
<td>-0.3362695</td>
<td>0.000000</td>
</tr>
<tr>
<td>R6</td>
<td>-0.4175977</td>
<td>0.000000</td>
</tr>
<tr>
<td>R7</td>
<td>0.2353628</td>
<td>0.000000</td>
</tr>
<tr>
<td>R8</td>
<td>0.3431437</td>
<td>0.000000</td>
</tr>
<tr>
<td>R9</td>
<td>0.1328016</td>
<td>0.000000</td>
</tr>
<tr>
<td>AAPL</td>
<td>0.2832558</td>
<td>0.000000</td>
</tr>
<tr>
<td>AMD</td>
<td>0.6577707E-02</td>
<td>0.000000</td>
</tr>
<tr>
<td>ORCL</td>
<td>0.7101665</td>
<td>0.000000</td>
</tr>
</tbody>
</table>

(Excel Solver produces the same return.)

16. Optimal solution:
Local optimal solution found.
Objective value:  7.503540
Total solver iterations:  18
Model Title: MARKOWITZ WITH SEMIVARIANCE

<table>
<thead>
<tr>
<th>Variable</th>
<th>Value</th>
<th>Reduced Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>D1N</td>
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</tr>
<tr>
<td>D2N</td>
<td>0.8595142</td>
<td>0.000000</td>
</tr>
<tr>
<td>D3N</td>
<td>3.412762</td>
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</tr>
<tr>
<td>D4N</td>
<td>2.343876</td>
<td>0.000000</td>
</tr>
<tr>
<td>D5N</td>
<td>4.431505</td>
<td>0.000000</td>
</tr>
<tr>
<td>FS</td>
<td>0.000000</td>
<td>6.491646</td>
</tr>
<tr>
<td>IB</td>
<td>0.6908001</td>
<td>0.000000</td>
</tr>
<tr>
<td>LG</td>
<td>0.6408726E-01</td>
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</tr>
<tr>
<td>LV</td>
<td>0.000000</td>
<td>14.14185</td>
</tr>
<tr>
<td>SG</td>
<td>0.8613837E-01</td>
<td>0.000000</td>
</tr>
<tr>
<td>SV</td>
<td>0.1589743</td>
<td>0.000000</td>
</tr>
<tr>
<td>R1</td>
<td>21.04766</td>
<td>0.000000</td>
</tr>
<tr>
<td>R2</td>
<td>9.140486</td>
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<tr>
<td>R3</td>
<td>6.587238</td>
<td>0.000000</td>
</tr>
<tr>
<td>R4</td>
<td>7.656124</td>
<td>0.000000</td>
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<tr>
<td>R5</td>
<td>5.568495</td>
<td>0.000000</td>
</tr>
<tr>
<td>RBAR</td>
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<td>0.000000</td>
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<tr>
<td>RMIN</td>
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<tr>
<td>D1P</td>
<td>11.04766</td>
<td>0.000000</td>
</tr>
<tr>
<td>D2P</td>
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<td>0.3438057</td>
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<tr>
<td>D3P</td>
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<tr>
<td>D4P</td>
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</tr>
<tr>
<td>D5P</td>
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</table>

The solution calls for investing 69.1% of the portfolio in the intermediate-term bond fund, 6.4% in the large-cap growth fund, 8.6% in the small-cap growth fund, and 15.9% in the small-cap value fund.

18.
Max Variance | Exp Return
---|---
20 | Infeasible
25 | 9.645
30 | 10.449
35 | 11.172
40 | 11.835
45 | 12.450
50 | 13.022
55 | 13.526
60 | 13.976

(Excel Solver may have trouble with this problem, depending upon the starting solution that is used; a starting solution of each fund at 0.167 will produce the optimal value.)

20. Call option price for Friday, August 25, 2006, is approximately $C = 1.524709.$

22. Optimal solution: Produce 10 chairs at Aynor, cost = $1350; 30 chairs at Spartanburg, cost = $3150; Total cost = $4500

Chapter 9

2. a. A–D–G
   b. No; Time = 15 months

   b. 22 weeks
   c. No, it is a critical activity.
   d. Yes, 2 weeks
   e. Schedule for activity E:

<table>
<thead>
<tr>
<th>Activity E</th>
<th>Earliest start</th>
<th>Latest start</th>
<th>Earliest finish</th>
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<tr>
<td></td>
<td>3</td>
<td>4</td>
<td>10</td>
<td>11</td>
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</tbody>
</table>

8. a.
b. B–C–E–F–H

10. a. 

<table>
<thead>
<tr>
<th>Activity</th>
<th>最早开始</th>
<th>最早完成</th>
<th>最晚开始</th>
<th>最晚完成</th>
<th>slack</th>
<th>关键活动</th>
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<tbody>
<tr>
<td>A</td>
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<td>2</td>
<td>6</td>
<td>8</td>
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<tr>
<td>B</td>
<td>0</td>
<td>0</td>
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<td>8</td>
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</tr>
<tr>
<td>C</td>
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<td>8</td>
<td>20</td>
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<td>0</td>
<td>Yes</td>
</tr>
<tr>
<td>D</td>
<td>20</td>
<td>22</td>
<td>24</td>
<td>26</td>
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<tr>
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<td>20</td>
<td>26</td>
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<td>0</td>
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</tr>
<tr>
<td>F</td>
<td>26</td>
<td>26</td>
<td>41</td>
<td>41</td>
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<td>38</td>
<td>41</td>
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<td>H</td>
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<td>41</td>
<td>49</td>
<td>49</td>
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<td>Yes</td>
</tr>
</tbody>
</table>

d. Yes, time = 49 weeks

11. a. 

<table>
<thead>
<tr>
<th>活动</th>
<th>最优</th>
<th>可能</th>
<th>最终</th>
<th>完成</th>
<th>期望时间</th>
<th>方差</th>
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<tbody>
<tr>
<td>A</td>
<td>4</td>
<td>5.0</td>
<td>6</td>
<td>5.0</td>
<td>5.00</td>
<td>0.11</td>
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<tr>
<td>B</td>
<td>8</td>
<td>9.0</td>
<td>10</td>
<td>9.0</td>
<td>9.00</td>
<td>0.11</td>
</tr>
<tr>
<td>C</td>
<td>7</td>
<td>7.5</td>
<td>11</td>
<td>8.0</td>
<td>8.00</td>
<td>0.44</td>
</tr>
<tr>
<td>D</td>
<td>7</td>
<td>9.0</td>
<td>10</td>
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<td>E</td>
<td>6</td>
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<td>9</td>
<td>7.17</td>
<td>7.17</td>
<td>0.25</td>
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<tr>
<td>F</td>
<td>5</td>
<td>6.0</td>
<td>7</td>
<td>6.00</td>
<td>6.00</td>
<td>0.11</td>
</tr>
</tbody>
</table>

c. 52 weeks (1 year)

d. 0.0934

e. 10 month doubtful
   13 month very likely
   Estimate 12 months (1 year)


b. 25.66 days

c. 0.2578


d. 0.0951, yes


c. 0.0951, yes

d. The probability estimate from (c) based on both paths is more accurate.
20. a.

<table>
<thead>
<tr>
<th>Activity</th>
<th>Maximum Crash</th>
<th>Crash Cost/Week</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>2</td>
<td>400</td>
</tr>
<tr>
<td>B</td>
<td>3</td>
<td>667</td>
</tr>
<tr>
<td>C</td>
<td>1</td>
<td>500</td>
</tr>
<tr>
<td>D</td>
<td>2</td>
<td>300</td>
</tr>
<tr>
<td>E</td>
<td>1</td>
<td>350</td>
</tr>
<tr>
<td>F</td>
<td>2</td>
<td>450</td>
</tr>
<tr>
<td>G</td>
<td>5</td>
<td>360</td>
</tr>
<tr>
<td>H</td>
<td>1</td>
<td>1000</td>
</tr>
</tbody>
</table>

Min $400X_A + 667X_B + 500X_C + 300X_D + 350X_E + 450X_F + 360X_G + 1000X_H$

s.t.

- $x_A + y_A \geq 3$
- $x_E + y_E - x_D \geq 4$
- $x_H + y_H - x_G \geq 3$
- $x_B + y_B \geq 6$
- $x_F + y_F - x_E \geq 3$
- $x_H \leq 16$
- $x_C + y_C - x_A \geq 2$
- $x_G + y_G - x_C \geq 9$
- $x_D + y_D - x_C \geq 5$
- $x_G + y_G - x_B \geq 9$
- $x_D + y_D - x_B \geq 5$
- $x_H + y_H - x_F \geq 3$

Maximum Crashing:

- $y_A \leq 2$
- $y_B \leq 3$
- $y_C \leq 1$
- $y_D \leq 2$
- $y_E \leq 1$
- $y_F \leq 2$
- $y_G \leq 5$
- $y_H \leq 1$

All $x, y \geq 0$

b. Crash B(1 week), D(2 weeks), E(1 week), F(1 week), G(1 week)

Total cost = $2427

c. All activities are critical

21. a.

<table>
<thead>
<tr>
<th>Activity</th>
<th>Earliest Start</th>
<th>Latest Start</th>
<th>Earliest Finish</th>
<th>Latest Finish</th>
<th>Slack</th>
<th>Critical Activity</th>
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</thead>
<tbody>
<tr>
<td>A</td>
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<td>0</td>
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<td>3</td>
<td>0</td>
<td>Yes</td>
</tr>
<tr>
<td>B</td>
<td>0</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>C</td>
<td>3</td>
<td>3</td>
<td>8</td>
<td>8</td>
<td>0</td>
<td>Yes</td>
</tr>
<tr>
<td>D</td>
<td>2</td>
<td>3</td>
<td>7</td>
<td>8</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>E</td>
<td>8</td>
<td>8</td>
<td>14</td>
<td>14</td>
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<tr>
<td>F</td>
<td>8</td>
<td>10</td>
<td>10</td>
<td>12</td>
<td>2</td>
<td></td>
</tr>
<tr>
<td>G</td>
<td>10</td>
<td>12</td>
<td>12</td>
<td>14</td>
<td>2</td>
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</tr>
</tbody>
</table>

Critical path: A–C–E
Project completion time = 14 days

b. Total cost = $8400

22. a.

<table>
<thead>
<tr>
<th>Activity</th>
<th>Max Crash Days</th>
<th>Crash Cost/Day</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>1</td>
<td>600</td>
</tr>
<tr>
<td>B</td>
<td>1</td>
<td>700</td>
</tr>
<tr>
<td>C</td>
<td>2</td>
<td>400</td>
</tr>
<tr>
<td>D</td>
<td>2</td>
<td>500</td>
</tr>
<tr>
<td>E</td>
<td>2</td>
<td>400</td>
</tr>
<tr>
<td>F</td>
<td>1</td>
<td>500</td>
</tr>
<tr>
<td>G</td>
<td>1</td>
<td>500</td>
</tr>
</tbody>
</table>

Min $600X_A + 700X_B + 400X_C + 400X_D + 500X_E + 400X_F + 400X_G$

s.t.

- $X_A + Y_A \geq 3$
- $X_B + Y_B \geq 2$
- $-X_A + X_C + Y_C \geq 5$
- $-X_B + X_D + Y_D \geq 5$
- $-X_C + X_E + Y_E \geq 6$
- $-X_D + X_E + Y_E \geq 6$
- $-X_C + X_F + Y_F \geq 2$
- $-X_D + X_F + Y_F \geq 2$
- $-X_F + X_G + Y_G \geq 2$
- $X_E + X_{FIN} \leq 0$
- $X_G + X_{FIN} \leq 0$
- $X_{FIN} \leq 12$
- $Y_A \leq 1$
- $Y_B \leq 1$
- $Y_C \leq 2$
- $Y_D \leq 2$
- $Y_E \leq 2$
- $Y_F \leq 1$
- $Y_G \leq 1$

All $X, Y \geq 0$

b. Solution of the linear programming model in part (a) shows

<table>
<thead>
<tr>
<th>Activity</th>
<th>Crash</th>
<th>Crashing Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>C</td>
<td>1 day</td>
<td>$400</td>
</tr>
<tr>
<td>E</td>
<td>1 day</td>
<td>$500</td>
</tr>
</tbody>
</table>

Total $900$

c. Total cost = $9300

24. a.
Appendix E  Self-Test Solutions and Answers to Even-Numbered Problems  845

Chapter 10

1. a. $Q^* = \sqrt{\frac{2DC_o}{C_h}} = \sqrt{\frac{2(3600)(20)}{0.25}(3)} = 438.18$

b. $r = \frac{dm}{250} = \frac{3600}{250} = 72$

c. $T = \frac{250Q^*}{q} = \frac{250(438.18)}{3600} = 30.43$ days

d. $TC = \frac{1}{2}QC_h + \frac{D}{Q}C_o$

$$= \frac{1}{2}(438.18)(0.25)(3) + \frac{3600}{438.18}(20) = 328.63$$

2. $164.32$ for each; Total cost = $328.64$

4. a. $1095.45$

b. $240$

c. $22.82$ days

d. $273.86$ for each; Total cost = $547.72$

6. a. $Q_{pencils}^{\text{pen}} = 101$ days

$Q_{pencils} = 120$ days

$TC_{pencils}^{\text{pen}} = 94.87$

$TC_{pencils} = 880$

Total cost = $174.87$

b. $22.88$

8. $Q^* = 11.73$; use 12

5 classes per year

$225,500$

10. $Q^* = 1414.21$

$T = 28.28$ days

Production runs of 7.07 days

12. a. 1500

b. 4 production runs; 3 month cycle time

c. Yes, savings = $12,510$

13. a. $Q^* = \sqrt{\frac{2DC_o}{(1-D/P)C_h}}$

$$= \sqrt{\frac{2(7200)(150)}{1 - 7200/25000}(0.18)(14.50)} = 1078.12$$

b. Number of production runs = $\frac{D}{Q^*} = \frac{7200}{1078.12} = 6.68$

c. $T = \frac{250Q}{D} = \frac{250(1078.12)}{7200} = 37.43$ days

d. Production run length = $\frac{Q}{P/250}$

$$= \frac{1078.12}{25000/250} = 10.78$ days

e. Maximum inventory = $\left(1 - \frac{D}{P}\right)Q$

$$= \left(1 - \frac{7200}{25000}\right)(1078.12) = 767.62$$

f. Holiday cost = $\frac{1}{2}(a-D/P)QC_h$

$$= \frac{1}{2}\left(1 - \frac{7200}{25000}\right)(1078.12)(0.18)(14.50) = 1001.74$$

Ordering cost = $\frac{D}{Q}C_o = \frac{7200}{1078.12}(150) = 1001.74$

Total cost = $2003.48$

g. $r = \frac{dm}{250} = \frac{7200}{250}(15) = 432$

14. New $Q^* = 4509$

15. a. $Q^* = \sqrt{\frac{2DC_a}{C_h + C_b}}$

$$= \sqrt{\frac{2(12,000)(25)(0.50 + 5)}{0.50(0.50 + 5)}} = 1148.91$$

b. $S^* = \frac{Q^*}{C_h + C_b}$

$$= 1148.91\left(\frac{0.50}{0.50 + 5}\right) = 104.45$$

c. Max inventory = $Q^* - S^* = 104.45$

d. $T = \frac{250Q^*}{12,000} = \frac{250(1148.91)}{12,000} = 23.94$ days

e. Holding = $\frac{(Q - S)^2}{2Q}C_h = 237.38$

Ordering = $\frac{D}{Q}C_o = 261.12$

Backorder = $\frac{S^2}{2Q}C_b = 23.74$
Appendix E  Self-Test Solutions and Answers to Even-Numbered Problems

Total cost = $522.24
The total cost for the EOQ model in Problem 4 was $547.72; allowing backorders reduces the total cost.

16. $135.55; r = dm − S; less than

18. 64, 24.44

20. Q* = 100; Total cost = $3601.50

21. $5128.56

22. Q* = 300; Savings = $480

24. a. 8352 magazines
b. 8828 magazines

25. a. $150
b. $240 − $150 = $90
c. 47
d. 0.625

28. a. 440
b. 0.60
c. 710
d. c_o = $17
4. 0.3333, 0.2222, 0.1481, 0.0988; 0.1976

5. a. \[ P_0 = 1 - \frac{\lambda}{\mu} = 1 - \frac{10}{12} = 0.1667 \]

   b. \[ L_q = \frac{\lambda^2}{\mu(\mu - \lambda)} = \frac{10^2}{12(12 - 10)} = 4.1667 \]

   c. \[ W_q = \frac{L_q}{\lambda} = 0.4167 \text{ hour (25 minutes)} \]

   d. \[ W = W_q + \frac{1}{\lambda} = 0.5 \text{ hour (30 minutes)} \]

   e. \[ P_w = \frac{\lambda}{\mu} = \frac{10}{12} = 0.8333 \]

6. a. 0.3750
   b. 1.0417
   c. 0.8333 minutes (50 seconds)
   d. 0.6250
   e. Yes

8. 0.20, 3.2, 4, 3.2, 4, 0.80
   Slightly poorer service

10. a. New: 0.3333, 1.3333, 2, 0.6667, 1, 0.6667
    Experienced: 0.50, 0.50, 1, 0.25, 0.50, 0.50
    b. New $74; experienced $50; hire experienced

11. a. \( \lambda = 2.5; \mu = \frac{60}{10} = 6 \) customers per hour

   \[ L_q = \frac{\lambda^2}{\mu(\mu - \lambda)} = \frac{(2.5)^2}{6(6 - 2.5)} = 0.2976 \]

   \[ L = L_q + \frac{\lambda}{\mu} = 0.7143 \]

   \[ W_q = \frac{L_q}{\lambda} = 0.1190 \text{ hours (7.14 minutes)} \]

   \[ W = W_q + \frac{1}{\mu} = 0.2857 \text{ hours} \]

   \[ P_w = \frac{\lambda}{\mu} = \frac{2.5}{6} = 0.4167 \]

   b. No; \( W_q = 7.14 \) minutes; firm should increase the service rate (\( \mu \)) for the consultant or hire a second consultant.

   c. \( \mu = \frac{60}{8} = 7.5 \) customers per hour

   \[ L_q = \frac{\lambda^2}{\mu(\mu - \lambda)} = \frac{(2.5)^2}{7.5(7.5 - 2.5)} = 0.1667 \]

   \[ W_q = \frac{L_q}{\lambda} = 0.0667 \text{ hours (4 minutes)} \]

   The service goal is being met.

12. a. 0.25, 2.25, 3, 0.15 hours, 0.20 hours, 0.75
    b. The service needs improvement.

14. a. 8
    b. 0.3750
    c. 1.0417
    d. 12.5 minutes
    e. 0.6250
    f. Add a second consultant.

16. a. 0.50
    b. 0.50
    c. 0.10 hours (6 minutes)
    d. 0.20 hours (12 minutes)
    e. Yes, \( W_q = 6 \) minutes is most likely acceptable for a marina.

18. a. \( k = 2; \lambda/\mu = 5.4/3 = 1.8; P_0 = 0.0526 \)

   \[ L_q = \frac{\left(\frac{\lambda}{\mu}\right)^2 \lambda \mu}{(k - 1)!(2\mu - \lambda)^2} P_0 = \frac{(1.8)^2(5.4)(3)}{(2 - 1)!(6 - 5.4)^2}(0.0526) = 7.67 \]

   \[ L = L_q + \frac{\lambda}{\mu} = 7.67 + 1.8 = 9.47 \]

   \[ W_q = \frac{L_q}{\lambda} = \frac{7.67}{5.4} = 1.42 \text{ minutes} \]

   \[ W = W_q + \frac{1}{\mu} = 1.42 + 0.33 = 1.75 \text{ minutes} \]

   \[ P_w = \frac{1}{k!} \left(\frac{\lambda}{\mu}\right)^k \frac{k \mu}{\lambda} P_0 = \frac{1}{1!} \left(\frac{1.8}{5.4}\right)^2 \frac{6}{6 - 5.4} P_0 = 0.8526 \]

   b. \( L_q = 7.67; \) Yes

   c. \( W = 1.75 \text{ minutes} \)

20. a. Use \( k = 2 \)

   \[ W = 3.7037 \text{ minutes} \]

   \[ L = 4.4444 \]

   \[ P_w = 0.7111 \]

   b. For \( k = 3 \)

   \[ W = 7.1778 \text{ minutes} \]

   \[ L = 15.0735 \text{ customers} \]

   \[ P_N = 0.8767 \]

   Expand post office.

21. From Problem 11, a service time of 8 minutes has \( \mu = 60/8 = 7.5 \).

   \[ L_q = \frac{\lambda^2}{\mu(\mu - \lambda)} = \frac{(2.5)^2}{7.5(7.5 - 2.5)} = 0.1667 \]

   \[ L = L_q + \frac{\lambda}{\mu} = 0.50 \]
Total cost = $25 + $16 = 25(0.50) + 16 = $28.50

Two channels: \( \lambda = 2.5; \mu = 60/10 = 6 \)

With \( P_0 = 0.6552 \),

\[
L_q = \frac{(\lambda/\mu)^2 \lambda \mu}{1!(2 \mu - \lambda)} P_0 = 0.0189
\]

\[
L = L_q + \frac{\lambda}{\mu}_q = 0.4356
\]

Total cost = 25(0.4356) + 2(16) = $42.89

Use one consultant with an 8-minute service time.

### 22.

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>( A )</th>
<th>( B )</th>
<th>( C )</th>
</tr>
</thead>
<tbody>
<tr>
<td>a. ( P_0 )</td>
<td>0.2000</td>
<td>0.5000</td>
<td>0.4286</td>
</tr>
<tr>
<td>b. ( L_q )</td>
<td>3.2000</td>
<td>0.5000</td>
<td>0.1524</td>
</tr>
<tr>
<td>c. ( L )</td>
<td>4.0000</td>
<td>1.0000</td>
<td>0.9524</td>
</tr>
<tr>
<td>d. ( W_q )</td>
<td>0.1333</td>
<td>0.0208</td>
<td>0.0063</td>
</tr>
<tr>
<td>e. ( W )</td>
<td>0.1667</td>
<td>0.0417</td>
<td>0.0397</td>
</tr>
<tr>
<td>f. ( P_w )</td>
<td>0.8000</td>
<td>0.5000</td>
<td>0.2286</td>
</tr>
</tbody>
</table>

The two-channel System C provides the best service.

### 24.

\( \lambda = 4, W = 10 \) minutes

- a. \( \mu = 0.5 \)
- b. \( W_q = 8 \) minutes
- c. \( L = 40 \)

### 26.

- a. 0.2668, 10 minutes, 0.6667
- b. 0.0667, 7 minutes, 0.4669
- c. $25.33; $33.34; one-channel

### 27.

- a. \( \frac{3}{2} \) hours = 0.25 per hour
- b. 1/3.2 hours = 0.3125 per hour
- c. \( L_q = \frac{\lambda^2 \sigma^2 + (\lambda/\mu)^2}{2(1 - \lambda/\mu)} \)
  
  \[
  = \frac{(0.25)^2(2)^2 + (2.5/0.3125)^2}{2(1 - 0.25/0.3125)} = 2.225
  \]
- d. \( W_q = \frac{L_q}{\lambda} = \frac{2.225}{0.25} = 8.9 \) hours
- e. \( W = W_q + \frac{1}{\mu} = 8.9 + \frac{1}{0.3125} = 12.1 \) hours
- f. Same as \( P_w = \frac{\lambda}{\mu} = \frac{0.25}{0.3125} = 0.80 \)

The welder is busy 80% of the time.

### 30.

- a. \( \lambda = 42; \mu = 20 \)

### Table

<table>
<thead>
<tr>
<th>( i )</th>
<th>( (\lambda/\mu)^i/\beta )</th>
<th>( P_j )</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>1.0000</td>
<td>0.1460</td>
</tr>
<tr>
<td>1</td>
<td>2.1000</td>
<td>0.3066</td>
</tr>
<tr>
<td>2</td>
<td>2.2050</td>
<td>0.3220</td>
</tr>
<tr>
<td>3</td>
<td>1.5435</td>
<td>0.2254</td>
</tr>
</tbody>
</table>

Total 6.8485

### Calculation

\[
P_0 = \frac{0.2254}{0.3110} = 0.7276
\]

**Appendix E Self-Test Solutions and Answers to Even-Numbered Problems**
Chapter 12

2. a. \( c = \text{variable cost per unit} \) \\
   \( x = \text{demand} \) \\
   \( \text{Profit} = (50 - c)x - 30,000 \)
   b. Base: \( \text{Profit} = (50 - 20) \times 1200 - 30,000 = 6,000 \) \\
   Worst: \( \text{Profit} = (50 - 24) \times 300 - 30,000 = -22,200 \) \\
   Best: \( \text{Profit} = (50 - 16) \times 1000 - 30,000 = 41,400 \) \\
   c. Simulation will be helpful in estimating the probability of a loss.

4. a. Number of New Accounts \\
   \begin{array}{c|c}
   \text{Interval} & \text{Number of Accounts} \\
   \hline
   0 & 0.00 but less than 0.01 \\
   1 & 0.01 but less than 0.05 \\
   2 & 0.05 but less than 0.15 \\
   3 & 0.15 but less than 0.40 \\
   4 & 0.40 but less than 0.80 \\
   5 & 0.80 but less than 0.95 \\
   6 & 0.95 but less than 1.00 \\
   \end{array}
   b. 4, 3, 3, 5, 2, 6, 4, 4, 2 \\
   37 new accounts \\
   c. Commission from 10 seminars = $185,000 \\
   Cost of 10 seminars = $35,000 \\
   Yes

5. a. Stock Price Change \\
   \begin{array}{c|c}
   \text{Interval} & \text{Price Change} \\
   \hline
   \text{Beginning price} & $39 \\
   0.1091 & \text{indicates −1 change; $38} \\
   0.9407 & \text{indicates +4 change; $42} \\
   0.1941 & \text{indicates 0 change; $42} \\
   0.8083 & \text{indicates +3 change; $45 (ending price)} \\
   \end{array}
   b. 4 claims paid; Total = $22,000

8. a. Atlanta wins each game if random number is in interval 0.00–0.60, 0.00–0.55, 0.00–0.48, 0.00–0.45, 0.00–0.48, 0.00–0.55, 0.00–0.50. \\
   b. Atlanta wins games 1, 2, 4, and 6. \\
   Atlanta wins series 4 to 2. \\
   c. Repeat many times; record % of Atlanta wins.

9. a. Base-case based on most likely; \\
   Time = 6 + 5 + 14 + 8 = 33 weeks \\
   b. 0.1778 for A: 5 weeks \\
   0.9617 for B: 7 weeks \\
   0.6849 for C: 14 weeks \\
   0.4503 for D: 8 weeks; Total = 34 weeks

10. a. Hand Value \\
   \begin{array}{c|c}
   \text{Interval} & \text{Hand Value} \\
   \hline
   17 & 0.0000 but less than 0.1654 \\
   18 & 0.1654 but less than 0.2717 \\
   19 & 0.2717 but less than 0.3780 \\
   20 & 0.3780 but less than 0.4797 \\
   21 & 0.4797 but less than 0.5769 \\
   \end{array}
   b, c, & d. Dealer wins 13 hands, player wins 5, 2 pushes. \\
   e. Player wins 7, dealer wins 13.

12. a. $7, $3, $12 \\
   b. Purchase: 0.00–0.25, 0.25–0.70, 0.70–1.00 \\
   Labor: 0.00–0.10, 0.10–0.35, 0.35–0.70, 0.70–1.00 \\
   Transportation: 0.00–0.75, 0.75–1.00 \\
   c. $5 \\
   d. $7 \\
   e. Provide probability profit less than $5/unit.

14. Selected cell formulas for the worksheet shown in Figure E12.14 are as follows:

```
<table>
<thead>
<tr>
<th>Cell</th>
<th>Formula</th>
</tr>
</thead>
<tbody>
<tr>
<td>B13</td>
<td>=$C$7+RANDBETWEEN($C$8,$C$9)</td>
</tr>
<tr>
<td>C13</td>
<td>=NORMINV(RAND(),$G$7,$G$8)</td>
</tr>
<tr>
<td>D13</td>
<td>=($C$3−B13)*C13−$C$4</td>
</tr>
</tbody>
</table>
```

a. The mean profit should be approximately $6000; simulation results will vary, with most simulations having a mean profit between $5500 and $6500.

b. 120 to 150 of the 500 simulation trials should show a loss; thus, the probability of a loss should be between 0.24 and 0.30.

c. This project appears too risky.

16. a. About 36% of simulation runs will show $130,000 as the winning bid.
   b. $150,000; $10,000 \\
   c. Recommended $140,000

18. Selected cell formulas for the worksheet shown in Figure E12.18 are as follows:

```
<table>
<thead>
<tr>
<th>Cell</th>
<th>Formula</th>
</tr>
</thead>
<tbody>
<tr>
<td>B10</td>
<td>=$B$4+ RANDBETWEEN($B$5,$B$6)</td>
</tr>
<tr>
<td>C10</td>
<td>=NORMINV(RAND(),$E$4,$E$5)</td>
</tr>
<tr>
<td>D10</td>
<td>=MAX(B10:C10)</td>
</tr>
<tr>
<td>C1013</td>
<td>=COUNTIF(D10:D1009,”&lt;750000”)</td>
</tr>
<tr>
<td>D1013</td>
<td>=C1013 / COUNT(D10:D1009)</td>
</tr>
</tbody>
</table>
```
FIGURE E12.14 WORKSHEET FOR THE MADEIRA MANUFACTURING SIMULATION

<table>
<thead>
<tr>
<th></th>
<th>A</th>
<th>B</th>
<th>C</th>
<th>D</th>
<th>E</th>
<th>F</th>
<th>G</th>
<th>H</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Madeira Manufacturing Company</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>Selling Price per Unit</td>
<td>$50</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>Fixed Cost</td>
<td>$30,000</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>5</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>Variable Cost (Uniform Distribution)</td>
<td>Demand (Normal Distribution)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>Smallest Value</td>
<td>$16</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>Largest Value</td>
<td>$24</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>9</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>10</td>
<td>Simulation</td>
<td></td>
<td></td>
<td></td>
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<td></td>
</tr>
<tr>
<td>11</td>
<td>Trial</td>
<td>Unit Variable Cost</td>
<td>Demand</td>
<td>Profit</td>
<td></td>
<td></td>
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</tr>
<tr>
<td>12</td>
<td>1</td>
<td>$17.81</td>
<td>788</td>
<td>($4,681)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>13</td>
<td>2</td>
<td>$18.86</td>
<td>1078</td>
<td>$3,580</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

FIGURE E12.18 WORKSHEET FOR THE CONTRACTOR BIDDING SIMULATION

<table>
<thead>
<tr>
<th></th>
<th>A</th>
<th>B</th>
<th>C</th>
<th>D</th>
<th>E</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Contractor Bidding</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>Contractor A (Uniform Distribution)</td>
<td>Contractor A (Normal Distribution)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>Smallest Value</td>
<td>$600,000</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>Largest Value</td>
<td>$800,000</td>
<td></td>
<td></td>
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</tr>
<tr>
<td>6</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>7</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>Simulation</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>9</td>
<td>Trial</td>
<td>Contractor A’s Bid</td>
<td>Contractor B’s Bid</td>
<td>Highest Bid</td>
<td></td>
</tr>
<tr>
<td>10</td>
<td>1</td>
<td>$785,020</td>
<td>$630,729</td>
<td>$785,020.16</td>
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</tr>
<tr>
<td>11</td>
<td>2</td>
<td>$698,925</td>
<td>$742,675</td>
<td>$742,675.28</td>
<td></td>
</tr>
<tr>
<td>1008</td>
<td>999</td>
<td>$795,023</td>
<td>$822,027</td>
<td>$822,027.17</td>
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</tr>
<tr>
<td>1009</td>
<td>1000</td>
<td>$672,159</td>
<td>$708,791</td>
<td>$708,791.25</td>
<td></td>
</tr>
<tr>
<td>1010</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1011</td>
<td>Results</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1012</td>
<td>Contractor’s Bid</td>
<td>Number of Wins</td>
<td>Probability of Winning</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1013</td>
<td>$750,000</td>
<td>641</td>
<td>0.641</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1014</td>
<td>$775,000</td>
<td>826</td>
<td>0.826</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1015</td>
<td>$785,000</td>
<td>894</td>
<td>0.894</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

a. The probability of winning the bid should be between 0.60 and 0.65.
b. Probability of $750,000 winning should be roughly 0.82; probability of $785,000 winning should be roughly 0.88.

20. a. Results vary with each simulation run.
 Approximate results:
  50,000 provided $230,000
  60,000 provided $190,000
  70,000 less than $100,000
b. Recommend 50,000 units.
c. Roughly 0.75
22. Very poor operation; some customers wait 30 minutes or more.

24. a. Mean interarrival time and mean service time are both approximately 4 minutes.
   b. Waiting time is approximately 0.8 minutes.
   c. 30% to 35% of customers have to wait.

Chapter 13

1. a.

![Decision Tree Diagram]

b. | Decision | Maximum Profit | Minimum Profit |
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>d₁</td>
<td>250</td>
<td>25</td>
</tr>
<tr>
<td>d₂</td>
<td>100</td>
<td>75</td>
</tr>
</tbody>
</table>

Optimistic approach: Select d₁
Conservative approach: Select d₂
Regret or opportunity loss table:

<table>
<thead>
<tr>
<th>Decision</th>
<th>s₁</th>
<th>s₂</th>
<th>s₃</th>
</tr>
</thead>
<tbody>
<tr>
<td>d₁</td>
<td>0</td>
<td>0</td>
<td>50</td>
</tr>
<tr>
<td>d₂</td>
<td>150</td>
<td>0</td>
<td>50</td>
</tr>
</tbody>
</table>

Maximum regret: 50 for d₁ and 150 for d₂; select d₁

2. a. Optimistic: d₁
   Conservative: d₃
   Minimax regret: d₃
   c. Optimistic: d₁
   Conservative: d₂ or d₃
   Minimax regret: d₂

3. a. Decision: Choose the best plant size from the two alternatives—a small plant and a large plant.
   Chance event: Market demand for the new product line with three possible outcomes (states of nature): low, medium, and high
   b. Influence Diagram:

![Influence Diagram]

4. a. The decision faced by Amy is to select the best lease option from three alternatives (Hepburn Honda, Midtown Motors, and Hopkins Automotive). The chance event is the number of miles Amy will drive.

<table>
<thead>
<tr>
<th>Dealer</th>
<th>Actual Miles Driven Annually</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hepburn Honda</td>
<td>$10,764, $12,114, $13,464</td>
</tr>
<tr>
<td>Midtown Motors</td>
<td>$11,160, $11,160, $12,960</td>
</tr>
<tr>
<td>Hopkins Automotive</td>
<td>$11,700, $11,700, $11,700</td>
</tr>
</tbody>
</table>
c. The minimum and maximum payoffs for each of Amy’s three alternatives are:

<table>
<thead>
<tr>
<th>Dealer</th>
<th>Minimum Cost</th>
<th>Maximum Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hepburn Honda</td>
<td>$10,764</td>
<td>$13,464</td>
</tr>
<tr>
<td>Midtown Motors</td>
<td>$11,160</td>
<td>$12,960</td>
</tr>
<tr>
<td>Hopkins Automotive</td>
<td>$11,700</td>
<td>$11,700</td>
</tr>
</tbody>
</table>

Thus:
- The optimistic approach results in selection of the Hepburn Automotive lease option (which has the smallest minimum cost of the three alternatives—$10,764).
- The conservative approach results in selection of the Hopkins Automotive lease option (which has the smallest maximum cost of the three alternatives—$11,700).
- The minimax regret approach results in selection of the Hopkins Automotive lease option (which has the smallest regret of the three alternatives: $936).

d. The expected value approach results in selection of the Midtown Motors lease option (which has the minimum expected value of the three alternatives—$11,340).

e. The risk profile for the decision to lease from Midtown Motors is as follows:

![Risk Profile Diagram]

Note that although we have three chance outcomes (drive 12,000 miles annually, drive 15,000 miles annually, and drive 18,000 miles annually), we only have two unique costs on this graph. This is because for this decision alternative (lease from Midtown Motors) there are only two unique payoffs associated with the three chance outcomes—the payoff (cost) associated with the Midtown Motors lease is the same for two of the chance outcomes (whether Amy drives 12,000 miles or 15,000 miles annually, her payoff is $11,160).

The expected value approach results in selection of either the Midtown Motors lease option or the Hopkins Automotive lease option (both of which have the minimum expected value of the three alternatives—$11,700).

5. a. 
\[ EV(d_1) = 0.65(250) + 0.15(100) + 0.20(25) + 182.5 \]
\[ EV(d_2) = 0.65(100) + 0.15(100) + 0.20(75) + 95 \]
The optimal decision is \( d_1 \).

6. a. Pharmaceuticals; 3.4%
b. Financial; 4.6%

7. a. 
\[ EV(own\ staff) = 0.2(650) + 0.5(650) + 0.3(600) = 635 \]
\[ EV(outside\ vendor) = 0.2(900) + 0.5(650) + 0.3(500) = 635 \]
Optimal decision: Hire an outside vendor with an expected cost of $570,000

b. 

<table>
<thead>
<tr>
<th>Cost</th>
<th>Probability</th>
</tr>
</thead>
<tbody>
<tr>
<td>300</td>
<td>0.3</td>
</tr>
<tr>
<td>600</td>
<td>0.5</td>
</tr>
<tr>
<td>900</td>
<td>0.2</td>
</tr>
<tr>
<td>1000</td>
<td>1.0</td>
</tr>
</tbody>
</table>

8. a. 
\[ EV(d_1) = p(10) + (1 - p)(1) = 9p + 1 \]
\[ EV(d_2) = p(4) + (1 - p)(3) = 1p + 3 \]

b. 
\[ d_2 \text{ is optimal for } p \geq 0.25, d_1 \text{ is optimal for } p \geq 0.25 \]
c. As long as the payoff for \( s_1 \geq 2 \), then \( d_2 \) is optimal.

10. b. Space Pirates
\[ EV = 724,000 \]
\[ \$84,000 \text{ better than Battle Pacific} \]

c. 
\| $200 | 0.18          |
| $400 | 0.32          |
| $800 | 0.30          |
| $1600| 0.20          |

d. \( P(\text{Competition}) > 0.7273 \)

12. a. Decision: Whether to lengthen the runway
Chance event: The location decisions of Air Express and DRI
Consequence: Annual revenue
14. a. If \( s_1 \), then \( d_1 \); if \( s_2 \), then \( d_1 \) or \( d_2 \); if \( s_3 \), then \( d_2 \\

b. \( EvwPI = 0.65(250) + 0.15(100) + 0.20(75) = 192.5 \)

c. From the solution to Problem 5, we know that \( EV(d_1) = 182.5 \) and \( EV(d_2) = 95 \); thus, recommended decision is \( d_1 \); hence, \( EvwoPI = 182.5 \).

d. \( EVPI = EvwPI - EvwoPI = 192.5 - 182.5 = 10 \)

16. a. 

\[ 
\begin{array}{cccc}
& d_1 & d_2 & \\
\text{F} & x_1 & x_2 & 300 \\
\text{J} & d_1 & d_2 & 400 \\
\text{2} & s_1 & s_2 & 200 \\
\text{3} & s_1 & s_2 & 100 \\
\text{4} & s_1 & s_2 & 300 \\
\text{5} & s_1 & s_2 & 200 \\
\text{6} & s_1 & s_2 & 100 \\
\text{7} & s_1 & s_2 & 300 \\
\text{8} & s_1 & s_2 & 200 \\
\text{9} & s_1 & s_2 & 100 \\
\text{10} & s_1 & s_2 & 300 \\
\end{array} 
\]

\[ \text{Profit Payoff} \]

\( EV (\text{node 6}) = 0.57(100) + 0.43(300) = 186 \)

\( EV (\text{node 7}) = 0.57(400) + 0.43(200) = 314 \)

\( EV (\text{node 8}) = 0.18(100) + 0.82(200) = 264 \)

\( EV (\text{node 9}) = 0.18(400) + 0.82(200) = 236 \)

\( EV (\text{node 10}) = 0.40(100) + 0.60(300) = 220 \)

\( EV (\text{node 11}) = 0.40(400) + 0.60(200) = 280 \)

\( EV (\text{node } 3) = \text{Max}(186,314) = 314d_2 \)

\( EV (\text{node } 4) = \text{Max}(264,236) = 264d_1 \)

\( EV (\text{node } 5) = \text{Max}(220,280) = 280d_2 \)

\( EV (\text{node } 2) = 0.56(314) + 0.44(264) = 292 \)

\( EV (\text{node } 1) = \text{Max}(292,280) = 292 \)

b. Lengthen the runway.

c. $270,000

d. No

e. If unfavorable, decision \( d_3 \) 

If favorable, decision \( d_1 \)

18. a. \( 5000 - 200 - 2000 - 150 = 2650 \)

\( 3000 - 200 - 2000 - 150 = 650 \)

b. Expected values at nodes:

<table>
<thead>
<tr>
<th>Payoff (in millions)</th>
<th>Probability</th>
</tr>
</thead>
<tbody>
<tr>
<td>-200</td>
<td>0.20</td>
</tr>
<tr>
<td>800</td>
<td>0.32</td>
</tr>
<tr>
<td>2800</td>
<td>0.48</td>
</tr>
<tr>
<td>100</td>
<td>1.00</td>
</tr>
</tbody>
</table>

c. Cost would have to decrease by at least $130,000.

d. $87,500; better method of predicting success

20. a. Order two lots; $60,000

b. If \( E \), order two lots

If \( V \), order one lot

\( EV = 60,500 \)

c. \( EVPI = 14,000 \)

\( EVSI = 500 \)

Efficiency = 3.6%

Yes, use consultant.

23.

\begin{array}{cccc}
\text{State of Nature} & P(s_j) & P(I|s_j) & P(I \cap s_j) & P(s_j|I) \\
\hline
s_1 & 0.2 & 0.10 & 0.020 & 0.1905 \\
\hline
s_2 & 0.5 & 0.05 & 0.025 & 0.2381 \\
\hline
s_3 & 0.3 & 0.20 & 0.060 & 0.5714 \\
\hline
1.0 & & & & 1.0000 \\
\end{array} 

24. a. 0.695, 0.215, 0.090

0.98, 0.02

0.79, 0.21

0.00, 1.00

c. If \( C \), Expressway

If \( O \), Expressway

If \( R \), Queen City

26.6 minutes

26. a. \( EV(d_1) = 10,000 \)

\( EV(d_2) = 0.96(0) + 0.03(100,000) + 0.01(200,000) = 5,000 \)

Using EV approach, we should choose No Insurance \( d_2 \).
b. Lottery:
\[ p = \text{probability of a $0 Cost} \]
\[ 1 - p = \text{probability of a $200,000 Cost} \]

c.

<table>
<thead>
<tr>
<th></th>
<th>( s_1 )</th>
<th>( s_2 )</th>
<th>( s_3 )</th>
</tr>
</thead>
<tbody>
<tr>
<td>Insurance</td>
<td>( d_1 )</td>
<td>9.9</td>
<td>9.9</td>
</tr>
<tr>
<td>No Insurance</td>
<td>( d_1 )</td>
<td>10.0</td>
<td>6.0</td>
</tr>
</tbody>
</table>

\[ \text{EU}(d_1) = 9.9 \]
\[ \text{EU}(d_2) = 0.96(10.0) + 0.03(6.0) + 0.01(0.0) = 9.78 \]

\therefore \text{Using EU approach} \rightarrow \text{Insurance} (d_1)

d. Use expected utility approach. The EV approach results in a decision that can be very risky since it means that the decision maker could lose up to $200,000. Most decision makers (particularly those considering insurance) are risk averse.

28. a.

b. A - Risk avoider  
B - Risk taker  
C - Risk neutral

c. Risk avoider A, at $20 payoff \( p = 0.70 \)
Thus, \( \text{EV(Lottery)} = 0.70(100) + 0.30(-100) = $40 \)
Therefore, will pay 40 - 20 = $20
Risk taker B, at $20 payoff \( p = 0.45 \)
Thus, \( \text{EV(Lottery)} = 0.45(100) + 0.55(-100) = -$10 \)
Therefore, will pay 20 + (-10) = $30

d. Use expected utility approach. The EV approach results in a decision that can be very risky since it means that the decision maker could lose up to $200,000. Most decision makers (particularly those considering insurance) are risk averse.

30. Monetary Payoff, \( x \)  
<table>
<thead>
<tr>
<th></th>
<th>Utility, ( U(x) )</th>
</tr>
</thead>
<tbody>
<tr>
<td>-200</td>
<td>-1.226</td>
</tr>
<tr>
<td>-100</td>
<td>-0.492</td>
</tr>
<tr>
<td>0</td>
<td>0.000</td>
</tr>
<tr>
<td>100</td>
<td>0.330</td>
</tr>
<tr>
<td>200</td>
<td>0.551</td>
</tr>
<tr>
<td>300</td>
<td>0.699</td>
</tr>
<tr>
<td>400</td>
<td>0.798</td>
</tr>
<tr>
<td>500</td>
<td>0.865</td>
</tr>
</tbody>
</table>

Chapter 14

2. a. Let \( x_1 = \) number of shares of AGA Products purchased  
\( x_2 = \) number of shares of Key Oil purchased

To obtain an annual return of exactly 9%:
\[ 0.06(50)x_1 + 0.10(100)x_2 = 0.09(50,000) \]
\[ 3x_1 + 10x_2 = 4500 \]

To have exactly 60% of the total investment in Key Oil:
\[ 100x_2 = 0.60(50,000) \]
\[ x_2 = 300 \]

Therefore, we can write the goal programming model as follows:

Min \( P_1(d_1^i) + P_2(d_2^i) \)

s.t.
\[ 50x_1 + 100x_2 \leq 50,000 \quad \text{Funds available} \]
\[ 3x_1 + 10x_2 - d_1^i - d_1^i = 4,500 \quad P_1 \text{ goal} \]
\[ x_2 - d_2^i + d_2^i = 300 \quad P_2 \text{ goal} \]
\[ x_1, x_2, d_1^i, d_1^i, d_2^i, d_2^i \geq 0 \]

b. In the following graphical solution, \( x_1 = 250 \) and \( x_2 = 375 \).

4. a. Min \( P_1(d_1^i) + P_2(d_1^i) + P_2(d_2^i) + P_2(d_2^i) + P_3(d_3^i) \)

s.t.
\[ 20x_1 + 30x_2 - d_1^i + d_1^i = 4800 \]
\[ 20x_1 + 30x_2 - d_1^i + d_1^i = 6000 \]
\[ x_1 - d_2^i + d_2^i = 100 \]
\[ x_2 - d_2^i + d_2^i = 120 \]
\[ x_1 + x_2 - d_2^i + d_2^i = 300 \]
\[ x_1, x_2, \text{all deviation variables} \geq 0 \]
6. a. Let \( x_1 = \) number of letters mailed to group 1 customers
   \[ x_2 = \] number of letters mailed to group 2 customers
   
   \[
   \begin{align*}
   \text{Min} & \quad P_1(d_1^1) + P_2(d_2^1) + P_2(d_1^2) \\
   \text{s.t.} & \quad x_1 - d_1^1 + d_1^1 = 40,000 \\
   & \quad x_2 - d_2^2 + d_2^2 = 50,000 \\
   & \quad x_1 + x_2 - d_1^3 + d_3^3 = 70,000 \\
   & \quad x_1, x_2, \text{ all deviation variables} \geq 0 \\
   \end{align*}
   \]

   b. \( x_1 = 40,000, \quad x_2 = 50,000 \)

   c. Optimal solution does not change.

8. a. Min \( d_1^1 + d_2^1 + e_1^1 + e_1^1 + d_2^2 + d_2^2 + e_2^2 + d_3^2 + e_3^2 + e_3^2 \)

   s.t.
   \[
   \begin{align*}
   x_1 + d_1^1 - d_1^1 & = 1 \\
   x_2 + e_1^1 - e_1^1 & = 7 \\
   x_1 + d_2^2 - d_2^2 & = 5 \\
   x_2 + e_2^2 - e_2^2 & = 9 \\
   x_1 + d_3^2 - d_3^2 & = 6 \\
   x_2 + e_3^2 - e_3^2 & = 2 \\
   \end{align*}
   \]

   b. \( x_1 = 5, \quad x_2 = 7 \)

9. Scoring calculations

<table>
<thead>
<tr>
<th>Criterion</th>
<th>Analyst Chicago</th>
<th>Accountant Denver</th>
<th>Auditor Houston</th>
</tr>
</thead>
<tbody>
<tr>
<td>Career advancement</td>
<td>35</td>
<td>20</td>
<td>20</td>
</tr>
<tr>
<td>Location</td>
<td>10</td>
<td>12</td>
<td>8</td>
</tr>
<tr>
<td>Management</td>
<td>30</td>
<td>25</td>
<td>35</td>
</tr>
<tr>
<td>Salary</td>
<td>28</td>
<td>32</td>
<td>16</td>
</tr>
<tr>
<td>Prestige</td>
<td>32</td>
<td>20</td>
<td>24</td>
</tr>
<tr>
<td>Job security</td>
<td>8</td>
<td>10</td>
<td>16</td>
</tr>
<tr>
<td>Enjoyment of the work</td>
<td>28</td>
<td>20</td>
<td>20</td>
</tr>
<tr>
<td>Total</td>
<td>171</td>
<td>139</td>
<td>139</td>
</tr>
</tbody>
</table>

The analyst position in Chicago is recommended.

10. 178, 184, 151

Marysville

12. 170, 168, 190, 183

Handover College

14. a. 220 Bowrider (194)
   
   b. 240 Sundancer (144)

16. Step 1: Column totals are \( \frac{17}{12}, \frac{21}{12}, \) and 12.
Appendix E  Self-Test Solutions and Answers to Even-Numbered Problems

Step 3:

<table>
<thead>
<tr>
<th>Flavor</th>
<th>A</th>
<th>B</th>
<th>C</th>
<th>Average</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>0.545</td>
<td>0.714</td>
<td>0.250</td>
<td>0.503</td>
</tr>
<tr>
<td>B</td>
<td>0.182</td>
<td>0.238</td>
<td>0.625</td>
<td>0.348</td>
</tr>
<tr>
<td>C</td>
<td>0.273</td>
<td>0.048</td>
<td>0.125</td>
<td>0.148</td>
</tr>
</tbody>
</table>

c. Step 1:

\[
\begin{align*}
0.503 & \quad \frac{1}{2} + 0.348 \quad \frac{1}{3} + 0.148 \quad \frac{2}{5} \\
0.168 & \quad \frac{1}{4} + 0.348 & \quad \frac{2}{3} + 0.740 & \quad \frac{1.845}{1.258} \\
0.252 & \quad \frac{1}{4} + 0.070 & \quad \frac{1}{1} + 0.148 & \quad \frac{0.470}{0.470}
\end{align*}
\]

Step 2: \(1.845/0.503 = 3.668\)
\(1.258/0.348 = 3.615\)
\(0.470/0.148 = 3.123\)

Step 3: \(\lambda_{\text{max}} = (3.668 + 3.615 + 3.123)/3 = 3.469\)

Step 4: CI = \((3.469 - 3)/2 = 0.235\)

Step 5: CR = \(0.235/0.58 = 0.415\)

Because CR = 0.415 is greater than 0.10, the individual’s judgments are not consistent.

22. a.

<table>
<thead>
<tr>
<th></th>
<th>D</th>
<th>S</th>
<th>N</th>
</tr>
</thead>
<tbody>
<tr>
<td>D</td>
<td>1/4</td>
<td>1/5</td>
<td></td>
</tr>
<tr>
<td>S</td>
<td>4/1</td>
<td>3/1</td>
<td></td>
</tr>
</tbody>
</table>

Chapter 15

1. The following table shows the calculations for parts (a), (b), and (c).

<table>
<thead>
<tr>
<th>Week</th>
<th>Time Series Value</th>
<th>Forecast</th>
<th>Forecast Error</th>
<th>Absolute Value of Forecast Error</th>
<th>Squared Forecast Error</th>
<th>Percentage Error</th>
<th>Absolute Value of Percentage Error</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>18</td>
<td>18</td>
<td>-5</td>
<td>5</td>
<td>25</td>
<td>-38.46</td>
<td>38.46</td>
</tr>
<tr>
<td>2</td>
<td>13</td>
<td>18</td>
<td>-5</td>
<td>5</td>
<td>25</td>
<td>-45.45</td>
<td>45.45</td>
</tr>
<tr>
<td>3</td>
<td>16</td>
<td>13</td>
<td>3</td>
<td>3</td>
<td>9</td>
<td>18.75</td>
<td>18.75</td>
</tr>
<tr>
<td>4</td>
<td>11</td>
<td>16</td>
<td>-5</td>
<td>5</td>
<td>25</td>
<td>-35.29</td>
<td>35.29</td>
</tr>
<tr>
<td>5</td>
<td>17</td>
<td>11</td>
<td>6</td>
<td>6</td>
<td>36</td>
<td>-21.43</td>
<td>21.43</td>
</tr>
<tr>
<td>6</td>
<td>14</td>
<td>17</td>
<td>-3</td>
<td>3</td>
<td>9</td>
<td>-51.30</td>
<td>51.30</td>
</tr>
</tbody>
</table>

Total 22 104 -51.30 159.38

24. Criteria: Yield and Risk

Step 1: Column totals are 1.5 and 3.

Step 2:

<table>
<thead>
<tr>
<th>Yield</th>
<th>Risk</th>
<th>Priority</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.667</td>
<td>0.667</td>
<td>0.667</td>
</tr>
<tr>
<td>0.333</td>
<td>0.333</td>
<td>0.333</td>
</tr>
</tbody>
</table>

With only two criteria, CR = 0; no need to compute CR; preceding calculations for Yield and Risk provide

<table>
<thead>
<tr>
<th>Stocks</th>
<th>Yield Priority</th>
<th>Risk Priority</th>
</tr>
</thead>
<tbody>
<tr>
<td>CCC</td>
<td>0.750</td>
<td>0.333</td>
</tr>
<tr>
<td>SRI</td>
<td>0.250</td>
<td>0.667</td>
</tr>
</tbody>
</table>

Overall Priorities:

- CCC: 0.667(0.750) + 0.333(0.333) = 0.611
- SRI: 0.667(0.250) + 0.333(0.667) = 0.389

CCC is preferred.

26. a. Criterion: 0.608, 0.272, 0.120
Price: 0.557, 0.123, 0.320
Sound: 0.137, 0.239, 0.623
Reception: 0.579, 0.187, 0.046

b. 0.446, 0.162, 0.392
System A is preferred.
Appendix E  Self-Test Solutions and Answers to Even-Numbered Problems

a. MAE = 22/5 = 4.4

b. MSE = 104/5 = 20.8

c. MAPE = 159.38/5 = 31.88

d. Forecast for week 7 is 14.

2. The following table shows the calculations for parts (a), (b), and (c).

<table>
<thead>
<tr>
<th>Week</th>
<th>Time Series Value</th>
<th>Forecast</th>
<th>Absolute Value of Forecast Error</th>
<th>Squared Forecast Error</th>
<th>Percentage Error</th>
<th>Absolute Value of Percentage Error</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>18</td>
<td></td>
<td>5.00</td>
<td>25.00</td>
<td>−38.46</td>
<td>38.46</td>
</tr>
<tr>
<td>2</td>
<td>13</td>
<td>18.00</td>
<td>−5.00</td>
<td>25.00</td>
<td>−38.46</td>
<td>38.46</td>
</tr>
<tr>
<td>3</td>
<td>16</td>
<td>15.50</td>
<td>0.50</td>
<td>0.25</td>
<td>3.13</td>
<td>3.13</td>
</tr>
<tr>
<td>4</td>
<td>11</td>
<td>15.67</td>
<td>−4.67</td>
<td>21.81</td>
<td>−42.45</td>
<td>42.45</td>
</tr>
<tr>
<td>5</td>
<td>17</td>
<td>14.50</td>
<td>2.50</td>
<td>6.25</td>
<td>14.71</td>
<td>14.71</td>
</tr>
<tr>
<td>6</td>
<td>14</td>
<td>15.00</td>
<td>−1.00</td>
<td>1.00</td>
<td>−7.14</td>
<td>7.14</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Total</td>
<td>13.67</td>
<td>54.31</td>
<td>−70.21</td>
</tr>
</tbody>
</table>

a. MAE = 13.67/5 = 2.73

b. MSE = 54.31/5 = 10.86

c. MAPE = 105.89/5 = 21.18

d. Forecast for week 7 is (18 + 13 + 16 + 11 + 17 + 14)/6 = 14.83.

3. By every measure, the approach used in Problem 2 appears to be the better method.

4. a. MSE = 363/6 = 60.5
   Forecast for month 8 is 15.

b. MSE = 216.72/6 = 36.12
   Forecast for month 8 is 18.

c. The average of all the previous values is better because MSE is smaller.

5. a. The data appear to follow a horizontal pattern.

   b.

<table>
<thead>
<tr>
<th>Week</th>
<th>Time Series Value</th>
<th>Forecast</th>
<th>Forecast Error</th>
<th>Squared Forecast Error</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>18</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>13</td>
<td>18.00</td>
<td>−5.00</td>
<td>25.00</td>
</tr>
<tr>
<td>3</td>
<td>16</td>
<td>15.50</td>
<td>0.50</td>
<td>0.25</td>
</tr>
<tr>
<td>4</td>
<td>11</td>
<td>15.67</td>
<td>−4.67</td>
<td>21.81</td>
</tr>
<tr>
<td>5</td>
<td>17</td>
<td>14.50</td>
<td>2.50</td>
<td>6.25</td>
</tr>
<tr>
<td>6</td>
<td>14</td>
<td>15.00</td>
<td>−1.00</td>
<td>1.00</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Total</td>
<td>13.67</td>
</tr>
</tbody>
</table>

   MSE = 35.67/5 = 11.89
   The forecast for week 7 = (11 + 17 + 14)/3 = 14.

   c.

<table>
<thead>
<tr>
<th>Week</th>
<th>Time Series Value</th>
<th>Forecast</th>
<th>Forecast Error</th>
<th>Squared Forecast Error</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>18</td>
<td></td>
<td>−5.00</td>
<td>25.00</td>
</tr>
<tr>
<td>2</td>
<td>13</td>
<td>18.00</td>
<td>−5.00</td>
<td>25.00</td>
</tr>
<tr>
<td>3</td>
<td>16</td>
<td>17.00</td>
<td>−1.00</td>
<td>1.00</td>
</tr>
<tr>
<td>4</td>
<td>11</td>
<td>16.80</td>
<td>−5.80</td>
<td>33.64</td>
</tr>
<tr>
<td>5</td>
<td>17</td>
<td>15.64</td>
<td>1.36</td>
<td>1.85</td>
</tr>
<tr>
<td>6</td>
<td>14</td>
<td>15.91</td>
<td>−1.91</td>
<td>3.66</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Total</td>
<td>65.15</td>
</tr>
</tbody>
</table>

   MSE = 65.15/5 = 13.03
   The forecast for week 7 is 0.2(14) + (1 − 0.2)(5) = 15.91 = 15.53.

d. The three-week moving average provides a better forecast because it has a smaller MSE.

   e. Alpha = 0.367694922

<table>
<thead>
<tr>
<th>Week</th>
<th>Time Series Value</th>
<th>Forecast</th>
<th>Forecast Error</th>
<th>Squared Forecast Error</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>18</td>
<td></td>
<td>−5.00</td>
<td>25.00</td>
</tr>
<tr>
<td>2</td>
<td>13</td>
<td>18.00</td>
<td>−5.00</td>
<td>25.00</td>
</tr>
<tr>
<td>3</td>
<td>16</td>
<td>16.80</td>
<td>−0.80</td>
<td>0.64</td>
</tr>
<tr>
<td>4</td>
<td>11</td>
<td>16.10</td>
<td>−0.90</td>
<td>0.81</td>
</tr>
<tr>
<td>5</td>
<td>17</td>
<td>14.23</td>
<td>2.77</td>
<td>7.69</td>
</tr>
<tr>
<td>6</td>
<td>14</td>
<td>15.25</td>
<td>−0.75</td>
<td>0.56</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Total</td>
<td>60.30</td>
</tr>
</tbody>
</table>

   MSE = 60.30/5 = 12.061

6. a. The data appear to follow a horizontal pattern.

   b. MSE = 110/4 = 27.5
   The forecast for week 8 is 19.

c. MSE = 252.87/6 = 42.15
   The forecast for week 7 is 19.12.
d. The three-week moving average provides a better forecast because it has a smaller MSE.

e. \(\alpha = 0.351404848\) MSE = 39.61428577

8. a.

<table>
<thead>
<tr>
<th>Week</th>
<th>Forecast</th>
</tr>
</thead>
<tbody>
<tr>
<td>4</td>
<td>19.3</td>
</tr>
<tr>
<td>5</td>
<td>21.3</td>
</tr>
<tr>
<td>6</td>
<td>19.8</td>
</tr>
<tr>
<td>7</td>
<td>17.8</td>
</tr>
<tr>
<td>8</td>
<td>18.3</td>
</tr>
<tr>
<td>9</td>
<td>18.3</td>
</tr>
<tr>
<td>10</td>
<td>20.3</td>
</tr>
<tr>
<td>11</td>
<td>20.3</td>
</tr>
<tr>
<td>12</td>
<td>17.8</td>
</tr>
</tbody>
</table>

b. MSE = 11.49

Prefer the unweighted moving average here; it has a smaller MSE.

c. You could always find a weighted moving average at least as good as the unweighted one. Actually, the unweighted moving average is a special case of the weighted one where the weights are equal.

10. b. The more recent data receives the greater weight or importance in determining the forecast. The moving averages method weights the last \(n\) data values equally in determining the forecast.

d. The data appear to follow a horizontal pattern.

b. MSE(3-month) = 0.12

MSE(4-month) = 0.14

Use 3-month moving averages.

c. 9.63

12. a. The data appear to follow a horizontal pattern.

b. MSE(3-Month) = 17,988.52/9 = 1998.72

MSE(\(\alpha = 0.2\)) = 27,818.49/11 = 2528.95

Based on the above MSE values, the 3-month moving average appears better. However, exponential smoothing was penalized by including month 2, which was difficult for any method to forecast. Using only the errors for months 4–12, the MSE for exponential smoothing is

MSE(\(\alpha = 0.2\)) = 14,694.49/9 = 1632.72

Thus, exponential smoothing was better considering months 4–12.

c. Using exponential smoothing,

\[F_{13} = \alpha Y_{12} + (1 - \alpha)F_{12} = 0.20(230) + 0.80(267.53) = 260\]

13. a. The data appear to follow a horizontal pattern.

b. MSE(3-Month) = 17,988.52/9 = 1998.72

MSE(\(\alpha = 0.2\)) = 27,818.49/11 = 2528.95

Based on the above MSE values, the 3-month moving average appears better. However, exponential smoothing was penalized by including month 2, which was difficult for any method to forecast. Using only the errors for months 4–12, the MSE for exponential smoothing is

MSE(\(\alpha = 0.2\)) = 14,694.49/9 = 1632.72

Thus, exponential smoothing was better considering months 4–12.

c. Using exponential smoothing,

\[F_{13} = \alpha Y_{12} + (1 - \alpha)F_{12} = 0.20(230) + 0.80(267.53) = 260\]

14. a. The data appear to follow a horizontal pattern.

b. Values for months 2–12 are as follows:

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17,988.52  27,818.49

16. a.
Appendix E  Self-Test Solutions and Answers to Even-Numbered Problems

b. This time series plot indicates a possible linear trend in the data, so forecasting methods discussed in this chapter are appropriate to develop forecasts for this time series.
c. Equation for linear trend: \( \hat{y}_t = 24170.506 + 596.366t \)

17. a. The time series plot shows a linear trend.

\[ \begin{array}{c|c|c|c|c} 
\text{Year} & \text{Sales} & \text{Forecast} & \text{Forecast Error} & \text{Squared Error} \\
\hline 1 & 6.00 & 6.80 & -0.80 & 0.64 \\
2 & 11.00 & 8.90 & 2.10 & 4.41 \\
3 & 9.00 & 11.00 & -2.00 & 4.00 \\
4 & 14.00 & 13.10 & 0.90 & 0.81 \\
5 & 15.00 & 15.20 & -0.20 & 0.04 \\
6 & & 17.30 & & \text{Total} 9.9 \\
\end{array} \]

MSE = 9.9/5 = 1.98
c. \( T_6 = 4.7 + 2.1(6) = 17.3 \)

18. a.

The time series plot indicates a horizontal pattern.

\[ T_{10} = 4.72 + 1.46(10) = 19.28 \]

c. \( T_{10} = 4.72 + 1.46(10) = 19.28 \)

22. a. The time series plot shows a upward linear trend.
b. \( T_t = 19.9928 + 1.7738t \)
c. $1.77

d. \( T_9 = 19.9928 + 1.7738(9) = 35.96 \)

24. a. The time series plot shows a horizontal pattern. But, there is a seasonal pattern in the data. For instance, in each year the lowest value occurs in quarter 2 and the highest value occurs in quarter 4.

(Continued)
c. The quarterly forecasts for next year are as follows:
Quarter 1 forecast = 77.0 - 10.0(1) - 30.0(0) - 20.0(0) = 67
Quarter 2 forecast = 77.0 - 10.0(0) - 30.0(1) - 20.0(0) = 47
Quarter 3 forecast = 77.0 - 10.0(0) - 30.0(0) - 20.0(1) = 57
Quarter 4 forecast = 77.0 - 10.0(0) - 30.0(0) - 20.0(0) = 77

26. a. There appears to be a seasonal pattern in the data and perhaps a moderate upward linear trend.
b. Sales = 2492 - 712 Qtr1 - 1512 Qtr2 + 327 Qtr3
c. The quarterly forecasts for next year are as follows:
Quarter 1 forecast = 1780
Quarter 2 forecast = 980
Quarter 3 forecast = 2819
Quarter 4 forecast = 2492
d. Sales = 2307 - 642 Qtr1 - 1465 Qtr2 + 350 Qtr3 + 23.1t
The quarterly forecasts for next year are as follows:
Quarter 1 forecast = 2058
Quarter 2 forecast = 1258
Quarter 3 forecast = 3096
Quarter 4 forecast = 2769

28. a. The time series plot shows both a linear trend and seasonal effects.
b. Revenue = 70.0 + 10.0 Qtr1 + 105 Qtr2 + 245 Qtr3
Quarter 1 forecast = 80
Quarter 1 forecast = 175
Quarter 1 forecast = 315
Quarter 1 forecast = 70
c. The equation is
Revenue = -70.1 + 45.0 Qtr1 + 128 Qtr2 + 257 Qtr3 + 11.7 Period
Quarter 1 forecast = 221
Quarter 1 forecast = 315
Quarter 1 forecast = 456
Quarter 1 forecast = 211

Appendix A

2. =F6*F$3

4. Cell Formula
   D14 =C14*$B$3
   E14 =C14*$B$7
   F14 =C14*$B$9
   G14 =$B$5
   H14 =SUM(E14:G14)
   I14 =D14-H14
Appendix E  Self-Test Solutions and Answers to Even-Numbered Problems

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### Appendix E  Self-Test Solutions and Answers to Even-Numbered Problems

#### Course Grading Scale Based on Course Average:

- **A**: \(\sqrt{\text{Average}(B21:C21)}\)
- **A-**: \(\sqrt{\text{Average}(B16:C16)}\)
- **B+**: \(\sqrt{\text{Average}(B14:C14)}\)
- **B**: \(\sqrt{\text{Average}(B12:C12)}\)
- **B-**: \(\sqrt{\text{Average}(B10:C10)}\)
- **C+**: \(\sqrt{\text{Average}(B8:C8)}\)
- **C**: \(\sqrt{\text{Average}(B6:C6)}\)
- **C-**: \(\sqrt{\text{Average}(B4:C4)}\)
- **D**: \(\sqrt{\text{Average}(B2:C2)}\)
- **F**: \(\sqrt{\text{Average}(B0:C0)}\)

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**Total Volume**: 25974.5

### 10. Newton Scientific Calculators

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