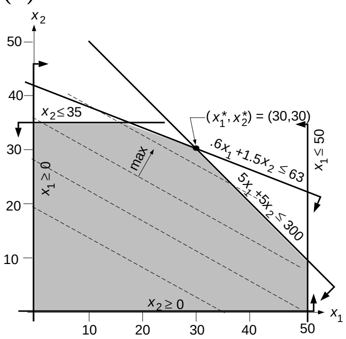
Chapter 2 Solutions [1,2]

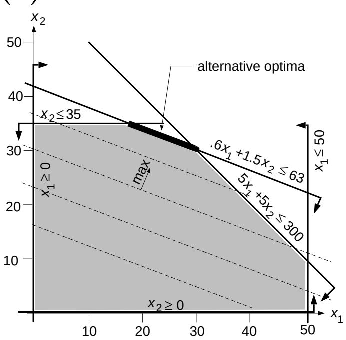
2-1. **(a)** max $200x_1 + 350x_2$ (max total profit), s.t. $5x_1 + 5x_2 \leq 300$ (legs), $0.6x_1 + 1.5x_2 \leq 63$ (assembly hours), $x_1 \leq 50$ (wood tops), $x_2 \leq 35$ (glass tops), $x_1 \geq 0$, $x_2 \geq 0$

(b) x_1^*=basic=30, x_2^*=deluxe=30

(c)



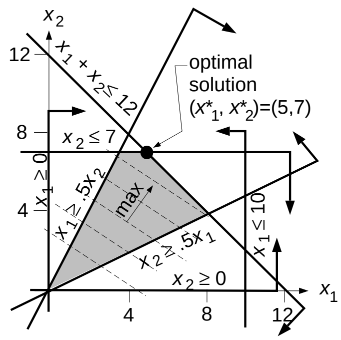
(d)



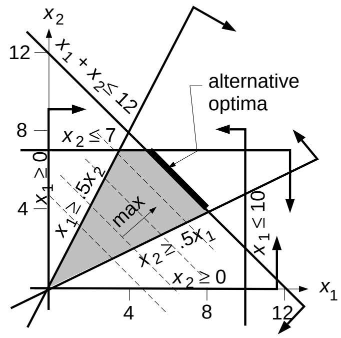
All optimal from $\mathbf{x} = (30, 30)$ to $\mathbf{x} = (17.5, 35)$.

2-2. **(a)** max $.11x_1 + .17x_2$ (max total return), s.t. $x_1 + x_2 \leq 12$ ($12 million investment), $x_1 \leq 10$ (max $10 million domestic), $x_2 \leq 7$ (max $7 million foreign), $x_1 \geq .5x_2$ (domestic at least half foreign), $x_2 \geq .5x_1$ (foreign at least half domestic), $x_1 \geq 0$, $x_2 \geq 0$ **(b)** x_1^*=domestic=$5 million, x_2^*= foreign=$7 million

(c)



(d)



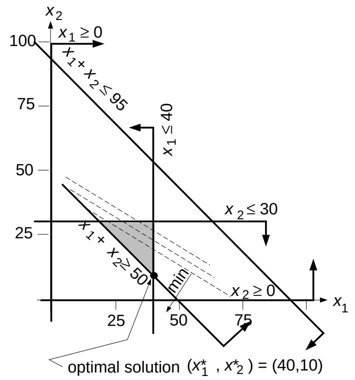
All optimal from $\mathbf{x} = (5, 7)$ to $\mathbf{x} = (8, 4)$.

2-3. **(a)** min $3x_1 + 5x_2$ (min total cost), s.t. $x_1 + x_2 \geq 50$ (at least 50 thousand acres), $x_1 \leq 40$ (at most 40 thousand from Squawking Eagle), $x_2 \leq 30$ (at most 30 thousand from Crooked Creek), $x_1 \geq 0$, $x_2 \geq 0$ **(b)** x_1^*=Squawking Eagle=40 thousand, x_2^*=Crooked Creek=10 thousand

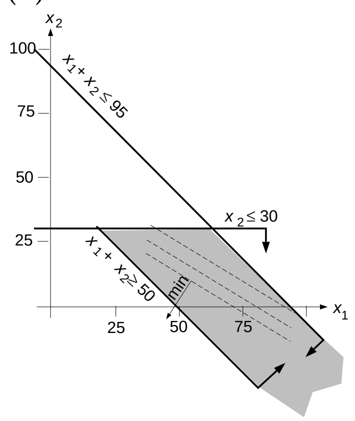
[1]Supplement to the 2nd edition of *Optimization in Operations Research*, by Ronald L. Rardin, Pearson Higher Education, Hoboken NJ, ©2017.

[2]As of September 24, 2015

(c)

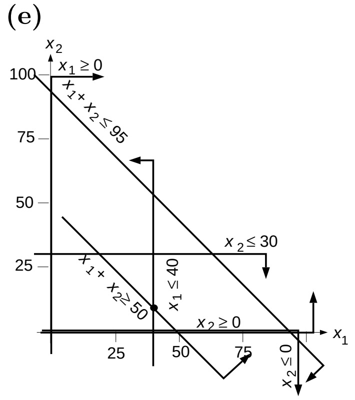


(d)



Improves forever in direction $\Delta x_1 = 1$, $\Delta x_2 = -1$.

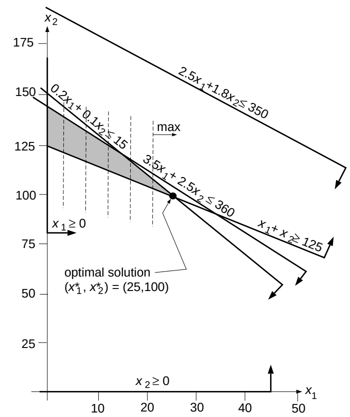
(e)



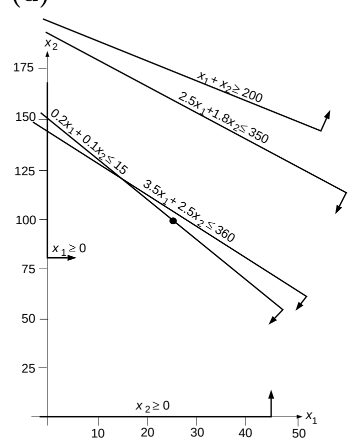
$x_2 = 0$ leaves no feasible.

2-4. **(a)** max x_1 (max beef content), s.t. $x_1 + x_2 \geq 125$ (weight at least 125), $2.5x_1 + 1.8x_2 \leq 350$ (calories at most 350), $0.2x_1 + 0.1x_2 \leq 15$ (fat at most 15), $3.5x_1 + 2.5x_2 \leq 360$ (sodium at most 360), $x_1 \geq 0$, $x_2 \geq 0$ **(b)** x_1^*=beef=25g, x_2^*=chicken=100g

(c)

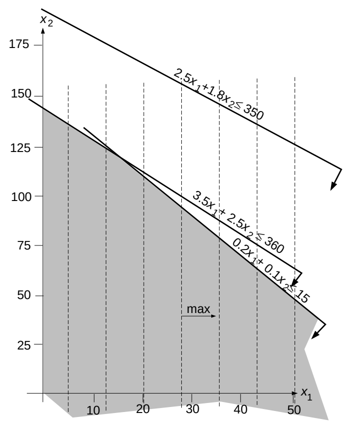


(d)



$x_1 + x_2 \geq 200$ leaves no feasible.

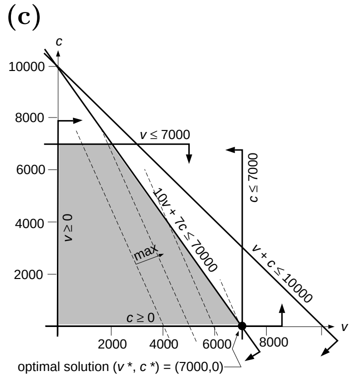
(e)



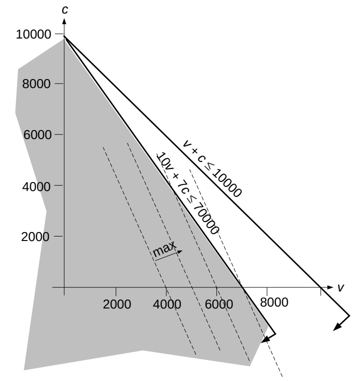
Improve forever in direction $\Delta x_1 = 1$, $\Delta x_2 = -2$.

2-5. **(a)** max $450v + 200c$ (max total profit), s.t. $10v + 7c \leq 70000$ (water at most 70000 units), $v + c \leq 10000$ (total acreage 10000), $v \leq 7000$ (at most 70% vegetables), $c \leq 7000$ (at most 70% cotton), $v \geq 0$, $c \geq 0$ **(b)** $v^* = 7000$, $c^* = 0$

(c)

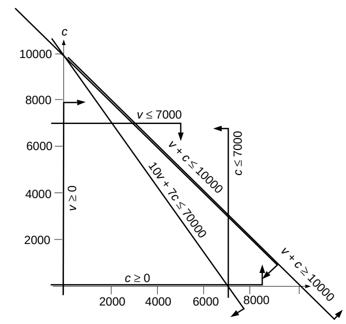


(d)



Improves forever in direction $\Delta v = 10$, $\Delta c = -7$.

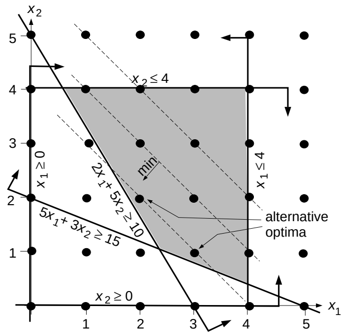
(e)



No solution with $v + c = 10000$.

2-6. **(a)** min $x_1 + x_2$ (min used stock), s.t. $5x_1 + 3x_2 \geq 15$ (cut at least 15 long rolls), $2x_1 + 5x_2 \geq 10$ (cut at least 10 short rolls), $x_1 \leq 4$ (at most 4 times on pattern 1), $x_2 \leq 4$ (at most 4 times on pattern 2), $x_1, x_2 \geq 0$ and integer. **(b)** Partial cuts make no physical sense because all unused material is scrap. **(c)** Either $x_1^* = x_2^* = 2$, or $x_1^* = 3$, $x_2^* = 1$

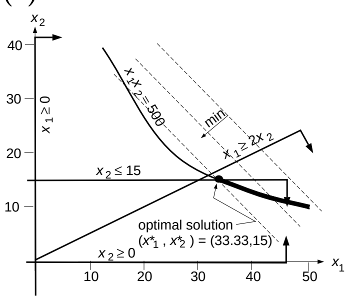
(d)



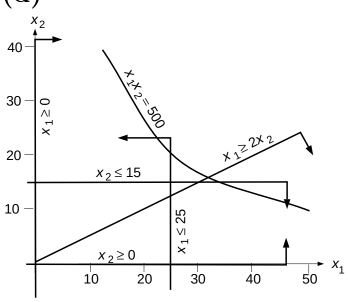
(e) Both $(2,2)$ and $(3,1)$ are feasible and lie on the best contour of the objective.

2-7. **(a)** min $16x_1 + 16x_2$ (min total wall area), s.t. $x_1 x_2 = 500$ (500 sqft pool), $x_1 \ge 2x_2$ (length at least twice width), $x_2 \le 15$ (width at most 15 ft), $x_1 \ge 0$, $x_2 \ge 0$ **(b)** x_1^*=length=$33\frac{1}{3}$ feet, x_2^*=width=15 feet

(c)



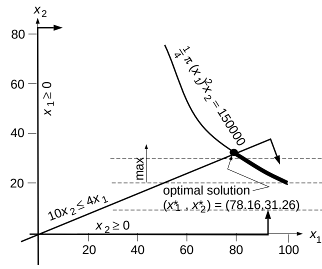
(d)



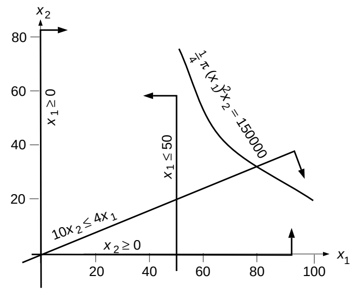
$x_1 \le 25$ leaves no feasible.

2-8. **(a)** max x_2 (max number of floors), s.t. $\pi/4(x_1)^2 x_2 = 150000$ (150000 sqft floor space), $10x_2 \le 4x_1$ (height at most 4 times diameter), $x_1 \ge 0$, $x_2 \ge 0$ **(b)** x_1^* = diameter = 78.16 feet, x_2^* = floors = 31.26

(c)



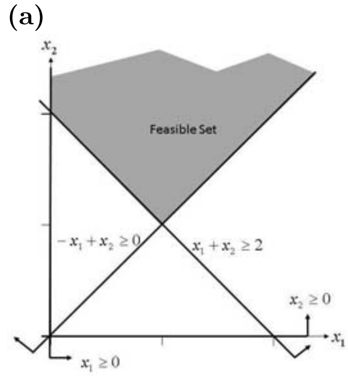
(d)



$x_1 \le 50$ leaves no feasible.

2-9.

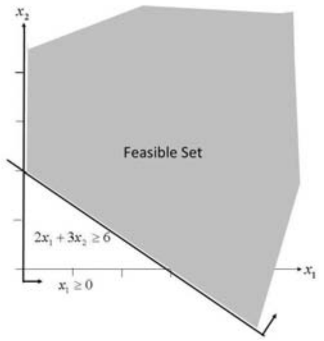
(a)



(b) min x_2 **(c)** min $x_1 + x_2$ **(d)** max x_2 **(e)** $x_2 \le 1/2$

2-10.

(a)



(b) min $x_1 + x_2$ **(c)** min x_1 **(d)** max x_1 **(e)** $x_1 + x_2 \leq 1$

2-11. **(a)** min $\sum_{i=3}^{4} i \sum_{j=1}^{2} y_{i,j}$
(b) max $\sum_{i=1}^{4} iy_{i,3}$
(c) max $\sum_{i=1}^{p} \alpha_i y_{i,4}$
(d) min $\sum_{i=1}^{t} \delta_i y_i$
(e) $\sum_{j=1}^{4} y_{i,j} = s_i,\ i = 1, \ldots, 3$
(f) $\sum_{j=1}^{4} a_{j,i} y_j = c_i,\ i = 1, \ldots, 3$

2-12. **(a)** $\sum_{i=1}^{17} x_{i,j,t} \leq 200,\ j = 1, \ldots, 5; t = \ldots, 7$; 35 constraints
(b) $\sum_{j=1}^{5} \sum_{t=1}^{7} x_{5,j,t} \leq 4000$; 1 constraint
(c) $\sum_{j=1}^{5} x_{i,j,t} \geq 100,\ i = 1, \ldots, 17; t = 1, \ldots, 7$; 119 constraints

2-13.

```
model; param m; param n; param
p; set products := 1 .. m; set lines
:= 1 .. n; set weeks := 1 .. p; var
x{i in products, j in lines, t in
weeks} >= 0; subject to
# part (a)
linecap {j in lines, t in weeks}: sum
{i in products} x[i,j,t] <= 200;
# part (b)
prod5lim: sum {j in lines, t in
weeks} x[5,j,t] <= 4000;
# part (c)
minprodn{i in products, t in weeks}:
sum {j in lines} x[i,j,t] >= 100;
#
data; param m := 17; param n := 5;
param p := 7;
```

2-14. **(a)** $\sum_{j=1}^{9} x_{i,j,t} \leq p_i,\ i = 1, \ldots, 47; t = 1, \ldots, 10$; 470 constraints
(b) $0.25 \sum_{i=1}^{47} \sum_{j=1}^{9} x_{i,j,t} \leq \sum_{i=1}^{47} x_{i,4,t}; t = 1, \ldots, 5$; 5 constraints
(c) $x_{i,1,t} \geq x_{i,j,t}\ i = 1, \ldots, 47;\ j = 1, \ldots, 9;\ t = 1, \ldots, 10$; 4230 constraints

2-15.

```
model; param m; param n; param
q; set plots := 1 .. m; set crops :=
1 .. n; set years := 1 .. q; param p
{i in plots }; var x{i in plots, j
crops, t in years} >= 0; subject to
# part (a)
acrelims {i in plots, t in years }:
sum {j in crops } x[i,j,t] <= p[i];
# part (b)
crop4min {t in years: t <= 5 }:
0.25* sum {i in plots, j in crops }
x[i,j,t] <= sum {i in plots }
x[i,4,t];
# part (c)
beam1st {i in plots, j in crops, t in
years}: x[i,1,t] >= x[i,j,t];
#
data; param m := 47; param n := 9;
param q := 10;
```

2-16. **(a)** $f(y_1, y_2, y_3) \triangleq (y_1)^2 y_2 / y_3$, $g_1(y_1, y_2, y_3) \triangleq y_1 + y_2 + y_3$, $b_1 = 13$, $g_2(y_1, y_2, y_3) \triangleq 2y_1 - y_2 + 9y_3$, $b_2 = 0$, $g_3(y_1, y_2, y_3) \triangleq y_1$, $b_3 = 0$, $g_4(y_1, y_2, y_3) \triangleq y_3$, $b_4 = 0$
(b) $f(y_1, y_2, y_3) \triangleq 13y_1 + 22y_2 + 10y_2y_3 + 100$, $g_1(y_1, y_2, y_3) \triangleq y_1 - y_2 + 9y_3$, $b_1 = -5$, $g_2(y_1, y_2, y_3) \triangleq 8y_2 - 4y_3$, $b_2 = 0$, $g_3(y_1, y_2, y_3) \triangleq y_1$, $b_3 = 0$, $g_4(y_1, y_2, y_3) \triangleq y_2$, $b_4 = 0$, $g_5(y_1, y_2, y_3 \triangleq y_3$, $b_5 = 0$,

2-17. **(a)** Linear because LHS is a weighted sum of the decision variables. **(b)** Linear because both LHS and RHS are weighted sums of the decision variables. **(c)** Nonlinear because LHS has reciprocal $1/x_9$. **(d)** Linear because LHS is a weighted sum of the decision variables. **(e)** Nonlinear because LHS has $(x_j)^2$ terms. **(f)** Nonlinear because LHS has $\log(x_1)$ term, and RHS has a product of variables. **(g)** Nonlinear because LHS has max operator. **(h)** Linear because LHS is a weighted sum of the decision variables.

2-18. **(a)** LP because the objective and all constraints are linear. **(b)** NLP because of the nonlinear objective function with reciprocal of w_2. **(c)** NLP because of the nonlinear first constraint. **(d)** LP because the objective and all constraints are linear.

2-19. **(a)** Continuous because fractions make sense. **(b)** Discrete because they either closed or not. **(c)** Discrete because a specific process must be used. **(d)** Continuous because fractions can probably be ignored.

2-20. **(a)** $\sum_{j=1}^{8} x_j = 3$ **(b)** $x_1 + x_2 + x_4 + x_5 \geq 2$ **(c)** $x_3 + x_8 \leq 1$ **(d)** $x_4 \geq x_1$

2-21. **(a)** max $85x_1 + 70x_2 + 62x_3 + 93x_4$ (max total score), s.t. $700x_1 + 400x_2 + 300x_3 + 600x_4 \leq 1000$ (\$1 million available), $x_j = 0$ or 1, $j = 1, \ldots, 4$ **(b)** Fund 2 and 4, i.e. $x_1^* = x_3^* = 0$, $x_2^* = x_4^* = 1$

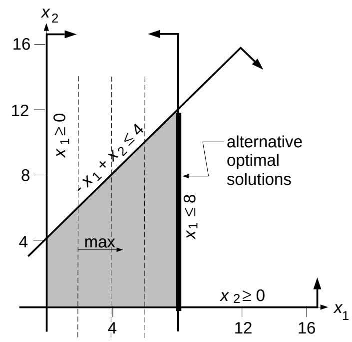
2-22. **(a)** min $43y_1 + 175y_2 + 60y_3 + 35y_4$ (min total land cost), s.t. $y_2 + y_4 \geq 1$ (service NW), $y_1 + y_2 + y_4 \geq 1$ (service SW), $y_2 + y_3 \geq 1$ (service capital), $y_1 + y_4 \geq 1$ (service NE), $y_1 + y_2 + y_3 \geq 1$ (service SE), $y_j = 0$ or 1, $j = 1, \ldots, 4$ **(b)** Build 3 and 4, i.e. $y_1^* = y_2^* = 0$, $y_3^* = y_4^* = 1$

2-23. **(a)** ILP because the objective and all constraints are linear, but variables are discrete. **(b)** NLP because the objective is nonlinear and all variables are continuous. **(c)** INLP because the objective is nonlinear and variables are discrete. **(d)** LP because the objective and all constraints are linear, and all variables are continuous. **(e)** INLP because the one constraint is nonlinear, and z_3 are discrete. **(f)** ILP because the objective and all constraints are linear, but variables z_1 and z_3 are discrete. **(g)** LP because the objective and all constraints are linear, and all variables are continuous. **(h)** INLP because the objective is nonlinear and z_3 is discrete.

2-24. **(a)** Model (d) because LP's are generally more tractable than ILP's. **(b)** Model (d) because LP's are generally more tractable than NLP's. **(c)** Model (d) because LP's are generally more tractable than INLP's. **(d)** Model (f) because ILP's are generally more tractable than INLP's. **(e)** Model (g) because LP's are generatlly more tranctable than ILP's.

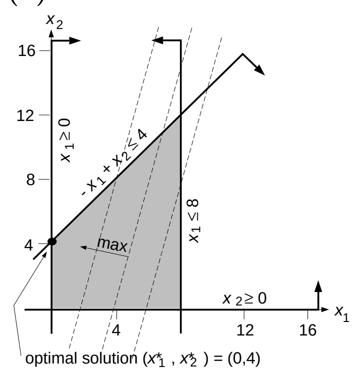
2-25.

(a)



Alternative optima from $x_1^* = 8$, $x_2^* = 0$ to $x_1^* = 8$, $x_2^* = 12$

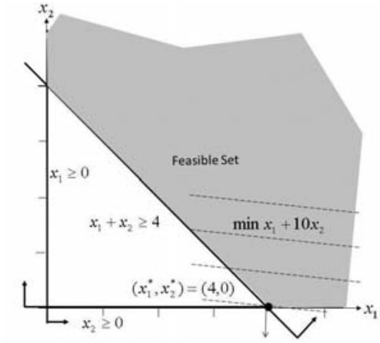
(b)



Unique optimum $x_1^* = 0$, $x_2^* = 4$ **(c)** Helping one can hurt the other.

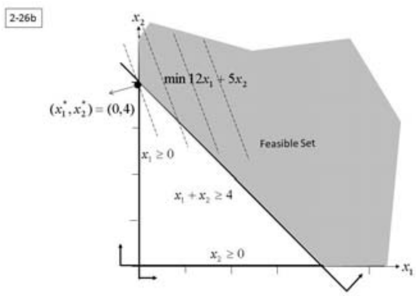
2-26.

(a)



Unique optimum $x_1^* = 4$, $x_2^* = 0$

(b)



Unique optimum $x_1^* = 0$, $x_2^* = 4$ **(c)** Helping one can hurt the other.

2-27. **(a)** min $.092x_4 + .112x_5 + .141x_6 + .420x_9 + .719x_{12}$ (min total cost),
s.t. $x_4 + x_5 + x_6 + x_9 + x_{12} = 16000$ (16000m line),
$.279x_4 + .160x_5 + .120x_6 + .065x_9 + .039x_{12} \leq 1600$ (at most 1600 Ohms resistance),
$.00175x_4 + .00130x_5 + .00161x_6 + .00095x_9 + .00048x_{12} \leq 8.5$ (at most 8.5 dBell attenuation),
$x_4, x_5, x_6, x_9, x_{12} \geq 0$
(b) Nonzeros: $x_5^* = 1000$, $x_{12}^* = 15000$

2-28. **(a)** Pump rates are the decisions to be made.
(b) $u_j \triangleq$ the capacity of pump j, $c_j \triangleq$ the pumping cost of pump j
(c) min $\sum_{j=1}^{10} c_j x_j$
(d) $x_1 + x_4 + x_7 \leq 3000$ (well 1),
$x_2 + x_5 + x_8 \leq 2500$ (well 2),
$x_3 + x_6 + x_9 + x_{10} \leq 7000$ (well 3)
(e) $x_j \leq u_j$, $j = 1, \ldots, 10$
(f) $\sum_{j=1}^{10} x_j \geq 10000$
(g) $x_j \geq 0$, $j = 1, \ldots, 10$
(h) A single objective LP because the one objective and all constraints are linear, and all variables are continuous.
(i) $x_1^* = x_2^* = x_3^* = 1100$, $x_4^* = x_6^* = 1500$, $x_5^* = 1400$, $x_7^* = 400$¡ $x_8^* = x_{10}^* = 0$, $x_9^* = 1900$

2-29. **(a)** The decisions to be made are which projects to undertake.
(b) $p_j \triangleq$ the profit for project j, $m_j \triangleq$ the man-days required on project j, and $t_j \triangleq$ the CPU time required on project j.
(c) max $\sum_{j=1}^{8} p_j x_j$
(d) $7 \leq \left(\sum_{j=1}^{8} m_j x_j\right)/240 \leq 10$
(e) $\sum_{j=1}^{8} t_j x_j \leq 1000$ (computer time), $\sum_{j=1}^{8} x_j \geq 3$ (select at least 3); $x_3 + x_4 + x_5 + x_8 \geq 1$ (include at least 1 of director's favorites)
(f) $x_j = 0$ or 1, $j = 1, \ldots, 8$
(g) A single objective ILP because the one objective and all constraints are linear, but variables are discrete.
(h) $x_1^* = x_3^* = x_6^* = x_7^* = 1$, others $= 0$

2-30. **(a)** We must decide what quantities to move from surplus sites to fulfill each need.
(b) $s_i \triangleq$ the supply available at i, $r_j \triangleq$ the quantity needed at j, $d_{i,j} \triangleq$ the distance from i to j.
(c) min $\sum_{i=1}^{4} \sum_{j=1}^{7} d_{i,j} x_{i,j}$
(d) $\sum_{j=1}^{7} x_{i,j} = s_i$, $i = 1, \ldots, 4$
(e) $\sum_{i=1}^{4} x_{i,j} = r_j$, $j = 1, \ldots, 7$
(f) $x_{i,j} \geq 0$, $i = 1, \ldots, 4$, $j = 1, \ldots, 7$
(g) A single objective LP because the one objective and all constraints are linear, and all variables are continuous.
(h) Nonzeros: $x_{1,1}^* = 81$, $x_{1,2}^* = 93$, $x_{1,3}^* = 166$, $x_{1,5}^* = 90$, $x_{1,6}^* = 85$, $x_{1,7}^* = 145$, $x_{2,2}^* = 301$, $x_{3,1}^* = 166$, $x_{3,4}^* = 105$, $x_{4,3}^* = 99$

2-31. **(a)** The values to be chosen are the

coefficients in the estimating relationship.
(b) min $\sum_{j=1}^{n}\left(c_j - k/(1+e^{a+bf_j})\right)^2$ (min total squared error)
(c) Single objective NLP because the objective is quadratic, there are no constraints, and all variables are continuous.
2-32. **(a)** The decisions to be made are where to assign each teacher.
(b) min $\sum_{i=1}^{22}\sum_{j=1}^{22} c_{i,j}x_{i,j}$ (min total cost), max $\sum_{i=1}^{22}\sum_{j=1}^{22} t_{i,j}x_{i,j}$ (max total teacher preference), max $\sum_{i=1}^{22}\sum_{j=1}^{22} s_{i,j}x_{i,j}$ (max total supervisor preference), max $\sum_{i=1}^{22}\sum_{j=1}^{22} p_{i,j}x_{i,j}$ (max total principal preference)
(c) $\sum_{j=1}^{22} x_{i,j} = 1$, $i = 1,\ldots,22$ (each teacher i)
(d) $\sum_{i=1}^{22} x_{i,j} = 1$, $j = 1,\ldots,22$ (each school j)
(e) $x_{i,j} = 0$ or 1, $i,j = 1,\ldots,22$
(f) A multiobjective ILP because the 4 objectives and all constraints are linear, but variables are discrete.
2-33. **(a)** Each task must go to Assistant 0 or Assistant 1.
(b) max $100(1-x_1) + 80x_1 + 85(1-x_2) + 70x_2 + 40(1-x_3) + 90x_3 + 45(1-x_4) + 85x_4 + 70(1-x_5) + 80x_5 + 82(1-x_6) + 65x_6$
(c) $\sum_{j=1}^{6} x_j = 3$
(d) $x_5 = x_6$
(e) $x_j = 0$ or 1, $j = 1,\ldots,6$
(f) A single objective ILP because the one objective and all constraints are linear, but variables are discrete.
(g) $x_2^* = x_3^* = x_4^* = 1$, others $= 0$
2-34. **(a)** Batch sizes are the decisions to be made.
(b) min x_j/d_j, $j = 1,\ldots,4$ (each burger j)
(c) $\sum_{j=1}^{4} t_j d_j / x_j \le 60$
(d) $0 \le x_j \le u_j$, $j = 1,\ldots,4$
(e) Multiobjective NLP because the first constraint is nonlinear and all variables are continuous.
2-35. **(a)** The issue is how many cars to move from where to where.
(b) Relatively large values can be rounded if fractional without much loss, and continuous is more tractable.
(c) $c_{i,j} \triangleq$ the cost of moving a car from i to j, $p_j \triangleq$ the number of cars presently at j, $n_j \triangleq$ the number of cars required at j
(d) min $\sum_{i=1}^{5}\sum_{j=1,j\neq i}^{5} c_{i,j}x_{i,j}$
(e) $\sum_{i=1,i\neq k}^{5} x_{i,k} - \sum_{j=1,j\neq k}^{5} x_{k,j} = n_k - p_k$, $k = 1,\ldots,5$ (each region k)
(f) $x_{i,j} \ge 0$, $i,j = 1,\ldots,5$, $i \neq j$
(g) A single objective LP because the one objective and all constraints are linear, and all variables are continuous.
(h) Nonzero values: $x_{4,2}^* = 115$, $x_{4,3}^* = 165$, $x_{5,1}^* = 85$, $x_{5,3}^* = 225$
2-36. **(a)** We must decide how much of what fuel to burn at each plant.
(b) min $\sum_{f=1}^{4}\sum_{p=1}^{23} c_{f,p}x_{f,p}$
(c) min $\sum_{f=1}^{4} s_f \sum_{p=1}^{23} x_{f,p}$
(d) $\sum_{f=1}^{4} e_f x_{f,p} \ge r_p$, $p = 1,\ldots,23$ (each plant p); 23 constraints
(e) $x_{f,p} \ge 0$, $f = 1,\ldots,4$, $p = 1,\ldots,23$; 92 constraints
(f) A multiobjective LP because the 2 objectives and all constraints are linear, and all variables are continuous.

2-37. **(a)** The available options are to buy whole logs or green lumber.
(b) Relatively large magnitudes can be rounded without much loss, and continuous is more tractable.
(c) min $70x_{10} + 200x_{15} + 620x_{20} + 1.55y_1 + 1.30y_2$
(d) $100(.09)x_{10} + 240(.09)x_{15} + 400(.09)x_{20} + .10y_1 + .08y_2 \ge 2350$
(e) $x_{10} + x_{15} + x_{20} \le 1500$ (sawing capacity), $100x_{10} + 240x_{15} + 400x_{20} + y_1 + y_2 \le 26500$ (drying capacity)
(f) $x_{10} \le 50$ (size 10 log availability), $x_{15} \le 25$ (size 15 log availability), $x_{20} \le 10$ (size 20 log availability), $y_1 \le 5000$ (grade 1 green lumber availability)
(g) $x_{10}, x_{15}, x_{20}, y_1, y_2 \ge 0$
(h) A single objective LP because the one

objective and all constraints are linear, and all variables are continuous.
(i) $x^*_{10} = 50$, $x^*_{15} = 25$, $x^*_{20} = 5$, $y^*_1 = 5000$, $y^*_2 = 8500$

2-38. **(a)** Decisions to be made are when to schedule each film.
(b) min $\sum_{j=1}^{m-1} \sum_{j'=j+1}^{m} a_{j,j'} \sum_{t=1}^{n} x_{j,t} x_{j',t}$
(c) $\sum_{t=1}^{n} x_{j,t} = 1$, $j = 1, \ldots, m$ (each film j)
(d) $\sum_{j=1}^{m} x_{j,t} \leq 4$, $t = 1, \ldots, n$ (each time t)
(e) $x_{j,t} = 0$ or 1, $j = 1, \ldots, m$; $t = 1, \ldots, n$
(f) A single objective INLP because the one objective is nonlinear, and variables are discrete. **(g)** `model; param m; param n; set films := 1 .. m; set slots := 1 .. n; var x{j in films, t in slots } binary; param a{ j in films, jp in films }; minimize totconflict: sum{ j in films, jp in films: j < m and jp > j } a[j,jp]*sum {t in slots} x[j,t]*x[jp,t]; subject to allin {j in films}: sum{ t in slots } x[j,t] = 1; max4 {t in slots}:sum{j in films} x[j,t] <= 4;`

2-39. **(a)** We need to decide both which offices to open and how to service customers from them.
(b) Offices must either be opened or not.
(c) $f_i \triangleq$ fixed cost of site i, $c_{i,j} \triangleq$ unit cost of audits at j from i, $r_j \triangleq$ required number of audits in state j
(d) min $\sum_{i=1}^{5} \sum_{j=1}^{5} c_{i,j} r_j x_{i,j} + \sum_{i=1}^{5} f_i y_i$
(e) $\sum_{i=1}^{5} x_{i,j} = 1$, $j = 1, \ldots, 5$ (each location j)
(f) $x_{i,j} \leq y_i$, $i, j = 1, \ldots, 5$ (each site i, location j combination)
(g) $x_{i,j} \geq 0$, $i, j = 1, \ldots, 5$, $y_i = 0$ or 1, $i = 1, \ldots, 5$
(h) A single objective ILP because the one objective and all constraints are linear, but the y_i variables are discrete.
(i) Nonzeros:
$x^*_{2,2} = x^*_{2,4} = x^*_{3,1} = x^*_{3,3} = x^*_{5,5} = 1$,
$y^*_2 = y^*_3 = y^*_5 = 1$ **(j)** `model; param m; param n; set sites := 1 .. m; set states := 1 .. n; var x{i in sites, j in states } >= 0; var y{i in sites } binary; param c {i in sites, j in states }; param f { i in sites } binary; param r { j in states }; minimize totcost: sum{i in sites, j in states} c[i,j]*r[j]*x[i,j] + sum{i in sites}f[i]*y[i]; x[j,t]*x[jp,t]; subject to doeach{j in states}: sum{i in sites}x[i,j] = 1; switch {i in sites, j in states }: x[i,j] <= y[i]; data; param m := 5; param n := 5; param f := 1 160 2 49 3 246 4 86 4 100; param r := 1 200 2 100 3 300 4 100 5 200; param c: 1 2 3 4 5 := 1 0.0 0.4 0.8 0.4 0.8 2 0.7 0.0 0.8 0.4 0.4 3 0.6 0.4 0.0 0.5 0.4 4 0.6 0.4 0.9 0.0 0.4 5 0.9 0.4 0.7 0.4 0.0 ;`

2-40. **(a)** max $\sum_{j=1}^{8} r_j x_j$, subject to, $\sum_{j=1}^{8} x_j \leq 4$, $x_1 + x_2 + x_3 \geq 2$, $x_4 + x_5 + x_6 + x_7 + x_8 \geq 1$, $x_2 + x_3 + x_4 + x_8 \geq 2$, $x_1 \ldots x_8 = 0$ or 1 **(b)** `model; param n ; set games := 1 .. n; #ratings param r{j in games}; #home? param h{j in games}; #state? param s{j in games}; #cover? var x{j in games} binary; maximize totrat: sum{j in games} r[j]*x[j]; subject to capacity: sum{j in games} x[j] <= 4; home: sum{j in games} h[j]*x[j] >= 2; away: sum{j in games}(1-h[j])* x[j] >= 1; state: sum{j in games}s[j]*x[j] >= 2; data; param n := 8; param r :=1 3.0 2 3.7 3 2.6 4 1.8 5 1.5 6 1.3 7 1.6 8 2.0; param h:=1 1 2 1 3 1 4 0 5 0 6 0 7 0 8 0; param s:=1 0 2 1 3 1 4 1 5 0 6 0 7 0 8 1;` **(c)** The model is an ILP because all constraints and the objective are linear, but decision variables are binary.

2-41. **(a)** How to divide funds is the issue.
(b) max $\sum_{j=1}^{n} v_j x_j$
(c) min $\sum_{j=1}^{n} r_j x_j$
(d) $\sum_{j=1}^{n} x_j = 1$
(e) $x_j \geq \ell_j$, $j = 1, \ldots, n$ (each category j)

(f) $x_j \leq u_j$, $j = 1, \ldots, n$ (each category j)
(g) A multiobjective LP because the 2 objectives and all constraints are linear, and all variables are continuous.

2-42. **(a)** The issue is which module goes to which site.
(b) If $x_{i,j} x_{i',j'} = 1$ the i is at j and i' is at j', so wire $d_{j,j'}$ will be required. Summing over all possible location pairs captures the wire requirements for i and i'.
(c) min $\sum_{i=1}^{m-1} \sum_{i'=i+1}^{m} a_{i,i'} \sum_{j=1}^{n} \sum_{j'=1}^{n} d_{j,j'} x_{i,j} x_{i',j'}$
(d) $\sum_{j=1}^{n} x_{i,j} = 1$, $i = 1, \ldots, m$ (each module i)
(e) $\sum_{i=1}^{m} x_{i,j} \leq 1$, $j = 1, \ldots, n$ (each site j)
(f) $x_{i,j} = 0$ or 1, $i = 1, \ldots, m$, $j = 1, \ldots, n$
(g) Single objective INLP because the one objective is nonlinear and variables are discrete. **(h)**

```
model; param m; param n; set modules := 1 .. m; set sites := 1 .. n; var x{i in modules, j in sites } binary; param a{ i in modules, ip in modules }; param d{ j in sites, jp in sites }; minimize totdist: sum{ i in modules, ip in modules: i < m and ip > i } a[i,ip] sum{j in sites, jp in sites : j < n and jp > j } d[j,jp]*x[i,j]*x[ip,jp]; subject to alli {i in modules }: sum{ j in sites } x[i,j] = 1; allj { j in sites }: sum { i in modules } x[i,j] <= 1;
```

2-43. $\max 199x_1 + 229x_2 + 188x_3 + 205x_4 - 180y_1 - 224y_2 - 497y_3$, subject to,
$23x_3 + 41x_4 \leq 2877y_1$, $14x_1 + 29x_2 \leq 2333y_2$,
$11x_3 + 27x_4 \leq 3011y_3$,
$x_1 + x_2 + x_3 + x_4 \geq 205$, $y_1 + y_2 + y_3 \leq 2$,
$x_1, \ldots, x_4 \geq 0$, $y_1, \ldots, y_3 = 0$ or 1

2-44. $\max 11x_{1,1} + 15x_{1,2} + 19x_{1,3} + 10x_{1,4} + 19x_{2,1} + 23x_{2,2} + 44x_{2,3} + 67x_{2,4} + 17x_{3,1} + 18x_{3,2} + 24x_{3,3} + 55x_{3,4}$, subject to, $15x_{1,1} + 24x_{2,1} + 17x_{3,1} \leq 7600$, $19x_{1,2} + 26x_{2,2} + 13x_{3,2} \leq 8200$, $23x_{1,3} + 18x_{2,3} + 16x_{3,3} \leq 6015$, $14x_{1,4} + 33x_{2,4} + 14x_{3,4} \leq 5000$, $31x_{1,1} + 26x_{2,1} + 21x_{3,1} \leq 6600$, $25x_{1,2} + 28x_{2,2} + 17x_{3,2} \leq 7900$, $39x_{1,3} + 22x_{2,3} + 20x_{3,2} \leq 5055$, $29x_{1,4} + 31x_{2,4} + 18x_{3,4} \leq 7777$, $x_{1,1} + x_{2,1} + x_{3,1} \geq 200$, $x_{1,2} + x_{2,2} + x_{3,2} \geq 300$, $x_{1,3} + x_{2,3} + x_{3,3} \geq 250$, $x_{1,4} + x_{2,4} + x_{3,4} \geq 500$, $x_{j,t} \geq 0$, $j = 1, \ldots 3$, $t = 1, \ldots 4$.