Instructor's Manual

OPTIMIZATION *In* OPERATIONS RESEARCH

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Contents

Chapter 1

Exercise Solutions

1-1. **(a)** The only unsettled quantity is decision variable s. **(b)** Given quantities or parameters are d, p and b. **(c)** Minimize the maximum error, i.e. objective min $(d/s)^2$ **(d)** We must have an integer number of sensors and not exceed the available budget, i.e. constraints $ps \leq b$, s nonnegative and integer.

1-2. **(a)** Feasible because $3.5(4) \leq 14$, and optimal because any larger s would not be feasible. **(b)** Infeasible and thus not optimal because $3.5(6) \not\leq 14$. **(c)** Feasible because $3.5(2) \leq 14$, but not optimal because feasible solution $s = 4$ yields a better objective value.

1-3. **(a)** The only quantities to be determined are x_1 and x_2, the numbers of lots on the 2 lines. **(b)** Given quantities or parameters are t_1, t_2, c_1, c_2, b and T. **(c)** Minimize total production cost or objective min $c_1x_1+c_2x_2$. **(d)** $t_1x_1+t_2x_2 \leq T$ (at most T hours of production), $x_1 + x_2 = b$ (produce b lots), $x_1, x_2 \geq 0$ and integer (numbers nonnegative integers).

1-4. **(a)** Infeasible and thus not optimal because $10(0) + 20(3) \not\leq 40$. **(b)** Feasible because $10(2) + 20(1) \leq 40$ and $2 + 1 = 3$. Also optimal because no more or less expensive x_2 can be used if $b = 3$ lots are to run. **(c)** Feasible because $10(3) + 20(0) \leq 40$ and $3 + 0 = 3$, but not optimal because $x_1 = 2$, $x_2 = 1$ yields a lower cost.

1-5. **(a)** Exact numerical optimization because it is the maximum feasible choice for the given set of parameter values. **(b)** Descriptive modeling because we have merely evaluated the consequences of a given choice of decision variables and parameters. **(c)** Closed-form optimization because an optimal solution is specified for each choice of decision variables. **(d)** Heuristic optimization because a good feasible solution is identified for the given choice of parameter values, but a non-usual layout might yield superior results.

1-6. **(a)** Provides optimum for all choices of input parameters, not just one. **(b)** Provides a provably best solution, not just a good feasible one. **(c)** Systematically searches for a good feasible solution, rather than just evaluating the consequences of one.

1-7. Higher tractability usually means loss of validity, so results from the model might not be useful in the application.

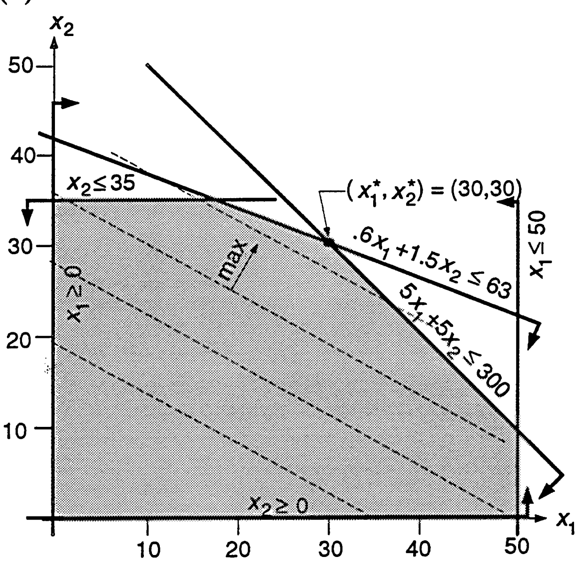
1-8. **(a)** (3 for the first) $\cdot$ (3 for the second) $\cdot \ldots \cdot$ (3 for the nth) $= 3^n$ combinations. **(b)** One run per second is 3,600 per hour, 86,400 per day, 31,536,000 per year. The $3^{10} = 59,049$ requires $59,049/3,600 = 16.4$ hours; $3^{15} = 14,348,907$ requires 166.1 days; $3^{20} \approx 3.49 \times 10^9$ requires 110.6 years; and $3^{30} \approx 2.06 \times 10^{14}$ requires 6.5 million years. **(c)** Practical computation would be limited to a few days which could accommodate no more than $10 - 11$ decision variables.

1-9. **(a)** Random variable because short term rainfall is unpredictable. **(b)** Deterministic quantity because annual rainfall averages are fairly stable. **(c)** Deterministic quantity because history can be known with certainty. **(d)** Random variable because future stock market behavior is highly uncertain. **(e)** Deterministic quantity because the seating capacity is fairly fixed. **(f)** Random variable because night to night arrivals are usually variable. **(g)** Random variable because breakdowns make the effective production rate uncertain. **(h)** Deterministic quantity because a reliable robot has a predictable rate of production. **(i)** Deterministic quantity because short term demand for such an expensive product would be fairly well known for the next few days. **(j)** Random variable because long term demand for a product is usually uncertain.

Chapter 2

Exercise Solutions

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)



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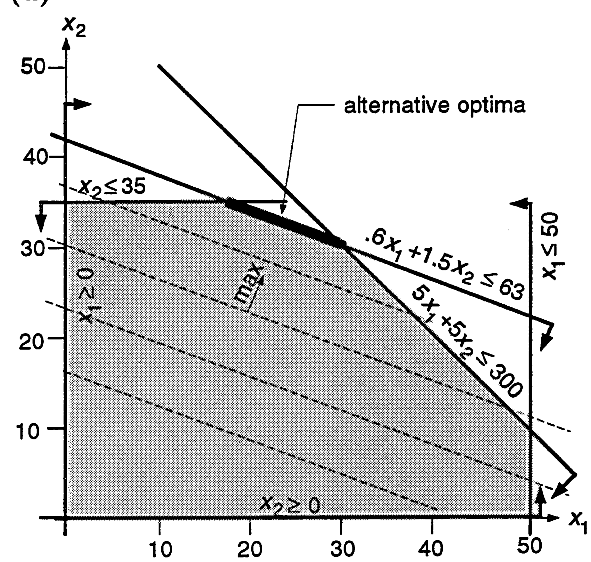
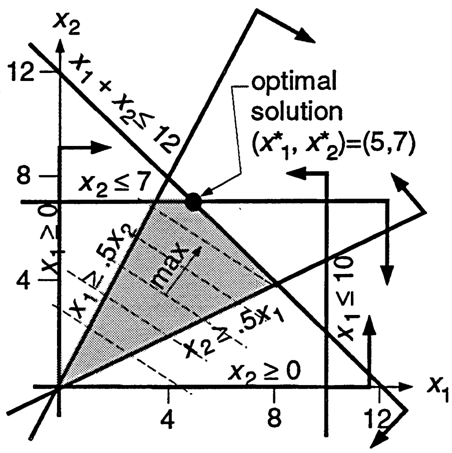


All optimal from $\mathbf{x} = (30, 30)$ to $\mathbf{x} = (17.5, 35)$.

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)



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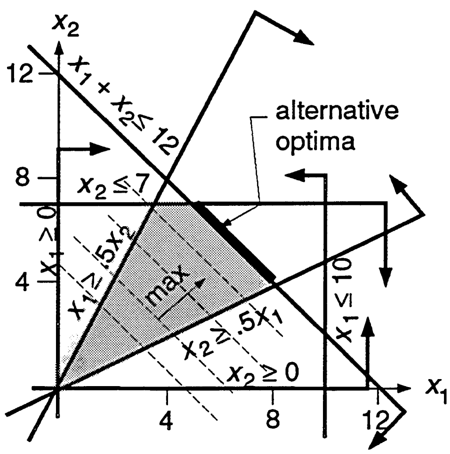
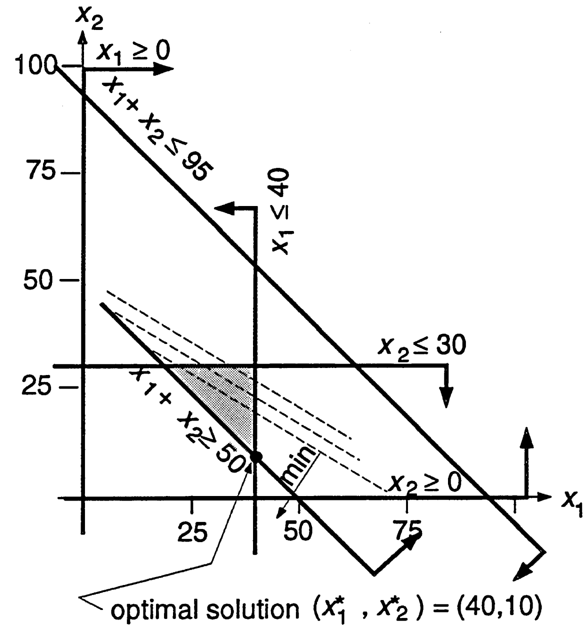


All optimal from $\mathbf{x} = (5,7)$ to $\mathbf{x} = (8,4)$.

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

(c)



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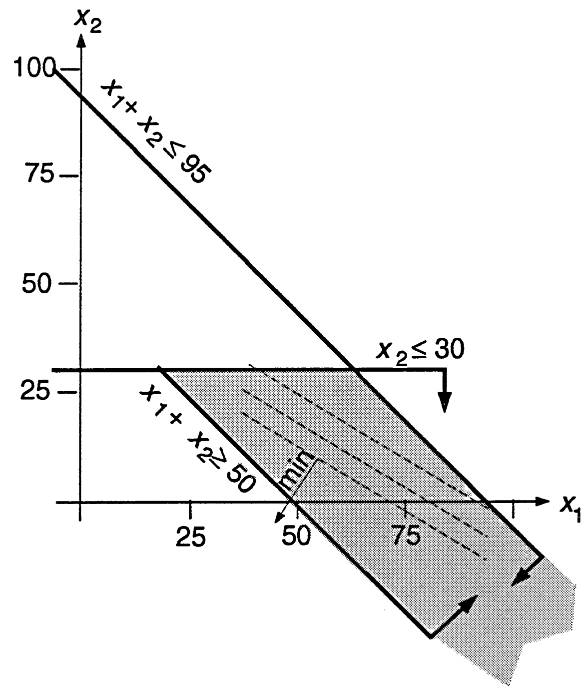
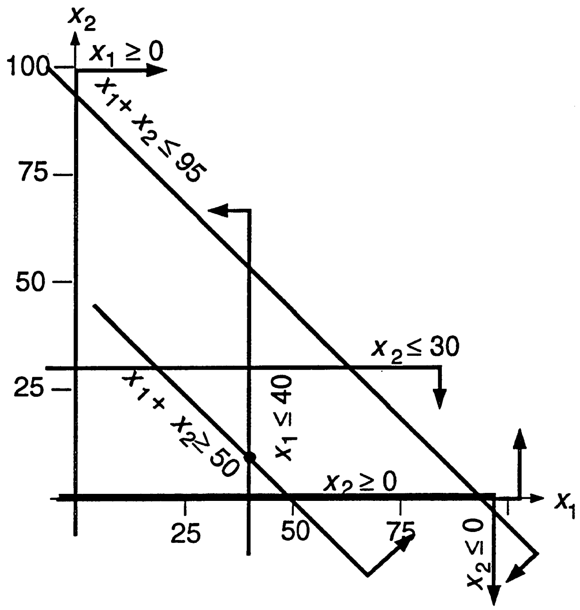


Improves forever in direction $\Delta x_1 = 1$, $\Delta x_2 = -1$.

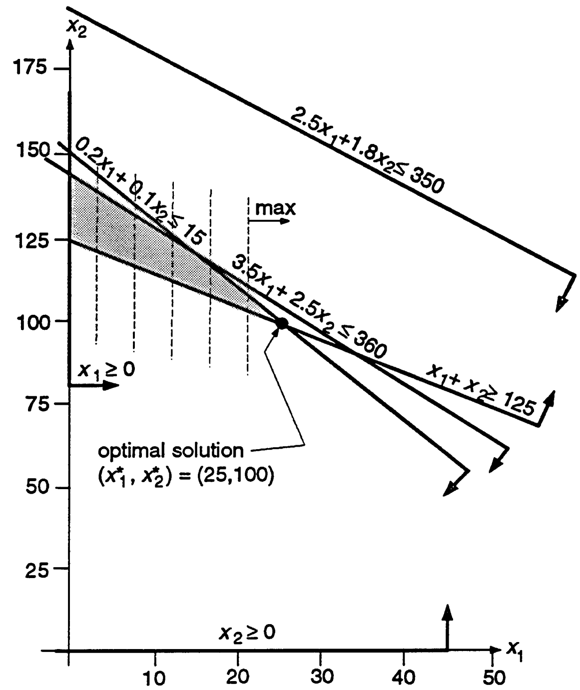
(e)



$x_2 = 0$ 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)



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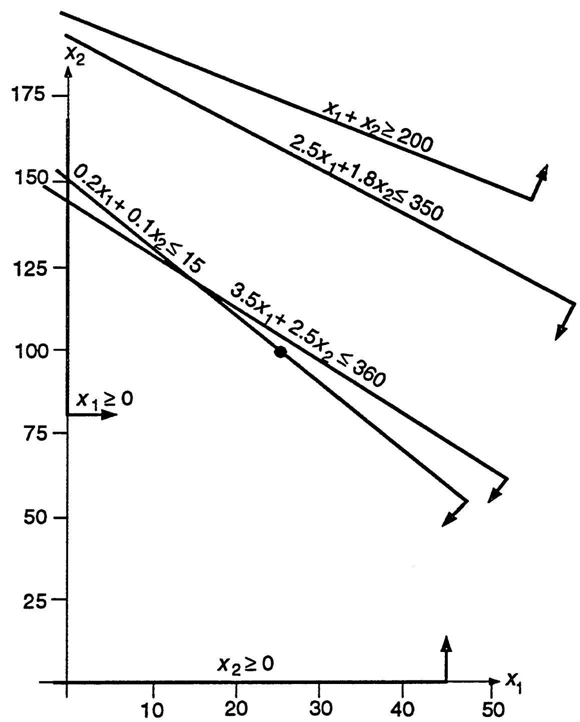
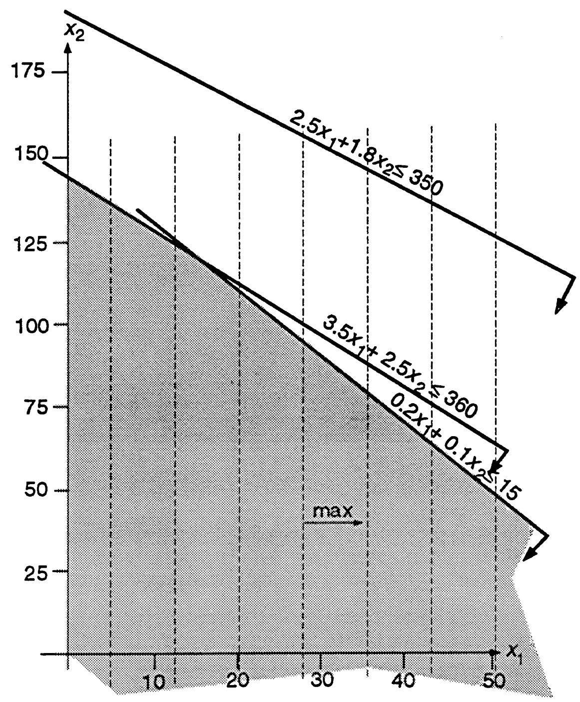


$x_1 + x_2 \geq 200$ leaves no feasible.

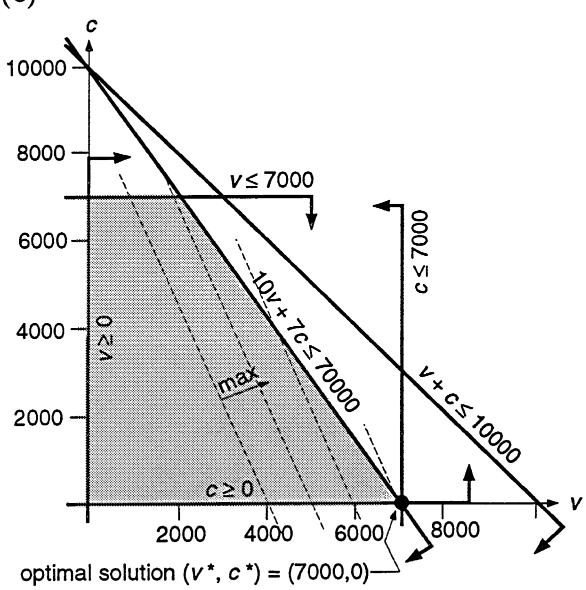
(e)



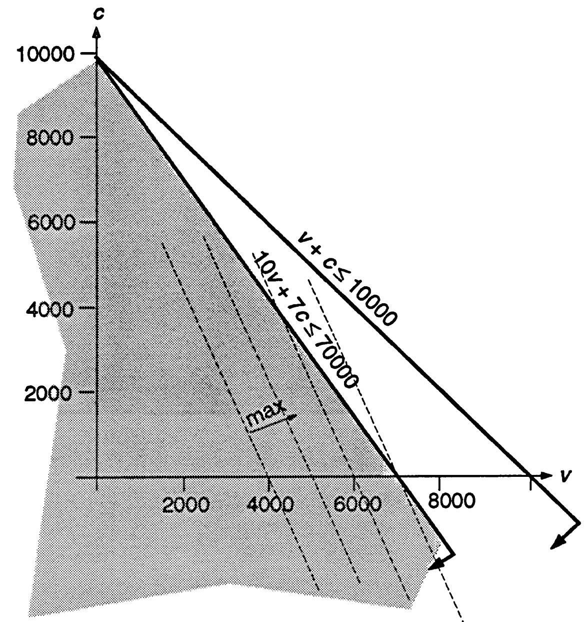
Improve forever in direction $\Delta x_1 = 1$, $\Delta x_2 = -2$.

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)

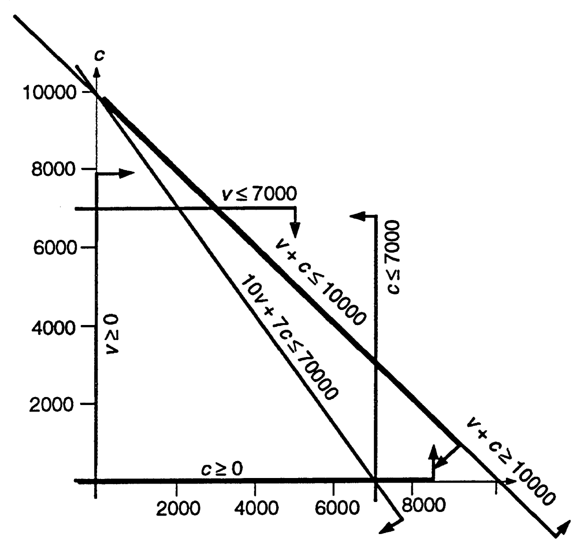


(d)



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

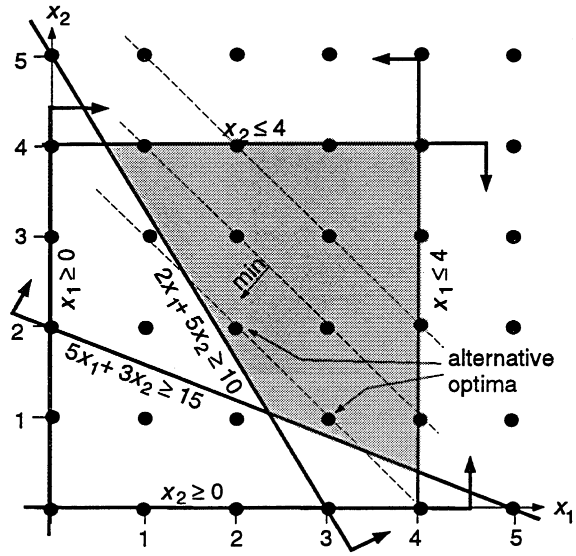
(e)



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 $x_1^* = 3$, $x_2^* = 1$

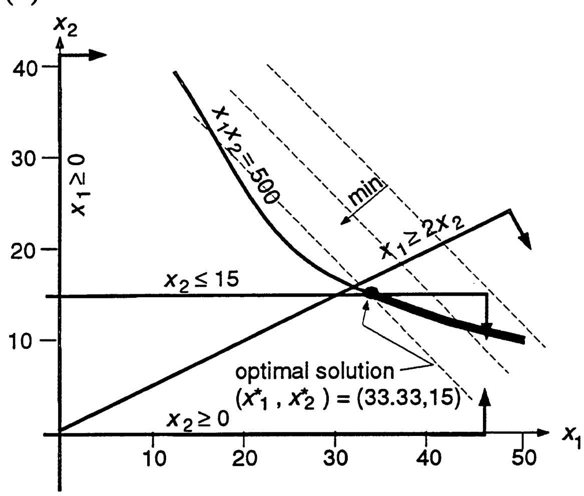
(d)



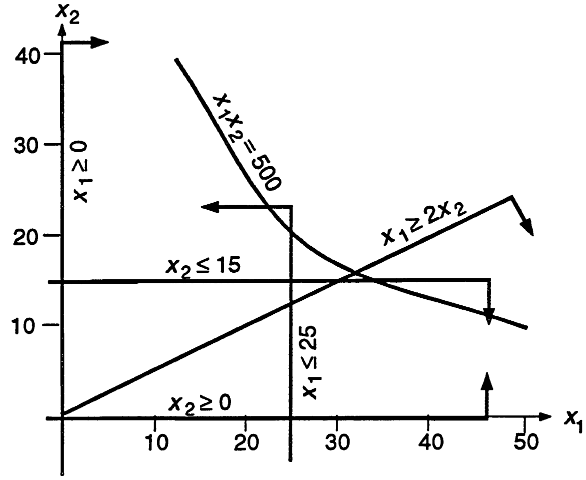
(e) Both (2, 2) and (3, 1) are feasible and lie on the best contour of the objective.

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

(c)



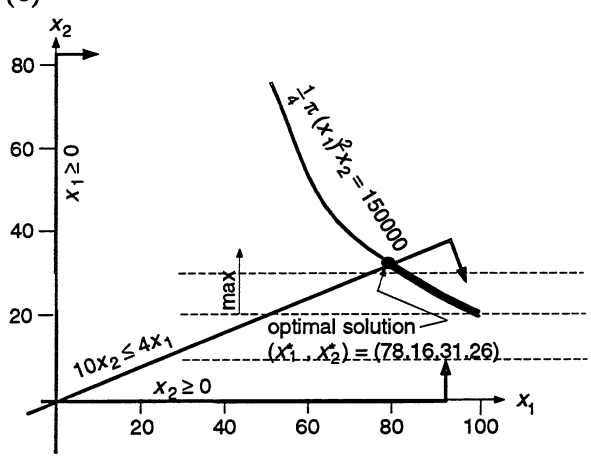
(d)



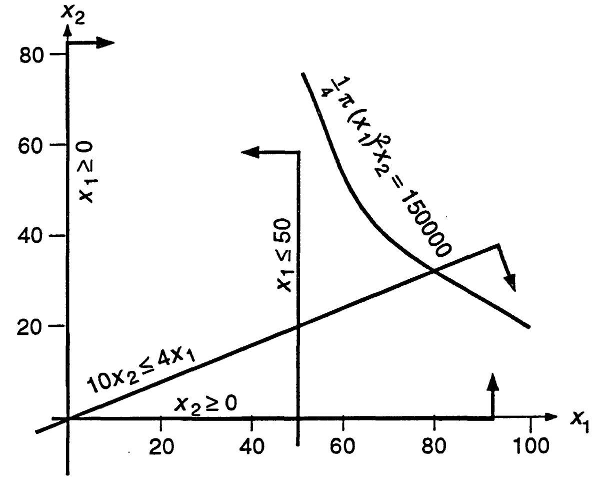
$x_1 \leq 25$ leaves no feasible.

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

(c)

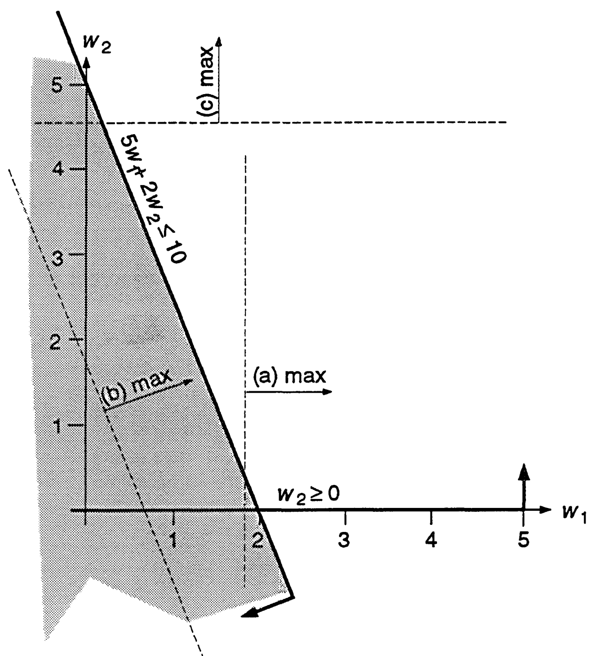


(d)



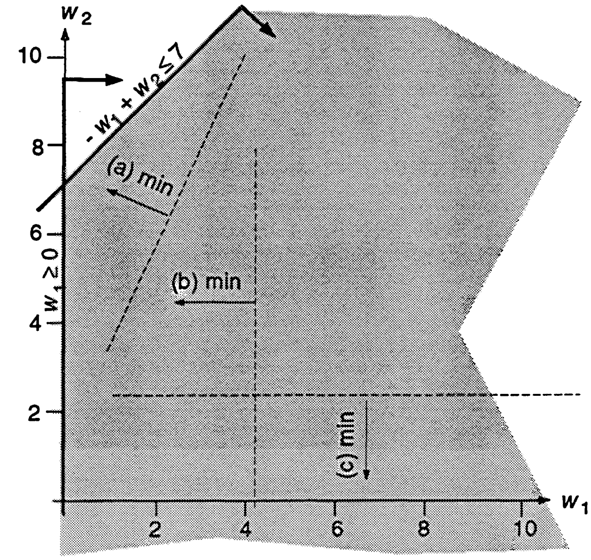
$x_1 \leq 50$ leaves no feasible.

2-9.



(a) max w_1 (b) max $5w_1 + 2w_2$ (c) max w_2

2-10.



(a) min $2w_1 - w_2$ (b) min w_1 (c) min w_2

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

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

2-14. (a) $\sum_{j=1}^{9} x_{i,j,t} \leq a_i$, $i = 1, \ldots, 47; t = 1, \ldots, 10$; 470 constraints
(b) $\sum_{i=1}^{47} x_{i,4,t} \geq 1000$, $t = 1, \ldots, 10$; 10 constraints
(c) $\sum_{i=1}^{47} \sum_{t=1}^{10} x_{i,2,t} \geq \frac{1}{3} \sum_{i=1}^{47} \sum_{j=1}^{9} \sum_{t=1}^{10} x_{i,j,t}$; 1 constraint

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) $f(y_1, y_2, y_3) \triangleq 14y_1y_2y_3 + 100$, $g_1(y_1, y_2, y_3) \triangleq y_1 - 3y_2 + y_3$, $b_1 = -2$, $g_2(y_1, y_2, y_3) \triangleq y_1 + 8y_2$, $b_2 = 10$, $g_3(y_1, y_2, y_3) \triangleq y_2$, $b_3 = 0$, $g_4(y_1, y_2, y_3) \triangleq y_3$, $b_4 = 0$

2-17. (a) Linear because LHS is a weighted sum of the decision variables. (b) Linear because

LHS is a weighted sum 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 $\ln(x_3)$ term. **(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. **(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 win or not. **(c)** Discrete because a specific process must be used. **(d)** Continuous because fractions make sense.

2-20. **(a)** $\sum_{j=1}^{8} x_j = 3$ **(b)** $\sum_{j=1}^{5} x_j \geq 2$ **(c)** $x_3 + x_8 \leq 1$ **(d)** $x_4 \leq x_1$

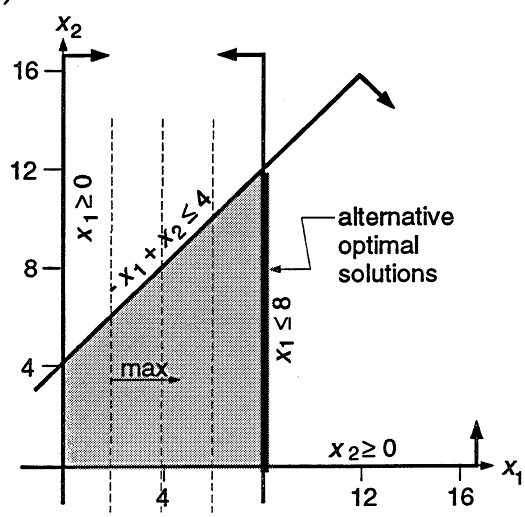
2-21. **(a)** max $85x_1 + 70x_2 + 62x_3 + 93x_4$ (max total score), s.t. $700x_1 + 400x_2 + 300x_3 + 600x_4 \leq 1000$ ($1 million available), $x_j = 0$ or 1, $j = 1, \ldots, 4$ **(b)** Fund 2 and 4, i.e. $x_1^* = x_3^* = 0$, $x_2^* = x_4^* = 1$

2-22. **(a)** min $200y_1 + 40y_2 + 55y_3 + 75y_4$ (min total land cost), s.t. $y_1 + y_2 \geq 1$ (service NW), $y_1 + y_2 + y_3 \geq 1$ (service SW), $y_1 + y_3 + y_4 \geq 1$ (service capital), $y_1 + y_2 \geq 1$ (service NE), $y_1 + y_4 \geq 1$ (service SE), $y_j = 0$ or 1, $j = 1, \ldots, 4$ **(b)** Build 2 and 4, i.e. $y_1^* = y_3^* = 0$, $y_2^* = y_4^* = 1$

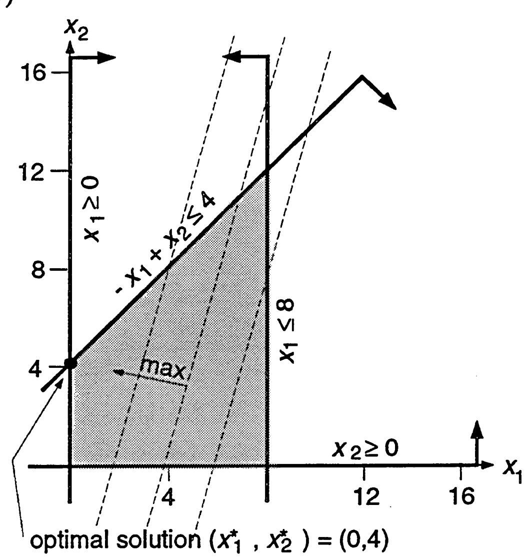
2-23. **(a)** ILP because the objective and all constraints are linear, but variables are discrete. **(b)** LP because the objective and all constraints are linear, and all variables are continuous. **(c)** INLP because the objective is nonlinear and variables are discrete. **(d)** NLP because the objective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

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

2-25.
(a)



(b)



(c) Helping one can hurt the other.

2-26. **(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),
$.00175x_4 + .00130x_5 + .00161x_6 + .00095x_9 + .00048x_{12} \le 8.5$ (at most 8.5 dBell attenuation),
$x_4, x_5, x_6, x_9, x_{12} \ge 0$
(b) Nonzeros: $x_5^* = 1000$, $x_{12}^* = 15000$

2-27. (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) $x_1 + x_4 + x_7 \le 3000$ (well 1), $x_2 + x_5 + x_8 \le 2500$ (well 2), $x_3 + x_6 + x_9 + x_{10} \le 7000$ (well 3)
(e) $x_j \le u_j$, $j = 1, \ldots, 10$
(f) $\sum_{j=1}^{10} x_j \ge 10000$
(g) $x_j \ge 0$, $j = 1, \ldots, 10$
(h) A single objective LP because the one objective and all constraints are linear, and all variables are continuous.
(i) $x_1^* = x_2^* = x_3^* = 1100$, $x_4^* = x_6^* = 1500$, $x_5^* = 1400$, $x_7^* = 400$¡ $x_8^* = x_{10}^* = 0$, $x_9^* = 1900$

2-28. (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) $7 \le \left(\sum_{j=1}^{8} m_j x_j\right)/240 \le 10$
(e) $\sum_{j=1}^{8} t_j x_j \le 1000$ (computer time), $\sum_{j=1}^{8} x_j \ge 3$ (select at least 3); $x_3+x_4+x_5+x_8 \ge 1$ (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 $= 0$

2-29. (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) $x_{i,j} \ge 0$, $i = 1, \ldots, 4$, $j = 1, \ldots, 7$
(g) A single objective LP because the one objective and all constraints are linear, and all variables are continuous.
(h) Nonzeros: $x_{1,1}^* = 81$, $x_{1,2}^* = 93$, $x_{1,3}^* = 166$, $x_{1,5}^* = 90$, $x_{1,6}^* = 85$, $x_{1,7}^* = 145$, $x_{2,2}^* = 301$, $x_{3,1}^* = 166$, $x_{3,4}^* = 105$, $x_{4,3}^* = 99$

2-30. (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.

2-31. (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.

2-32. (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 $= 0$

2-33. (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.

2-34. (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) $x_{i,j} \geq 0$, $i,j = 1,\ldots,5$, $i \neq j$
(g) A single objective LP because the one objective and all constraints are linear, and all variables are continuous.
(h) Nonzero values: $x^*_{4,2} = 115$, $x^*_{4,3} = 165$, $x^*_{5,1} = 85$, $x^*_{5,3} = 225$

2-35. (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) $\sum_{f=1}^{4} e_f x_{f,p} \geq r_p$, $p = 1,\ldots,23$ (each plant p); 23 constraints
(e) $x_{f,p} \geq 0$, $f = 1,\ldots,4$, $p = 1,\ldots,23$; 92 constraints
(f) A multiobjective LP because the 2 objectives and all constraints are linear, and all variables are continuous.

2-36. (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) $100(.09)x_{10} + 240(.09)x_{15} + 400(.09)x_{20} + .10y_1 + .08y_2 \geq 2350$
(e) $x_{10} + x_{15} + x_{20} \leq 1500$ (sawing capacity), $100x_{10}+240x_{15}+400x_{20}+y_1+y_2 \leq 26500$ (drying capacity)
(f) $x_{10} \leq 50$ (size 10 log availability), $x_{15} \leq 25$ (size 15 log availability), $x_{20} \leq 10$ (size 20 log availability), $y_1 \leq 5000$ (grade 1 green lumber availability)
(g) $x_{10}, x_{15}, x_{20}, y_1, y_2 \geq 0$
(h) A single objective LP because the one objective and all constraints are linear, and all variables are continuous.
(i) $x^*_{10} = 50$, $x^*_{15} = 25$, $x^*_{20} = 5$, $y^*_1 = 5000$, $y^*_2 = 8500$

2-37. (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.

2-38. (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 $\sum_{i=1}^{5}\sum_{j=1}^{5} c_{i,j}r_jx_{i,j} + \sum_{i=1}^{5} f_iy_i$
(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: $x^*_{2,2} = x^*_{2,4} = x^*_{3,1} = x^*_{3,3} = x^*_{5,5} = 1$, $y^*_2 = y^*_3 = y^*_5 = 1$

2-39. (a) How to divide funds is the issue.
(b) max $\sum_{j=1}^{n} v_jx_j$
(c) min $\sum_{j=1}^{n} r_jx_j$
(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.

2-40. (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.