CS352 (Winter 2018) - Homework 6

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Due Date: February 25, 2018

Problem 1: *(7 points)* Shortest paths can be cast as an LP using distances dv from the source s to a particular vertex v as variables.

We can compute the shortest path from s to t in a weighted directed graph by solving.
max dt
subject to
ds = 0
dv – du $\leq$ w(u,v) for all (u,v)$\in$E

We can compute the single-source by changing the objective function to
max $\sum_{v \in V} dv$

Use linear programming to answer the questions below. Submit a copy of the LP code and output.

a) Find the distance of the shortest path from G to C in the graph below.
The shortest path is G, H, B, C with a distance of 16. A copy of the LP code and output is in the appendix.

b) Find the distances of the shortest paths from G to all other vertices.
A copy of the LP code and output is in the appendix.

Vertex	Distance from G to Vertex
a	7
b	12
c	16
d	2
e	19
f	17
g	0
h	3

Problem 2: *(7 points)* Acme Industries produces four types of men's ties using three types of material. Your job is to determine how many of each type of tie to make each month. The goal is to maximize profit, profit per tie = selling price - labor cost – material cost. Labor cost is \$0.75 per tie for all four types of ties. The material requirements and costs are given below.

Material	Cost / Yard	Yards / Month
Silk	\$20	1,000
Polyester	\$6	2,000
Cotton	\$9	1,250

Product Info	Silk(s)	Poly(p)	Blend 1(b)	Blend2(c)
Sale Price	\$6.70	\$3.55	\$4.31	\$4.81
Min. Units / Month	6,000	10,000	13,000	6,000
Max. Units / Month	7,000	14,000	16,000	8,500

Material Info	Silk(s)	Poly(p)	Blend 1(b)	Blend2(c)
Silk	0.125	0	0	0
Polyester	0	0.08	0.05	0.03
Cotton	0	0	0.05	0.07

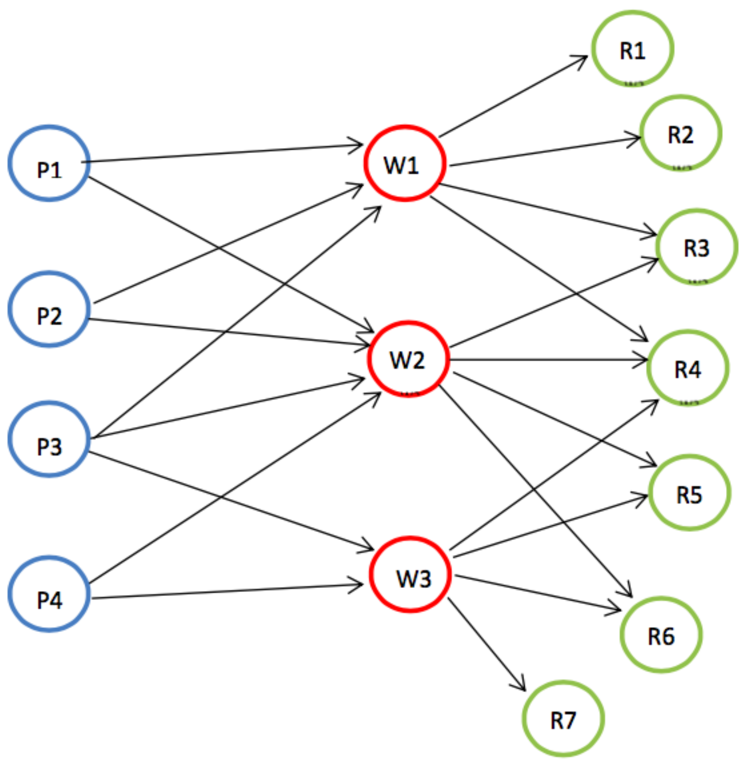
Type	Selling Price	Labor	Material	Profit/Tie
Silk(s)	6.7	0.75	2.5	3.45
Polyester(p)	3.55	0.75	0.48	2.32
Blend 1(b)	4.31	0.75	0.75	2.81
Blend 2(c)	4.81	0.75	0.81	3.25

Formulate the problem as a linear program with an objective function and all constraints. Determine the optimal solution for the linear program using any software you want. What are the optimal numbers of ties of each type to maximize profit? Include a copy of the code and output.

The maximized profit is \$120,196, which you would get from selling 7,000 silk, 13,625 polyester, 13,100 blend1, and 8,500 blend2 ties. A copy of the LP code and output is in the appendix.

Problem 3: Transshipment Model *(7 points)*
This is an extension of the transportation model. There are now intermediate transshipment points added between the sources (plants) and destinations (retailers). Items being shipped from a Plant (p_i) must be shipped to a Warehouse (w_j) before being shipped to the Retailer (r_k). Each Plant will have an associated supply (s_i) and each Retailer will have a demand (d_k). The number of plants is n, number of warehouses is q and the number of retailers is m. The edges (i,j) from plant (p_i)to warehouse (w_j) have costs associated denoted cp(i,j). The edges (j,k) from a warehouse (w_j)to a retailer (r_k) have costs associated denoted cw(j,k).

The graph below shows the transshipment map for a manufacturer of refrigerators. Refrigerators are produced at four plants and then shipped to a warehouse (weekly) before going to the retailer.



Below are the costs of shipping from a plant to a warehouse and then a warehouse to a retailer. If it is impossible to ship between the two locations an X is placed in the table.

Cost	W1	W2	W3
P1	\$10	\$15	X
P2	\$11	\$8	X
P3	\$13	\$8	\$9
P4	X	\$14	\$8

Cost	R1	R2	R3	R4	R5	R6	R7
W1	\$5	\$6	\$7	\$10	X	X	X
W2	X	X	\$12	\$8	\$10	\$14	X
W3	X	X	X	\$14	\$12	\$12	\$6

The tables below give the capacity of each plant (supply) and the demand for each retailer (per week).

	P1	P2	P3	P4
Supply	150	450	250	150

	R1	R2	R3	R4	R5	R6	R7
Demand	100	150	100	200	200	150	100

Your goal is to determine the number of refrigerators to be shipped plants to warehouses and then warehouses to retailers to minimize the cost. Formulate the problem as a linear program with an objective function and all constraints. Determine the optimal solution for the linear program using any software you want. What are the optimal shipping routes and minimum cost.
Include a copy of the code and output.

The minimum cost is \$17,100. The optimal shipping routes are shown in the graph below. A copy of the LP code and output is in the appendix.

Problem 4: A Mixture Problem *(9 points)*
Veronica the owner of Very Veggie Vegeria is creating a new healthy salad that is low in calories but meets certain nutritional requirements. A salad is any combination of the following ingredients:
Tomato, Lettuce, Spinach, Carrot, Smoked Tofu, Sunflower Seeds, Chickpeas, Oil
Each salad must contain:

- At least 15 grams of protein
- At least 2 and at most 8 grams of fat
- At least 4 grams of carbohydrates
- At most 200 milligrams of sodium
- At least 40% leafy greens by mass.

The nutritional contents of these ingredients (per 100 grams) and cost are:

Ingredient	Calories	Protein(g)	Fat(g)	Carbs(g)	Sodium(mg)	Cost(100g)
Tomato	21	0.85	0.33	4.64	9	$1.00
Lettuce	16	1.62	0.20	2.37	28	$0.75
Spinach	40	2.86	0.39	3.63	65	$0.50
Carrot	41	0.93	0.24	9.58	69	$0.50
Sunflower Seeds	585	23.4	48.7	15	3.8	$0.45
Smoked Tofu	120	16	5	3	120	$2.15
Chickpeas	164	9	2.6	27	78	$0.95
Oil	884	0	100	0	0	$2.00

Part A: Determine the combination of ingredients that minimizes calories but meets all nutritional requirements. Formulate the problem as a linear program with an objective function and all constraints. Determine the optimal solution for the linear program using any software you want. What is the cost of the low calorie salad?

The low calorie salad is made up of steamed tofu and lettuce. It costs $2.33.

Ingredient	Calories	Protein(g)	Fat(g)	Carbs(g)	Sodium(mg)	Cost(100g)
Lettuce (58.5 grams)	9.4	0.9	0.1	1.4	16.4	$0.44
Smoked Tofu (87.8 grams)	105.4	14.1	4.4	2.6	105.4	$1.89
Total (146.3 grams)	114.8	15	4.5	4	121.8	$2.33

Part B: Part B: Veronica realizes that it is also important to minimize the cost associated with the new salad. Unfortunately some of the ingredients can be expensive. Determine the combination of ingredients that minimizes cost. Formulate the problem as a linear program with an objective function and all constraints. Determine the optimal solution for the linear program using any software you want. How many calories are in the low cost salad?

The low cost salad is made up of chickpeas, sunflower seeds, and spinach. It has 278 calories. A copy of the LP code and output is in the appendix.

Ingredient	Calories	Protein(g)	Fat(g)	Carbs(g)	Sodium(mg)	Cost(100g)
Spinach (83.2 grams)	33.3	2.4	0.3	3	54.1	$0.42
Sunflower Seeds (9.6 grams)	56.2	2.2	4.7	1.4	0.4	$0.04
Chickpeas (115.2 grams)	189	10.4	3	31.1	89.9	$1.09
Total (208 grams)	278.5	15	8	35.5	144.4	$1.55

APPENDIX

QUESTION 1A

Lindo Input:

```
max dc
ST
    dg = 0
    df - da <= 10
    da - df <= 5
    da - dh <= 4
    dh - dg <= 3
    dc - df <= 3
    dd - dc <= 3
    de - dd <= 25
    dd - de <= 9
    de - df <= 2
    dg - de <= 7
    db - dh <= 9
    db - da <= 8
    db - df <= 7
    dc - db <= 4
    de - db <= 10
    dd - dg <= 2
    df - dd <= 18
END
```

Lindo Output:

```
 LP OPTIMUM FOUND AT STEP      6

        OBJECTIVE FUNCTION VALUE

        1)      16.00000

  VARIABLE        VALUE          REDUCED COST
        DC        16.000000          0.000000
        DG         0.000000          0.000000
        DF        13.000000          0.000000
        DA         4.000000          0.000000
        DH         3.000000          0.000000
        DD         0.000000          0.000000
        DE         0.000000          0.000000
        DB        12.000000          0.000000


       ROW   SLACK OR SURPLUS     DUAL PRICES
        2)         0.000000          1.000000
```

```
       3)         1.000000          0.000000
       4)        14.000000          0.000000
       5)         3.000000          0.000000
       6)         0.000000          1.000000
       7)         0.000000          0.000000
       8)        19.000000          0.000000
       9)        25.000000          0.000000
      10)         9.000000          0.000000
      11)        15.000000          0.000000
      12)         7.000000          0.000000
      13)         0.000000          1.000000
      14)         0.000000          0.000000
      15)         8.000000          0.000000
      16)         0.000000          1.000000
      17)        22.000000          0.000000
      18)         2.000000          0.000000
      19)         5.000000          0.000000

 NO. ITERATIONS=       6
```

QUESTION 1B

Lindo Input:

```
max d(a through h)
ST
    dg = 0
    df - da <= 10
    da - df <= 5
    da - dh <= 4
    dh - dg <= 3
    dc - df <= 3
    dd - dc <= 3
    de - dd <= 25
    dd - de <= 9
    de - df <= 2
    dg - de <= 7
    db - dh <= 9
    db - da <= 8
    db - df <= 7
    dc - db <= 4
    de - db <= 10
    dd - dg <= 2
    df - dd <= 18
END
```

Lindo Output:

```
 LP OPTIMUM FOUND AT STEP      0

        OBJECTIVE FUNCTION VALUE
```

1) 7.000000

VARIABLE	VALUE	REDUCED COST
DA	7.000000	0.000000
DG	0.000000	0.000000
DF	17.000000	0.000000
DH	3.000000	0.000000
DC	16.000000	0.000000
DD	2.000000	0.000000
DE	0.000000	0.000000
DB	12.000000	0.000000

ROW	SLACK OR SURPLUS	DUAL PRICES
2)	0.000000	1.000000
3)	0.000000	0.000000
4)	15.000000	0.000000
5)	0.000000	1.000000
6)	0.000000	1.000000
7)	4.000000	0.000000
8)	17.000000	0.000000
9)	27.000000	0.000000
10)	7.000000	0.000000
11)	19.000000	0.000000
12)	7.000000	0.000000
13)	0.000000	0.000000
14)	3.000000	0.000000
15)	12.000000	0.000000
16)	0.000000	0.000000
17)	22.000000	0.000000
18)	0.000000	0.000000
19)	3.000000	0.000000

NO. ITERATIONS= 0

LP OPTIMUM FOUND AT STEP 1

OBJECTIVE FUNCTION VALUE

1) 12.00000

VARIABLE	VALUE	REDUCED COST
DB	12.000000	0.000000
DG	0.000000	0.000000
DF	17.000000	0.000000
DA	7.000000	0.000000
DH	3.000000	0.000000
DC	16.000000	0.000000
DD	0.000000	0.000000

```
        DE        19.000000          0.000000


       ROW   SLACK OR SURPLUS     DUAL PRICES
        2)         0.000000          1.000000
        3)         0.000000          0.000000
        4)        15.000000          0.000000
        5)         0.000000          0.000000
        6)         0.000000          1.000000
        7)         4.000000          0.000000
        8)        19.000000          0.000000
        9)         6.000000          0.000000
       10)        28.000000          0.000000
       11)         0.000000          0.000000
       12)        26.000000          0.000000
       13)         0.000000          1.000000
       14)         3.000000          0.000000
       15)        12.000000          0.000000
       16)         0.000000          0.000000
       17)         3.000000          0.000000
       18)         2.000000          0.000000
       19)         1.000000          0.000000

 NO. ITERATIONS=       1


 LP OPTIMUM FOUND AT STEP      2

        OBJECTIVE FUNCTION VALUE

        1)      16.00000

  VARIABLE        VALUE          REDUCED COST
        DC        16.000000          0.000000
        DG         0.000000          0.000000
        DF        13.000000          0.000000
        DA         7.000000          0.000000
        DH         3.000000          0.000000
        DD         2.000000          0.000000
        DE        15.000000          0.000000
        DB        12.000000          0.000000


       ROW   SLACK OR SURPLUS     DUAL PRICES
        2)         0.000000          1.000000
        3)         4.000000          0.000000
        4)        11.000000          0.000000
        5)         0.000000          0.000000
        6)         0.000000          1.000000
        7)         0.000000          0.000000
```

8)	17.000000	0.000000
9)	12.000000	0.000000
10)	22.000000	0.000000
11)	0.000000	0.000000
12)	22.000000	0.000000
13)	0.000000	1.000000
14)	3.000000	0.000000
15)	8.000000	0.000000
16)	0.000000	1.000000
17)	7.000000	0.000000
18)	0.000000	0.000000
19)	7.000000	0.000000

NO. ITERATIONS= 2

LP OPTIMUM FOUND AT STEP 0

OBJECTIVE FUNCTION VALUE

1) 2.000000

VARIABLE	VALUE	REDUCED COST
DD	2.000000	0.000000
DG	0.000000	0.000000
DF	13.000000	0.000000
DA	7.000000	0.000000
DH	3.000000	0.000000
DC	16.000000	0.000000
DE	15.000000	0.000000
DB	12.000000	0.000000

ROW	SLACK OR SURPLUS	DUAL PRICES
2)	0.000000	1.000000
3)	4.000000	0.000000
4)	11.000000	0.000000
5)	0.000000	0.000000
6)	0.000000	0.000000
7)	0.000000	0.000000
8)	17.000000	0.000000
9)	12.000000	0.000000
10)	22.000000	0.000000
11)	0.000000	0.000000
12)	22.000000	0.000000
13)	0.000000	0.000000
14)	3.000000	0.000000
15)	8.000000	0.000000
16)	0.000000	0.000000
17)	7.000000	0.000000

18)	0.000000	1.000000
19)	7.000000	0.000000

NO. ITERATIONS= 0

LP OPTIMUM FOUND AT STEP 1

OBJECTIVE FUNCTION VALUE

1) 19.00000

VARIABLE	VALUE	REDUCED COST
DE	19.000000	0.000000
DG	0.000000	0.000000
DF	17.000000	0.000000
DA	7.000000	0.000000
DH	3.000000	0.000000
DC	16.000000	0.000000
DD	2.000000	0.000000
DB	12.000000	0.000000

ROW	SLACK OR SURPLUS	DUAL PRICES
2)	0.000000	1.000000
3)	0.000000	1.000000
4)	15.000000	0.000000
5)	0.000000	1.000000
6)	0.000000	1.000000
7)	4.000000	0.000000
8)	17.000000	0.000000
9)	8.000000	0.000000
10)	26.000000	0.000000
11)	0.000000	1.000000
12)	26.000000	0.000000
13)	0.000000	0.000000
14)	3.000000	0.000000
15)	12.000000	0.000000
16)	0.000000	0.000000
17)	3.000000	0.000000
18)	0.000000	0.000000
19)	3.000000	0.000000

NO. ITERATIONS= 1

LP OPTIMUM FOUND AT STEP 0

OBJECTIVE FUNCTION VALUE

1) 17.00000

VARIABLE	VALUE	REDUCED COST
DF	17.000000	0.000000
DG	0.000000	0.000000
DA	7.000000	0.000000
DH	3.000000	0.000000
DC	16.000000	0.000000
DD	2.000000	0.000000
DE	19.000000	0.000000
DB	12.000000	0.000000

ROW	SLACK OR SURPLUS	DUAL PRICES
2)	0.000000	1.000000
3)	0.000000	1.000000
4)	15.000000	0.000000
5)	0.000000	1.000000
6)	0.000000	1.000000
7)	4.000000	0.000000
8)	17.000000	0.000000
9)	8.000000	0.000000
10)	26.000000	0.000000
11)	0.000000	0.000000
12)	26.000000	0.000000
13)	0.000000	0.000000
14)	3.000000	0.000000
15)	12.000000	0.000000
16)	0.000000	0.000000
17)	3.000000	0.000000
18)	0.000000	0.000000
19)	3.000000	0.000000

NO. ITERATIONS= 0

LP OPTIMUM FOUND AT STEP 0

OBJECTIVE FUNCTION VALUE

1) 0.0000000E+00

VARIABLE	VALUE	REDUCED COST
DG	0.000000	0.000000
DF	17.000000	0.000000
DA	7.000000	0.000000
DH	3.000000	0.000000
DC	16.000000	0.000000
DD	2.000000	0.000000
DE	19.000000	0.000000

```
       DB        12.000000          0.000000


      ROW   SLACK OR SURPLUS     DUAL PRICES
       2)         0.000000          1.000000
       3)         0.000000          0.000000
       4)        15.000000          0.000000
       5)         0.000000          0.000000
       6)         0.000000          0.000000
       7)         4.000000          0.000000
       8)        17.000000          0.000000
       9)         8.000000          0.000000
      10)        26.000000          0.000000
      11)         0.000000          0.000000
      12)        26.000000          0.000000
      13)         0.000000          0.000000
      14)         3.000000          0.000000
      15)        12.000000          0.000000
      16)         0.000000          0.000000
      17)         3.000000          0.000000
      18)         0.000000          0.000000
      19)         3.000000          0.000000

NO. ITERATIONS=       0


LP OPTIMUM FOUND AT STEP      0

       OBJECTIVE FUNCTION VALUE

       1)      3.000000

 VARIABLE        VALUE          REDUCED COST
       DH         3.000000          0.000000
       DG         0.000000          0.000000
       DF        17.000000          0.000000
       DA         7.000000          0.000000
       DC        16.000000          0.000000
       DD         2.000000          0.000000
       DE        19.000000          0.000000
       DB        12.000000          0.000000


      ROW   SLACK OR SURPLUS     DUAL PRICES
       2)         0.000000          1.000000
       3)         0.000000          0.000000
       4)        15.000000          0.000000
       5)         0.000000          0.000000
       6)         0.000000          1.000000
       7)         4.000000          0.000000
```

```
        8)        17.000000          0.000000
        9)         8.000000          0.000000
       10)        26.000000          0.000000
       11)         0.000000          0.000000
       12)        26.000000          0.000000
       13)         0.000000          0.000000
       14)         3.000000          0.000000
       15)        12.000000          0.000000
       16)         0.000000          0.000000
       17)         3.000000          0.000000
       18)         0.000000          0.000000
       19)         3.000000          0.000000

 NO. ITERATIONS=       0
```

QUESTION 2

Lindo Input:

```
max 3.45s + 2.32p + 2.81b + 3.25c
ST
    s >= 0
    p >= 0
    b >= 0
    c >= 0
    s >= 6000
    s <= 7000
    p >= 10000
    p <= 14000
    b >= 13000
    b <= 16000
    c >= 6000
    c <= 8500
    .125s <= 1000
    .08p + .05b + .03c <= 2000
    .05b + .07c <= 1250
END
```

Lindo Output:

```
 LP OPTIMUM FOUND AT STEP      0

        OBJECTIVE FUNCTION VALUE

        1)      120196.0

  VARIABLE        VALUE          REDUCED COST
         S      7000.000000          0.000000
         P     13625.000000          0.000000
         B     13100.000000          0.000000
         C      8500.000000          0.000000
```

```
 ROW   SLACK OR SURPLUS     DUAL PRICES
  2)      7000.000000          0.000000
  3)     13625.000000          0.000000
  4)     13100.000000          0.000000
  5)      8500.000000          0.000000
  6)      1000.000000          0.000000
  7)         0.000000          3.450000
  8)      3625.000000          0.000000
  9)       375.000000          0.000000
 10)       100.000000          0.000000
 11)      2900.000000          0.000000
 12)      2500.000000          0.000000
 13)         0.000000          0.476000
 14)       125.000000          0.000000
 15)         0.000000         29.000000
 16)         0.000000         27.200001

NO. ITERATIONS=       0
```

QUESTION 3

Lindo Input:

```
min 10x11 + 15x12 + 11x21 + 8x22 + 13x31 + 8x32 + 9x33 + 14x42
+ 8x43 + 5y11 + 6y12 + 7y13 + 10y14 + 12y23 + 8y24 + 10y25 +
14y26 + 14y34 + 12y35 + 12y36 + 6y37
ST
    x11 >= 0
    x12 >= 0
    x21 >= 0
    x22 >= 0
    x31 >= 0
    x32 >= 0
    x33 >= 0
    x42 >= 0
    x43 >= 0
    y11 >= 0
    y12 >= 0
    y13 >= 0
    y14 >= 0
    y23 >= 0
    y24 >= 0
    y25 >= 0
    y26 >= 0
    y34 >= 0
    y35 >= 0
    y36 >= 0
    y37 >= 0
    x11 + x12 <= 150
    x21 + x22 <= 450
```

```
    x31 + x32 + x33 <= 250
    x42 + x43 <= 150
    y11 >= 100
    y12 >= 150
    y13 + y23 >= 100
    y14 + y24 + y34 >= 200
    y25 + y35 >= 200
    y26 + y36 >= 150
    y37 >= 100
    x11+x21+x31-y11-y12-y13-y14>=0
    x12+x22+x32+x42-y23-y24-y25-y26>=0
    x33+x43-y34-y35-y36-y37>=0
END
```

Lindo Output:

```
 LP OPTIMUM FOUND AT STEP     13

        OBJECTIVE FUNCTION VALUE

        1)      17100.00

  VARIABLE        VALUE          REDUCED COST
       X11       150.000000          0.000000
       X12         0.000000          8.000000
       X21       200.000000          0.000000
       X22       250.000000          0.000000
       X31         0.000000          2.000000
       X32       150.000000          0.000000
       X33       100.000000          0.000000
       X42         0.000000          7.000000
       X43       150.000000          0.000000
       Y11       100.000000          0.000000
       Y12       150.000000          0.000000
       Y13       100.000000          0.000000
       Y14         0.000000          5.000000
       Y23         0.000000          2.000000
       Y24       200.000000          0.000000
       Y25       200.000000          0.000000
       Y26         0.000000          1.000000
       Y34         0.000000          7.000000
       Y35         0.000000          3.000000
       Y36       150.000000          0.000000
       Y37       100.000000          0.000000


       ROW   SLACK OR SURPLUS     DUAL PRICES
        2)       150.000000          0.000000
        3)         0.000000          0.000000
        4)       200.000000          0.000000
        5)       250.000000          0.000000
```

6)	0.000000	0.000000
7)	150.000000	0.000000
8)	100.000000	0.000000
9)	0.000000	0.000000
10)	150.000000	0.000000
11)	100.000000	0.000000
12)	150.000000	0.000000
13)	100.000000	0.000000
14)	0.000000	0.000000
15)	0.000000	0.000000
16)	200.000000	0.000000
17)	200.000000	0.000000
18)	0.000000	0.000000
19)	0.000000	0.000000
20)	0.000000	0.000000
21)	150.000000	0.000000
22)	100.000000	0.000000
23)	0.000000	1.000000
24)	0.000000	0.000000
25)	0.000000	0.000000
26)	0.000000	1.000000
27)	0.000000	-16.000000
28)	0.000000	-17.000000
29)	0.000000	-18.000000
30)	0.000000	-16.000000
31)	0.000000	-18.000000
32)	0.000000	-21.000000
33)	0.000000	-15.000000
34)	0.000000	-11.000000
35)	0.000000	-8.000000
36)	0.000000	-9.000000

NO. ITERATIONS= 13

QUESTION 4A

Lindo Input:

```
min 21t + 16l + 40s + 41c + 585ss + 120 st + 164ch + 884o
ST
    t >= 0
    l >= 0
    s >= 0
    c >= 0
    ss >= 0
    st >= 0
    ch >= 0
    o >= 0
    .85t + 1.62l + 2.86s + 0.93c + 23.4ss + 16st + 9ch >= 15
    .33t + .2l + .39s + .24c + 48.7ss + 5st + 2.6ch + 100o >=
2
    .33t + .2l + .39s + .24c + 48.7ss + 5st + 2.6ch + 100o <=
```

```
8
    4.64t + 2.37l + 3.63s + 9.58c + 15ss + 3st + 27ch >= 4
    9t + 28l + 65s + 69c + 3.8ss + 120st + 78 ch <= 200
    .4l + .4s + .4t + .4c + .4ss + .4st + .4ch + .4o - l - s
<= 0
END
```

Lindo Output:

```
 LP OPTIMUM FOUND AT STEP     12

        OBJECTIVE FUNCTION VALUE

        1)      114.7541

  VARIABLE        VALUE          REDUCED COST
         T         0.000000         16.901640
         L         0.585480          0.000000
         S         0.000000         14.513662
         C         0.000000         36.289616
        SS         0.000000        408.387970
        ST         0.878220          0.000000
        CH         0.000000         97.551910
         O         0.000000        886.404358


       ROW   SLACK OR SURPLUS     DUAL PRICES
        2)         0.000000          0.000000
        3)         0.585480          0.000000
        4)         0.000000          0.000000
        5)         0.000000          0.000000
        6)         0.000000          0.000000
        7)         0.878220          0.000000
        8)         0.000000          0.000000
        9)         0.000000          0.000000
       10)         0.000000         -7.650273
       11)         2.508197          0.000000
       12)         3.491803          0.000000
       13)         0.022248          0.000000
       14)        78.220139          0.000000
       15)         0.000000          6.010929

 NO. ITERATIONS=      12
```

QUESTION 4B

Lindo Input:

```
min t + .75l + .5s + .5c + .45ss + 2.15st + 0.95ch + 2o
ST
    t >= 0
    l >= 0
    s >= 0
    c >= 0
```

```
    ss >= 0
    st >= 0
    ch >= 0
    o >= 0
    .85t + 1.62l + 2.86s + 0.93c + 23.4ss + 16st + 9ch >= 15
    .33t + .2l + .39s + .24c + 48.7ss + 5st + 2.6ch + 100o >=
2
    .33t + .2l + .39s + .24c + 48.7ss + 5st + 2.6ch + 100o <=
8
    4.64t + 2.37l + 3.63s + 9.58c + 15ss + 3st + 27ch >= 4
    9t + 28l + 65s + 69c + 3.8ss + 120st + 78 ch <= 200
    .4l + .4s + .4t + .4c + .4ss + .4st + .4ch + .4o - l - s
<= 0
END
```

Lindo Output:

```
 LP OPTIMUM FOUND AT STEP      3

        OBJECTIVE FUNCTION VALUE

        1)      1.554133

  VARIABLE        VALUE          REDUCED COST
         T         0.000000          1.002081
         L         0.000000          0.402912
         S         0.832298          0.000000
         C         0.000000          0.486914
        SS         0.096083          0.000000
        ST         0.000000          0.405609
        CH         1.152364          0.000000
         O         0.000000          7.281258


       ROW   SLACK OR SURPLUS     DUAL PRICES
        2)         0.000000          0.000000
        3)         0.000000          0.000000
        4)         0.832298          0.000000
        5)         0.000000          0.000000
        6)         0.096083          0.000000
        7)         0.000000          0.000000
        8)         1.152364          0.000000
        9)         0.000000          0.000000
       10)         0.000000         -0.131261
       11)         6.000000          0.000000
       12)         0.000000          0.051847
       13)        31.576324          0.000000
       14)        55.651089          0.000000
       15)         0.000000          0.241358

 NO. ITERATIONS=       3
```