Crafting S.L. market expansion

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Math 132A

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Description of the problem

The company Crafting S.L located in California produces cloth, yarn, and crafting materials. So far they have only sold their products in the state but now they have decided to start selling their goods to other states. Since sales in California have not been very good lately, the goal of the company is maximizing their weekly profit from sales to other states and not sell in California anymore. The profit is computed as the difference between the revenue from sales and the cost of materials. The marketing office has done some research and got to the conclusion that they could sell all that they produce at 30 per meter of cloth, 9 per skein of yarn, and 25 per pound of crafting materials. In order to produce one meter of cloth, it is necessary to use 1 skein of yarn, 0.1 pounds of crafting materials and 200 yards of sewing thread (the company buys thread at 0.5 per 100 yards). Other necessary materials and expenses, such as machinery, cost about 4 per meter of cloth. In addition, it takes 30 min. of labor to produce 1 meter of cloth. The company can produce a maximum of 5, 500 meters of cloth per week. In order to produce 1 skein of yarn, the company uses 100 yards of sewing thread, 0.05 pounds of crafting materials, as well as, 5 min. of labor. Additionally, the cost of the necessary machinery is about 2.5 per skein of yarn. The company can produce a maximum of 3, 000 skeins of yarn per week. To produce one pound of crafting materials, the company uses 50 min. of labor and the cost of the machinery used is 1.5 per pound. Additionally, they use 0.75 skeins of yarn and 0.12 meters of cloth. The maximum amount of crafting materials that the company can produce is 500 pounds per week. The company has a maximum of 2000 hrs of labor available each week. And since it does not have a warehouse, everything that is produced needs to be sold or used to produce other goods. The company has credit to buy thread and simple crafting materials every week. But the company cannot buy more than 1000 pounds of simple crafting materials per week and loses 2 per pound in this transaction (due to the payment of interests to the bank). Notice that the company does not make any profit in the sale of these units of crafting materials since it has to return the sales money to the bank.

1 Modeling the problem

1.1 LP Model

According to the problem description, we have the following model. Define:

$$
\begin{aligned}
x_1 &= \text{meters of cloth produced} \\
x_2 &= \text{skeins of yarn produced} \\
x_3 &= \text{pounds of craft material produced} \\
y_1 &= \text{meters of cloth for sell} \\
y_2 &= \text{skeins of yarn for sell} \\
y_3 &= \text{pounds of craft material for sell} \\
\text{z} &= \text{pounds of craft material purchased}
\end{aligned}
$$

	Cloth	Yarn	CM	CM for purchase	Max
Profit per unit	\$30	\$9	\$25	\$0	-
Cost Cloth	-	-	0.12	-	-
Cost Yarn	1	-	0.75	-	-
Cost CM	0.1	-	-	-	-
Cost Thread(Yard/\$)	200/-\$1	100/-\$0.5	-	-	-
Cost per unit	-	-	-	-\$2	-
Machinary	-\$4	-\$2.5	-\$1.5	-	-
Labor Time (min)	-30	-5	-50	-	120000(200 hrs)
Max	5500	3000	500	1000	-

Then we get the model:

$$\max = 30y_1 + 9y_2 + 25y_3 - 5x_1 - 3x_2 - 1.5x_3 - 2z$$
$$\text{subject to:}$$
$$(\text{Cloth 1})\ x_1 \leq 5500$$
$$(\text{Yarn 1})\ x_2 \leq 3000$$
$$(\text{Craft Material 1})\ x_3 \leq 500$$
$$(\text{Purchased Craft})\ z \leq 1000$$
$$(\text{Labour})\ 30x_1 + 5x_2 + 50x_3 \leq 120000$$
$$(\text{Cloth 2})\ x_1 - y_1 - 0.12x_3 = 0$$
$$(\text{Yarn 2})\ x_2 - y_2 - x_1 - 0.75x_3 = 0$$
$$(\text{Craft Material 2})\ x_3 + z - y_3 - 0.1x_1 - 0.05x_2 = 0$$
$$x_1 - y_1 \geq 0$$
$$x_2 - y_2 \geq 0$$
$$x_3 - y_3 \geq 0$$
$$x_1, x_2, x_3, y_1, y_2, y_3, z \geq 0$$

To calculate the profit, we need to use the revenue subtract the cost. It's clear that the revenue is the sum of resources' price time resources' sold amount which is $30y_1 + 9y_2 + 25y_3$. The cost include the machinery costs of resources' produced amount ($4x_1 + 2.5x_2 + 1.5x_3$), cost on thread($x_1 + 0.5x_2$), and cost on simple craft material(2z). Hence the final formula is $30y_1 + 9y_2 + 25y_3 - 5x_1 - 3x_2 - 1.5x_3 - 2z$.
The first four constraints are easy to understand, they follow the maximum production of resources and available purchasing of craft materials. The total labour hours equal to the sum of time producing cloth, yarns, and craft materials. Since there's no warehouse and everything need to be sold and be used for production, nothing could be left at the end. Hence, the produced resource should be equal to the amount sold or used.
Then we get: *Total resource - sold resources - used resource = 0*
The total resources equal to the sum of purchased ones and produced ones. Finally, we get: *Purchased resource + Produced resource - sold resources - used resource = 0*
Take **Cloth 2** constraint as an example, x_1 is produced cloth, y_1 is sold cloth, and $0.12x_3$ is cloth used in craft materials production. Since there's no purchased cloth, the final formula is $x_1 - y_1 - 0.12x_3 = 0$. The three constraints above the negative constraint is to restrict the amount of sold resources can not be greater than the amount produced. After all, we can't do magic.

1.2 Assumption

- **Proportionality** The total profit is proportional to the amount of cloth, yarn and crafting material. The decision variable in every equation appears with a constant coefficient. Therefore the proportionality assumption has been satisfied for this problem.
- **Additivity** There is no interaction among any decision variables. Each variables is added together instead of multiplied or divide by together. Hence, the additivity assumption has been satisfied for this problem.
- **Divisibility** All decision variable can take on fractional values, therefore the divisibility assumption cannot be satisfied for this problem.
- **Certainty** The certainty assumption cannot be met for this problem since there is a lot of uncertainty in real-world applications, such as an unanticipated labor strike and supply chain problems.

2 Solution and Discussion of Different Scenarios

2.1 Solution of the Original Model

The solution report from Lingo indicate that Crafting S.L could obtain maximum profit of 65750 dollar while producing 2625 meters of cloth, 3000 skeins of yarn, and 500 pounds of craft material. 2565 meters of produced cloth and 500 pounds of produced craft material should be sold to other states. Also, Crafting S.L have to purchase 412.5 craft material.

2.2 Noticed Demand and Price of Yarn

There will not be a change in profit from the sales to other states if the revenue form the yarn increased by 1 dollar because the sensitive shows the allowed increase of yarn without changing the optimal mix is 15.8 dollar. This means unless the revenue of yarn is more than 24.8 dollar, selling yarn won't be attractive. However, it's way more higher than the average sale price of a skein of good quality yarn which is 10 dollar. Hence, 15.8 dollar increment isn't realistic.

2.3 Sell 100 Skeins of Yarn

The shadow price for Yarn 2 constrains is -22.5 dollar. Since 100 skeins of yarn is sold to the good client so the loss is $100 \times -24.8 = -2480$. As we mentioned previously, yarn will be sold only if its revenue is greater than 24.8 dollar. Hence, increase the sale price to 11.5 dollar won't make any additional profit. Hence, the weekly profit will decrease 2480 dollar.

2.4 Resources

The resources should be labour because there are 1250 unused labour hour wasted.

2.5 New Activity: Cloth Bags

The Reduced Cost Coefficient of cloth bag is $15 * 0 + 0.3 * 0 + 0.01 * 1.3 = 0.013$ dollar. Hence, price of cloth bag should be at least 0.013 dollar.

2.6 Expanding Production capacity

If we increase the production of cloth by 50 meters per week, the profit won't increase because the with the current resources, only 2625 meters cloth can be produced. Hence, increase the production won't make a difference in the profit. If we increase the production of yarn by 30 skeins, we increase the profit by $30 \times 21.7 = 651$ dollar. Similarly, using shadow price, increasing production of craft material by 40 pounds result in $40 \times 1.3 = 52$ dollar increment in profit. It's clear that expand the production of yarn is most profitable.

2.7 Changing the price of thread

If the price of thread used to produce cloth has increased by 0.4 dollar, then the current price for 100 yards of thread would be 0.9 dollar. The objective function will be change to

$$\max = 30y_1 + 9y_2 + 25y_3 - 5.8x_1 - 3.4x_2 - 1.5x_3 - 2z$$

Here, the coefficient of X1 is changed from 5 to 5.8 and the coefficient of x2 is changed from 3 to 3.4. According to the sensitivity report, the allowable increase for X1 is 1.733 and the allowable increase for X2 is infinity. Since X1 and X2 do not exceed the allowable increase, the optimal mix won't change.Hence, the company doesn't need to reconsider the amount it produces for sale to maximize the profit.

2.8 Renting Warehouse

In prevention of scarcity of some materials due to the problems with the chain supply, the CEO of Crafting S.L. is considering renting the warehouse and stockpiling 500 skeins of yarn. The original constrain $x_2 - y_2 - x_1 - 0.75x_3 = 0$ will be changed to $x_2 - y_2 - x_1 - 0.75x_3 - 500 = 0$. There will be an extra 300 dollar cost if we rent the warehouse. The objective function will be:

$$\max = 30y_1 + 9y_2 + 25y_3 - 5x_1 - 3x_2 - 1.5x_3 - 2z - 300$$

The weekly profit in this scenario would be 53050 dollars. Therefore, it wouldn't be profitable to rent a warehouse.

2.9 Considering existing inventories

We need to manipulate the Cloth_2, Yarn_2, and Craft_Material_2 constrains. We add the existing inventories at the start to the left and add the desired inventories at the end to the right hand side of constraint. For example, if the existing inventories of yarn is 200 skeins at start and the desired inventories is 300 skeins at the end, we turn the constraint:

$$x_2 - y_2 - x_1 - 0.75x_3 = 0$$

into

$$200 + x_2 - y_2 - x_1 - 0.75x_3 = 300$$

$$\rightarrow x_2 - y_2 - x_1 - 0.75x_3 = 100$$

We manipulate the constraint in this way because the total resource = existing inventories + produced resource. The remained resource = total resource - sold resource - resourced used for other production.

2.10 Strike

1. **Best Case Scenario: Reducing available hours by 500 minutes.**
   In this scenario, the available hours is reduced by 500 minutes due to the strike. There will be a 500 decrease on the right hand side of the labour time constraint. According to the solution report, there are 1250 minutes unused labor time which results in the dual price of labour is 0 within the allowable decrease of 1250 minutes. Therefore, by estimation, reducing 500 minutes won't change the optimal mix and the total profit.

2. **Worst Case Scenario: Reducing available hours by 1300 minutes.**
   In this scenario, the available hours is reduced by 1300 minutes due to the strike. There will be a 1300 decrease on the right hand side of the labour time constraint. Hence, the labour constraint $30x_1 + 5x_2 + 50x_3 \leq 120000$ will be change to $30x_1 + 5x_2 + 50x_3 \leq 118700$. Since 1300 minutes exceed the allowable decrease of 1250 minutes, then the optimal mix will change and the basis will be relocated. We need to recalculate to get the optimal solution. According to the new solution report, the maximum profit is 65747.64 dollars when producing 2626.364 meters of cloth, 3000 skeins of yarns, 498.182 pounds of craft materials, and selling 2566.82 meters cloth, 0 skein of yarn, and 498.182 pounds craft materials. Also, purchasing 412.636 pounds craft materials. To reach the maximum profit, the Company should put more labour resource on cloth production instead of craft materials.

2.11 Other Scenario

1. **Scenario 1: Reducing number of craft materials can be purchased.**
   Crafting S.L. buy craft material from company A. However, the strike results in reducing production of company A. The production of craft material reduced to half which is 500 pounds. According to the sensitivity report, the allowable decrease of purchased craft material constraint is 587 pounds. This means the company don't have the money and interest to purchase more than 412.5 pounds craft materials. Hence, the reduce of right hand side of constraint won't make any difference on optimal mix and maximum profit.

2. **Scenario 2: Constraint on thread purchasing.**
   A new policy comes out which restrict the thread each company could purchase. Crafting S.L. can't buy more than 500000 yards thread. Since there is no constraint on thread before, we need to add a new constraint : $200x_1 + 100x_2 \leq 500000$. Then we calculate the LP problem again, the total profit decreased to 42241.67 dollars. 1541.7 meters cloth, 1916.7 skeins yarn, and 500 pounds of craft materials should be produced. Among them, 1481.7 meters cloth and 500 pounds of craft material should be sold.

Additionally, 250 pounds of craft material should be purchased. We can see that the company can't produce the yarn equal to the constraint which 3000 skeins so that the basis of this LP problem changes.

3 Recommendations

Summarizing the above scenarios, we observe 1250 hours of unused labor, so the company should consider downsizing the workforce. On the other hand, producing yarn will not make a profit if its price is less than 24.8 dollars. The company should either increase the price of yarn or consider producing a new product that is more economically profitable. If the company is able to expand production capacity, then increasing the production of yarn would be the most profitable choice. Minor change in the thread price or renting a warehouse to stockpile yarn doesn't have much impact on total profit.

When it comes to labor strikes, the company should be cautious if the available labor time is reduced by more than 1250 minutes. If the company is impacted by a massive labor strike, they should produce more cloth to mitigate the profit loss cause by labor strike. If there is a supply chain issue, such as reducing the craft materials they can purchase, the maximum profit will decrease if the purchase craft material are less than 413 pounds. Therefore, the company should be vigilant for potential labor strikes and supply chain issues as these factors may have a negative impact on the total profit.

A Computer Reports

A.1 Original model

solution report

```
Global optimal solution found.
  Objective value:                              65750.00
  Infeasibilities:                              0.000000
  Total solver iterations:                             3
  Elapsed runtime seconds:                          0.03

  Model Class:                                        LP

  Total variables:                     7
  Nonlinear variables:                 0
  Integer variables:                   0

  Total constraints:                  19
  Nonlinear constraints:               0

  Total nonzeros:                     39
  Nonlinear nonzeros:                  0
```

Variable	Value	Reduced Cost
Y_1	2565.000	0.000000
Y_2	0.000000	15.80000
Y_3	500.0000	0.000000
X_1	2625.000	0.000000
X_2	3000.000	0.000000
X_3	500.0000	0.000000
Z	412.5000	0.000000

Row	Slack or Surplus	Dual Price
1	65750.00	1.000000
2	2875.000	0.000000
3	0.000000	21.70000
4	0.000000	1.300000
5	587.5000	0.000000
6	1250.000	0.000000
7	0.000000	-30.00000
8	0.000000	-24.80000
9	0.000000	-2.000000
10	60.00000	0.000000
11	3000.000	0.000000
12	0.000000	-23.00000
13	2625.000	0.000000
14	3000.000	0.000000
15	500.0000	0.000000
16	2565.000	0.000000
17	0.000000	0.000000
18	500.0000	0.000000
19	412.5000	0.000000

Range Report

Ranges in which the basis is unchanged:

Objective Coefficient Ranges:

Variable	Current Coefficient	Allowable Increase	Allowable Decrease
Y_1	30.00000	1.494253	15.80000
Y_2	9.000000	15.80000	INFINITY
Y_3	25.00000	INFINITY	1.300000
X_1	-5.000000	1.733333	15.80000
X_2	-3.000000	INFINITY	21.70000
X_3	-1.500000	INFINITY	1.300000

Z	-2.000000	17.33333	23.00000

Righthand Side Ranges:

Row	Current RHS	Allowable Increase	Allowable Decrease
2	5500.000	INFINITY	2875.000
3	3000.000	35.71429	2565.000
4	500.0000	45.45455	500.0000
5	1000.000	INFINITY	587.5000
6	120000.0	INFINITY	1250.000
7	0.000000	2565.000	60.00000
8	0.000000	2565.000	41.66667
9	0.000000	587.5000	412.5000
10	0.000000	60.00000	INFINITY
11	0.000000	3000.000	INFINITY
12	0.000000	412.5000	587.5000
13	0.000000	2625.000	INFINITY
14	0.000000	3000.000	INFINITY
15	0.000000	500.0000	INFINITY
16	0.000000	2565.000	INFINITY
17	0.000000	0.000000	INFINITY
18	0.000000	500.0000	INFINITY
19	0.000000	412.5000	INFINITY

A.2 Changing the price of thread

Solution Report

```
   Global optimal solution found.
 Objective value:                              62450.00
 Infeasibilities:                              0.000000
 Total solver iterations:                             3
 Elapsed runtime seconds:                          0.04

 Model Class:                                        LP

 Total variables:                  7
 Nonlinear variables:              0
 Integer variables:                0

 Total constraints:               19
 Nonlinear constraints:            0

 Total nonzeros:                  39
 Nonlinear nonzeros:               0
```

Variable	Value	Reduced Cost
Y_1	2565.000	0.000000
Y_2	0.000000	15.00000
Y_3	500.0000	0.000000
X_1	2625.000	0.000000
X_2	3000.000	0.000000
X_3	500.0000	0.000000
Z	412.5000	0.000000

Row	Slack or Surplus	Dual Price
1	62450.00	1.000000
2	2875.000	0.000000
3	0.000000	20.50000
4	0.000000	1.900000
5	587.5000	0.000000
6	1250.000	0.000000
7	0.000000	-30.00000
8	0.000000	-24.00000
9	0.000000	-2.000000
10	60.00000	0.000000
11	3000.000	0.000000
12	0.000000	-23.00000
13	2625.000	0.000000
14	3000.000	0.000000
15	500.0000	0.000000
16	2565.000	0.000000
17	0.000000	0.000000
18	500.0000	0.000000
19	412.5000	0.000000

Range Report

Ranges in which the basis is unchanged:

Objective Coefficient Ranges:

Variable	Current Coefficient	Allowable Increase	Allowable Decrease
Y_1	30.00000	2.183908	15.00000
Y_2	9.000000	15.00000	INFINITY
Y_3	25.00000	INFINITY	1.900000
X_1	-5.800000	2.533333	15.00000
X_2	-3.400000	INFINITY	20.50000

X_3	-1.500000	INFINITY	1.900000
Z	-2.000000	25.33333	23.00000

Righthand Side Ranges:

Row	Current RHS	Allowable Increase	Allowable Decrease
2	5500.000	INFINITY	2875.000
3	3000.000	35.71429	2565.000
4	500.0000	45.45455	500.0000
5	1000.000	INFINITY	587.5000
6	120000.0	INFINITY	1250.000
7	0.000000	2565.000	60.00000
8	0.000000	2565.000	41.66667
9	0.000000	587.5000	412.5000
10	0.000000	60.00000	INFINITY
11	0.000000	3000.000	INFINITY
12	0.000000	412.5000	587.5000
13	0.000000	2625.000	INFINITY
14	0.000000	3000.000	INFINITY
15	0.000000	500.0000	INFINITY
16	0.000000	2565.000	INFINITY
17	0.000000	0.000000	INFINITY
18	0.000000	500.0000	INFINITY
19	0.000000	412.5000	INFINITY

A.3 Renting Warehouse

Solution Report

```
 Global optimal solution found.
  Objective value:                              53050.00
  Infeasibilities:                              0.000000
  Total solver iterations:                             3
  Elapsed runtime seconds:                          0.21

  Model Class:                                        LP

  Total variables:                  7
  Nonlinear variables:              0
  Integer variables:                0

  Total constraints:               19
  Nonlinear constraints:            0
```

```
Total nonzeros:                  39
Nonlinear nonzeros:               0
```

Variable	Value	Reduced Cost
Y_1	2065.000	0.000000
Y_2	0.000000	15.80000
Y_3	500.0000	0.000000
X_1	2125.000	0.000000
X_2	3000.000	0.000000
X_3	500.0000	0.000000
Z	362.5000	0.000000

Row	Slack or Surplus	Dual Price
1	53050.00	1.000000
2	3375.000	0.000000
3	0.000000	21.70000
4	0.000000	1.300000
5	637.5000	0.000000
6	16250.00	0.000000
7	0.000000	-30.00000
8	0.000000	-24.80000
9	0.000000	-2.000000
10	60.00000	0.000000
11	3000.000	0.000000
12	0.000000	-23.00000
13	2125.000	0.000000
14	3000.000	0.000000
15	500.0000	0.000000
16	2065.000	0.000000
17	0.000000	0.000000
18	500.0000	0.000000
19	362.5000	0.000000

Range Report

Ranges in which the basis is unchanged:

Objective Coefficient Ranges:

Variable	Current Coefficient	Allowable Increase	Allowable Decrease
Y_1	30.00000	1.494253	15.80000
Y_2	9.000000	15.80000	INFINITY

Y_3	25.00000	INFINITY	1.300000
X_1	-5.000000	1.733333	15.80000
X_2	-3.000000	INFINITY	21.70000
X_3	-1.500000	INFINITY	1.300000
Z	-2.000000	17.33333	23.00000

Righthand Side Ranges:

Row	Current RHS	Allowable Increase	Allowable Decrease
2	5500.000	INFINITY	3375.000
3	3000.000	464.2857	2065.000
4	500.0000	590.9091	500.0000
5	1000.000	INFINITY	637.5000
6	120000.0	INFINITY	16250.00
7	0.000000	2065.000	60.00000
8	500.0000	2065.000	541.6667
9	0.000000	637.5000	362.5000
10	0.000000	60.00000	INFINITY
11	0.000000	3000.000	INFINITY
12	0.000000	362.5000	637.5000
13	0.000000	2125.000	INFINITY
14	0.000000	3000.000	INFINITY
15	0.000000	500.0000	INFINITY
16	0.000000	2065.000	INFINITY
17	0.000000	0.000000	INFINITY
18	0.000000	500.0000	INFINITY
19	0.000000	362.5000	INFINITY

A.4 Strike - Best Scenario

Solution Report

```
 Global optimal solution found.
  Objective value:                              65750.00
  Infeasibilities:                              0.000000
  Total solver iterations:                             3
  Elapsed runtime seconds:                          0.03

  Model Class:                                        LP

  Total variables:                      7
  Nonlinear variables:                  0
  Integer variables:                    0

  Total constraints:                   19
```

```
Nonlinear constraints:              0

Total nonzeros:                    39
Nonlinear nonzeros:                 0
```

Variable	Value	Reduced Cost
Y_1	2565.000	0.000000
Y_2	0.000000	15.80000
Y_3	500.0000	0.000000
X_1	2625.000	0.000000
X_2	3000.000	0.000000
X_3	500.0000	0.000000
Z	412.5000	0.000000

Row	Slack or Surplus	Dual Price
1	65750.00	1.000000
2	2875.000	0.000000
3	0.000000	21.70000
4	0.000000	1.300000
5	587.5000	0.000000
6	750.0000	0.000000
7	0.000000	-30.00000
8	0.000000	-24.80000
9	0.000000	-2.000000
10	60.00000	0.000000
11	3000.000	0.000000
12	0.000000	-23.00000
13	2625.000	0.000000
14	3000.000	0.000000
15	500.0000	0.000000
16	2565.000	0.000000
17	0.000000	0.000000
18	500.0000	0.000000
19	412.5000	0.000000

Range Report

Ranges in which the basis is unchanged:

Objective Coefficient Ranges:

Variable	Current Coefficient	Allowable Increase	Allowable Decrease
Y_1	30.00000	1.494253	15.80000
Y_2	9.000000	15.80000	INFINITY

```
            Y_3        25.00000        INFINITY        1.300000
            X_1       -5.000000        1.733333        15.80000
            X_2       -3.000000        INFINITY        21.70000
            X_3       -1.500000        INFINITY        1.300000
              Z       -2.000000        17.33333        23.00000

                             Righthand Side Ranges:

                        Current       Allowable       Allowable
            Row             RHS        Increase        Decrease
              2        5500.000        INFINITY        2875.000
              3        3000.000        21.42857        2565.000
              4        500.0000        27.27273        500.0000
              5        1000.000        INFINITY        587.5000
              6        119500.0        INFINITY        750.0000
              7        0.000000        2565.000        60.00000
              8        0.000000        2565.000        25.00000
              9        0.000000        587.5000        412.5000
             10        0.000000        60.00000        INFINITY
             11        0.000000        3000.000        INFINITY
             12        0.000000        412.5000        587.5000
             13        0.000000        2625.000        INFINITY
             14        0.000000        3000.000        INFINITY
             15        0.000000        500.0000        INFINITY
             16        0.000000        2565.000        INFINITY
             17        0.000000        0.000000        INFINITY
             18        0.000000        500.0000        INFINITY
             19        0.000000        412.5000        INFINITY
```

A.5 Strike - Worst Scenario

Solution Report

```
Global optimal solution found.
  Objective value:                              65747.64
  Infeasibilities:                              0.000000
  Total solver iterations:                             4
  Elapsed runtime seconds:                          0.05

  Model Class:                                        LP

  Total variables:                      7
  Nonlinear variables:                  0
  Integer variables:                    0
```

```
Total constraints:           19
Nonlinear constraints:        0

Total nonzeros:              39
Nonlinear nonzeros:           0
```

Variable	Value	Reduced Cost
Y_1	2566.582	0.000000
Y_2	0.000000	14.38182
Y_3	498.1818	0.000000
X_1	2626.364	0.000000
X_2	3000.000	0.000000
X_3	498.1818	0.000000
Z	412.6364	0.000000

Row	Slack or Surplus	Dual Price
1	65747.64	1.000000
2	2873.636	0.000000
3	0.000000	20.04545
4	1.818182	0.000000
5	587.3636	0.000000
6	0.000000	0.4727273E-01
7	0.000000	-30.00000
8	0.000000	-23.38182
9	0.000000	-2.000000
10	59.78182	0.000000
11	3000.000	0.000000
12	0.000000	-23.00000
13	2626.364	0.000000
14	3000.000	0.000000
15	498.1818	0.000000
16	2566.582	0.000000
17	0.000000	0.000000
18	498.1818	0.000000
19	412.6364	0.000000

Range Report

```
Ranges in which the basis is unchanged:

                                       Objective Coefficient Ranges:
```

Variable	Current Coefficient	Allowable Increase	Allowable Decrease
Y_1	30.00000	1.494253	7.378731
Y_2	9.000000	14.38182	INFINITY
Y_3	25.00000	13.18333	1.300000
X_1	-5.000000	1.733333	7.910000
X_2	-3.000000	INFINITY	20.04545
X_3	-1.500000	13.18333	1.300000
Z	-2.000000	17.33333	23.00000

Righthand Side Ranges:

Row	Current RHS	Allowable Increase	Allowable Decrease
2	5500.000	INFINITY	2873.636
3	3000.000	391.4286	1.428571
4	500.0000	INFINITY	1.818182
5	1000.000	INFINITY	587.3636
6	118700.0	50.00000	13700.00
7	0.000000	2566.582	59.78182
8	0.000000	1.666667	456.6667
9	0.000000	587.3636	412.6364
10	0.000000	59.78182	INFINITY
11	0.000000	3000.000	INFINITY
12	0.000000	412.6364	587.3636
13	0.000000	2626.364	INFINITY
14	0.000000	3000.000	INFINITY
15	0.000000	498.1818	INFINITY
16	0.000000	2566.582	INFINITY
17	0.000000	0.000000	INFINITY
18	0.000000	498.1818	INFINITY
19	0.000000	412.6364	INFINITY

A.6 Reduce purchased Craft Materials

Solution Report

```
Global optimal solution found.
  Objective value:                              65750.00
  Infeasibilities:                              0.000000
  Total solver iterations:                             3
  Elapsed runtime seconds:                          0.03

  Model Class:                                        LP

  Total variables:                      7
```

```
Nonlinear variables:            0
Integer variables:              0

Total constraints:             19
Nonlinear constraints:          0

Total nonzeros:                39
Nonlinear nonzeros:             0
```

Variable	Value	Reduced Cost
Y_1	2565.000	0.000000
Y_2	0.000000	15.80000
Y_3	500.0000	0.000000
X_1	2625.000	0.000000
X_2	3000.000	0.000000
X_3	500.0000	0.000000
Z	412.5000	0.000000

Row	Slack or Surplus	Dual Price
1	65750.00	1.000000
2	2875.000	0.000000
3	0.000000	21.70000
4	0.000000	1.300000
5	87.50000	0.000000
6	1250.000	0.000000
7	0.000000	-30.00000
8	0.000000	-24.80000
9	0.000000	-2.000000
10	60.00000	0.000000
11	3000.000	0.000000
12	0.000000	-23.00000
13	2625.000	0.000000
14	3000.000	0.000000
15	500.0000	0.000000
16	2565.000	0.000000
17	0.000000	0.000000
18	500.0000	0.000000
19	412.5000	0.000000

Range Report

Ranges in which the basis is unchanged:

Objective Coefficient Ranges:

Variable	Current Coefficient	Allowable Increase	Allowable Decrease
Y_1	30.00000	1.494253	15.80000
Y_2	9.000000	15.80000	INFINITY
Y_3	25.00000	INFINITY	1.300000
X_1	-5.000000	1.733333	15.80000
X_2	-3.000000	INFINITY	21.70000
X_3	-1.500000	INFINITY	1.300000
Z	-2.000000	17.33333	23.00000

Righthand Side Ranges:

Row	Current RHS	Allowable Increase	Allowable Decrease
2	5500.000	INFINITY	2875.000
3	3000.000	35.71429	2565.000
4	500.0000	45.45455	500.0000
5	500.0000	INFINITY	87.50000
6	120000.0	INFINITY	1250.000
7	0.000000	2565.000	60.00000
8	0.000000	2565.000	41.66667
9	0.000000	87.50000	412.5000
10	0.000000	60.00000	INFINITY
11	0.000000	3000.000	INFINITY
12	0.000000	412.5000	87.50000
13	0.000000	2625.000	INFINITY
14	0.000000	3000.000	INFINITY
15	0.000000	500.0000	INFINITY
16	0.000000	2565.000	INFINITY
17	0.000000	0.000000	INFINITY
18	0.000000	500.0000	INFINITY
19	0.000000	412.5000	INFINITY

A.7 Constraint on thread purchasing

Solution Report

```
Global optimal solution found.
  Objective value:                              42241.67
  Infeasibilities:                              0.000000
  Total solver iterations:                             7
  Elapsed runtime seconds:                          0.03
```

```
Model Class:                                    LP

Total variables:                     7
Nonlinear variables:                 0
Integer variables:                   0

Total constraints:                  20
Nonlinear constraints:               0

Total nonzeros:                     41
Nonlinear nonzeros:                  0



                          Variable           Value        Reduced Cost
                               Y_1        1481.667            0.000000
                               Y_2        0.000000            1.333333
                               Y_3        500.0000            0.000000
                               X_1        1541.667            0.000000
                               X_2        1916.667            0.000000
                               X_3        500.0000            0.000000
                                 Z        250.0000            0.000000

                               Row    Slack or Surplus      Dual Price
                                 1        42241.67            1.000000
                                 2        3958.333            0.000000
                                 3        1083.333            0.000000
                                 4        0.000000            12.15000
                                 5        750.0000            0.000000
                                 6        0.000000           0.7233333E-01
                                 7        39166.67            0.000000
                                 8        0.000000           -30.00000
                                 9        0.000000           -10.33333
                                10        0.000000           -2.000000
                                11        60.00000            0.000000
                                12        1916.667            0.000000
                                13        0.000000           -23.00000
                                14        1541.667            0.000000
                                15        1916.667            0.000000
                                16        500.0000            0.000000
                                17        1481.667            0.000000
                                18        0.000000            0.000000
                                19        500.0000            0.000000
                                20        250.0000            0.000000
```

Range Report

Ranges in which the basis is unchanged:

Objective Coefficient Ranges:

Variable	Current Coefficient	Allowable Increase	Allowable Decrease
Y_1	30.00000	32.83784	4.000000
Y_2	9.000000	1.333333	INFINITY
Y_3	25.00000	INFINITY	12.15000
X_1	-5.000000	48.60000	4.000000
X_2	-3.000000	2.000000	21.70000
X_3	-1.500000	INFINITY	12.15000
Z	-2.000000	INFINITY	23.00000

Righthand Side Ranges:

Row	Current RHS	Allowable Increase	Allowable Decrease
2	5500.000	INFINITY	3958.333
3	3000.000	INFINITY	1083.333
4	500.0000	870.3704	500.0000
5	1000.000	INFINITY	750.0000
6	500000.0	325000.0	444500.0
7	120000.0	INFINITY	39166.67
8	0.000000	1481.667	60.00000
9	0.000000	1625.000	2875.000
10	0.000000	750.0000	250.0000
11	0.000000	60.00000	INFINITY
12	0.000000	1916.667	INFINITY
13	0.000000	250.0000	750.0000
14	0.000000	1541.667	INFINITY
15	0.000000	1916.667	INFINITY
16	0.000000	500.0000	INFINITY
17	0.000000	1481.667	INFINITY
18	0.000000	0.000000	INFINITY
19	0.000000	500.0000	INFINITY
20	0.000000	250.0000	INFINITY