ETM

ENGINEERING & TECHNOLOGY MANAGEMENT

Title: Minimum Cost Shop Loading in an Investment Casting Plant

Course:

Year: 1988

Author(s): G. Maffett, T. Lee and C. Hood

Report No: P88001

ETM OFFICE USE ONLY	
Report No.:	See Above
Type:	Student Project
Note:	This project is in the filing cabinet in the ETM department office.

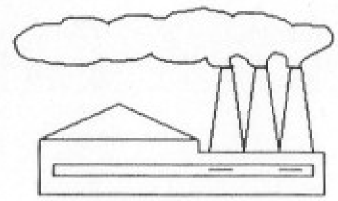
Abstract: A linear programming model was developed to identify the optimum shop loading option and the minimum aggregate manufacturing cost from three process alternatives in a metal casting company. The study stems from the needs expressed by the Marketing, Production Planning and Engineering Departments of the company, and is based on the market research which identified a growing need for a "CNC machining blank" for the medical prosthetic implant market.

MINIMUM COST SHOP LOADING IN AN INVESTMENT CASTING PLANT

G. Maffett, T. Lee, and C. Hood

EMP - P8801

EAS 543
Dr. Dundar Kocaoglu
Spring 1988



Minimum Cost Shop Loading in an Investment Casting Plant
Application of LINDO optimization to Engineering
Decision Making Process

Geoff Maffett
Teri Lee
Cliff Hood

Good work
(A)

Minimum Cost Shop Loading in an Investment Casting Plant,

Executive Summary

The following report stems from a need generated by the Marketing, Production Planning and Engineering Departments of Precision Castparts Corp. Market research identified a growing need for a CNC machining blank for the medical prosthetic implant market. This linear programming model identifies the best shop loading option and the aggregate cost to manufacture from three process options.

The product can be made by three different processes which have different labor requirements at each process step. Since the plant is highly constrained for capacity, the efficiency of a particular process at a more highly constrained operation will introduce it into the model despite a higher net cost. Results of the analysis revealed that the cost to manufacture increases with volume produced, an undesireable situation. Required production volumes can be achieved within the current process. The optimum solution which meets market demand is :

81 molds produced by Process A
11 molds produced by Process B
9 molds produced by Process C

The above mix yields a cost to manufacture of $59.51/piece. Marketing will have to assess the price the market will bear. Ballpark estimates of a $75 sales price suggest adequate profit margin.

Sensitivity analysis of the impact of volume changes upon process mix revealed that Process C predominates at low volume production. When furnace #2 capacity is maximized, we would begin to make process A product in addition to process C. Upon utilization of all overtime in wax assembly, Process B product is produced at the expense of process C product.

Engineering and Applied Science 543

Term Project

Minimum Cost Shop loading in an Investment Casting Plant

Geoff Maffett

Teri Lee

Cliff Hood

I. Description of the Problem

Precision Castparts manufactures aerospace and medical prosthetic investment castings. The problem at hand involves the medical products line. The product is a hip implant machining blank which the customer will use to CNC machine a variety of custom hip shapes. Marketing forecasts have shown that the demand for the product will be at least 3,000 pieces per month. PCC has a three distinct manufacturing options to produce this product. The model has been simplified to the two major process areas where capacity limitations actually impact the model. A significantly greater number of departmental costs and capacities were considered in the original program but analysis revealed that they were really not legitimate constraints. This model balances two major operations with overtime and capacity constraints to yield the best combination of three possible processes which minimizes total cost subject to a minimum market requirement.

II. Process Option A (Variable X1) Static Pour

Option A is called the static pour process. With this method, a wax assembly is produced which will yield 20 pieces for each mold cast. The assembly time per mold and the casting time per mold are identified as 3 hrs and .3 hours respectively. The manufacturing overhead rates for the departments are incorporated into a total cost per mold to manufacture without overtime. For Option A the total overhead cost is $1380 per mold. Advantages of this process include the low overhead rate for casting and low per piece assembly hour requirements. Disadvantages include the ineffecient gating ratio, which contributes significantly to a high per piece cost for this process.

III. Process Option B (Variable X2) Centrifugal Pour

Option B is the centrifugal casting option. This option yields more pieces per mold (48) at a higher per unit casting cost. The cost coefficient per mold produced is $2496. The furnace time per mold is 0.6 hrs. Since options B & C have to be produced in a different and more expensive casting furnace, the cost per unit time is significantly higher for furnace #2. The assembly time for option B is 5 hours per mold. This works out to a more favorable wax assembly time per piece of 0.1 hrs/pc versus 0.15 hrs/pc for the option A product. Therefore, from a wax assembly capacity standpoint, we can produce more product within the given capacity by using process B.

IV. Process Option C (Variable X3) High Volume Pour

Option C is the frame assembly process. This method utilizes an significantly higher pc/mold technique that gets more optimum use of the #2 casting furnace. However, it is more labor intensive in the wax operations where the rate is 0.2 hrs/pc. The casting rate is 0.8 hrs for the entire mold but when divided into the 96 pieces in the assembly, this realizes a more favorable casting rate than option B. The interplay of the two operations complicates the model sufficiently that it could not be easily solved by graphical means.

V. Development of the Objective Function

The objective function required running a cost analysis for all manufacturing operations based upon standards estimated from similar product lines. The initial estimate of cost was made from an assumption that there were absolutely no capacity constraints. This involved calculation of the hrs per piece per operation multiplied by the overhead rate for each department. There was no overtime included in the cost so we added variables to address the overtime cost. The objective function was based upon the following cost factors:

$1380	X1=	Cost per mold of Option A product
$2496	X2=	" " " " " B product
$4320	X3=	" " " " " C product
$ 8	X4=	Overtime cost per hour of assembly
$ 8	x5=	" " " " " investing
$ 24	x6=	Cost per Frame for Option C product

Note that there is no overtime in casting because it is loaded fully by machine hours and additional labor will not increase machine capability.

Given the above information, the objective function was ~~identified~~ developed as :

Minimize $1380\ X_1 + 2496\ X_2 + 4320\ X_3 + 8\ X_4 + 8\ X_5 + 24\ X_6$

VI. Identification Of Constraints

17 of the 19 operations contributing to the total cost to manufacture had sufficient capacity and were left unconstrained since they would not affect the LINDO output. These eliminated operations were left out of this discussion for conciseness. Several operations were not identified as "non-constraints" until the actual initial LINDO models were run. The remaining two operations were then constrained by available overtime and shop capacity.The primary constraints and the formulae expressing these limitations are:

A. Available Wax Assembly Hours without Overtime

The production planning department identified a sufficient labor inefficiency such that an additional 360 hours of labor could be absorbed without overtime. This is described in the model as:

$$3\ X_1 + 5\ X_2 + 20\ X_3 - X_4 <= 360$$

Where 3 X1= The number of hours per mold to assemble "A"
5 X2= The " " " " " "B"
20 X3= The " " " " " "C"
x4= The number of overtime hours used.

B. Investing Mold Handling Constraint

The investing department allocates manpower based upon the number of molds hand-dipped and the number of molds machine-dipped. This equation deals with the hand-dip capacity only. Since the operation is irrespective of the number of pieces per mold, the cost to invest is smaller for larger molds. Each mold gets ten (10) operations which account for 0.1 hrs/operation for a total processing time of 1 hour. Fortuitously, the molds and hours are interchangeable. This is the only operation where this assumption is true. The total available capacity on straight time is 100 molds. The formula for straight time capacity is:

$$X_1 + X_2 - X_5 <= 70$$

A similar equation exists for machine-dipped product. Since option C (X3) product is too heavy to dip by hand, the machine process is required. The machine dipping is constrained by the number of frames available for dipping, which is currently 50 . Since each assembly requires a machine attachment frame, the only way to increase capacity is to buy more frames. This yields:

$$X_3-X_6 <= 12$$

C. Overtime Constraints

Manufacturing management has established limits for the amount of overtime which does not result in a non-productive morale problems. The limits are established as :

Wax Assembly <= 120 hrs

Hand dip <= 60 hrs

Frame dip <= 24 frames

D. Casting Constraints

Available casting capacity on the #1 furnace is 34 hours. The equation relating the two is

$$0.3\ X_1 <= 34$$

Available casting capacity on the #2 furnace is only 14 hours. This is described as:

$$0.6\ X_2 + 0.8\ X_3 <= 14$$

Of the available furnace time, the amount available for centrifugal casting is limited to less than 10 hours. This is due to the turnaround time on the centrifuge table. The resultant equation is:

$$0.6\ X_2 >= 10$$

E. Market Demand Constraints

The Marketing department predicts that there will be a demand for at least 3,000 castings per month. The equation to meet the minimum requirements is:

$$20\ X_1 + 48\ X_2 + 96\ X_3 >= 3000$$

F. Whole Mold Constraint

A solution in which fractional amounts of molds were produced could not be implemented. The model is constrained to produce whole molds by using the number of molds of each process as the variable (rather than the number of pieces) and restricting these variables to be general intergers.

IX. Solution

LINDO Run #1 attached shows the optimum solution for the problem previously described. The total cost to produce 3000 parts per month is $179,236.00. The Process Option mix utilized to reach this optimum is:

Process Option A: 81 Molds (1620 pieces)

Process Option B: 11 Molds (528 pieces)

Process Option C: 9 Molds (864 pieces)

This combination yields a total of 3012 pieces at a cost of $59.51 each ($59.75 if only the 3000 could be sold).

X. Plant Capacity Limitations in Effect

A. Assembly

Regular time and overtime hours available are used completely. The dual price indicates that it if additional capacity could be obtained, it would be worth $145.25/hour.

B. Hand Dip Investing

All regular time capacity is used up, along with one third of the overtime capacity.

C. Frame Investing

Three quarters of the frames available are used. No additional frames are required.

D. Casting Constraints

Less than one third of the Furnace 1 hours available are being used. All of the Furnace 2 hours available were used. Additional capacity for Furnace 2 would be valued at $1911/hour.

XI. Sensitivity Analysis

Sensitivity analysis allows us to answer "what if?" questions. Beyond the values indicated above for additional plant capacity in specific areas, we will examine three further "what if" situations.

A. What if another product's order quantity was reduced and the number of Furnace 2 hours available was increased from 14 to 20 per month?

LINDO Run #2 (attached) for this altered problem yields the following solution:

The total cost to produce 3000 parts per month is

$169,852.00. The process option mix utilized to reach this optimum is:

Process Option A:	59 Molds	(1180 pieces)
Process Option B:	16 Molds	(768 pieces)
Process Option C:	11 Molds	(1056 pieces)

This combination yields a total of 3004 pieces at a cost of $56.54 each ($56.62 if only the 3000 could be sold).

B. What if the cost to produce Option C molds was underestimated by 10%?

LINDO Run #3 for this altered problem yields the following solution:
The total cost to produce 3000 parts per month is $189,922.00. The process option mix utilized to reach this optimum is:

Process Option A:	81 Molds	(1620 pieces)
Process Option B:	11 Molds	(528 pieces)
Process Option C:	9 Molds	(864 pieces)

This combination yields a total of 3012 pieces at a cost of $62.06 each ($62.31 if only the 3000 could be sold).

C. Demand variations. Our problem definition indicated that the demand would be at least 3,000 pieces per month. We need to know what our maximum current capacity is. We must quote prices competitively and we may not get the entire order. We therefore need to know how the production cost per part varies with the quantity produced. Answers to these questions (along with an in-depth understanding of the model) were obtained by:

a) Performing a parametric analysis on the right hand side of the demand equation, and then

b) Solving the model at the points where the basis variables change.

MAXIMUM CAPACITY

Parametric analysis shows that an artificial variable enters the solution when the demand is 3338.67 pieces per month. The maximum feasible production capacity is at the next smallest integer solution value, which is 3316 pieces per month at a cost of $63.41 per part.

MODEL ANALYSIS

Starting at 1000 pieces per month, parametric analysis (LINDO Run #4) shows that basis changes occur at eight different production levels (points labeled A through I on the graphs). Description of what happens in the model at each of these points as the number of pieces per month increases follows.

Note that parametric analysis was done without the general integer restrictions on X1, X2, and X3 so that more information could be obtained through the LINDO software. Results with the restrictions would vary slightly, but the behavior of the model is the same.

POINT A) 1000 pieces per month (LINDO Run #5).

This is the minimum value considered. Only Process Option C is utilized, and no plant capacity restrictions are in effect. Cost per part is $45.

POINT B) 1153 pieces per month (LINDO Run #6).

Frames for investing are all being used. Cost for additional frames will be incurred after this point (indicated by the entry of the variable X6 into the basis, and the departure of the slack variable from equation 4).

POINT C) 1681 pieces per month (LINDO Run #7).

At this point Furnace 2 capacity is all used up. Additional product is made by Process Option A (enter variable X1, exit slack variable from row 9). Note that Process Option B parts cost less per part to manufacture than Option A parts. However, since Furnace 2 capacity is already consumed, using Process Option B would reduce the number of Process C parts that could be made, which are the least costly to manufacture.

POINT D) 1747 pieces per month (LINDO Run #8).

All wax assembly regular time is consumed, additional parts made will reflect overtime costs. (Exit slack variable from row 2, enter X4).

POINT E) 2547 pieces per month (LINDO Run #9).

All wax assembly overtime is being used. To increase monthly production beyond this point, Process Option B must be used, displacing some of the more desirable Process Option C parts. (Enter variable X2, exit slack variable, row 5).

POINT F) 2810 pieces per month (LINDO Run #10).

All regular time hand-dip investing time is utilized, increased production quantities will require overtime. (Exit row 3 slack variable, enter variable X5).

POINT G) 2860 pieces per month (LINDO Run #11).

As the number of Process A and Process B parts has increased, the number of Process C parts has dropped, due to the Furnace 2 capacity constraint. At this point additional investing frames are no longer required. (Exit variable X6, enter slack variable for row 4).

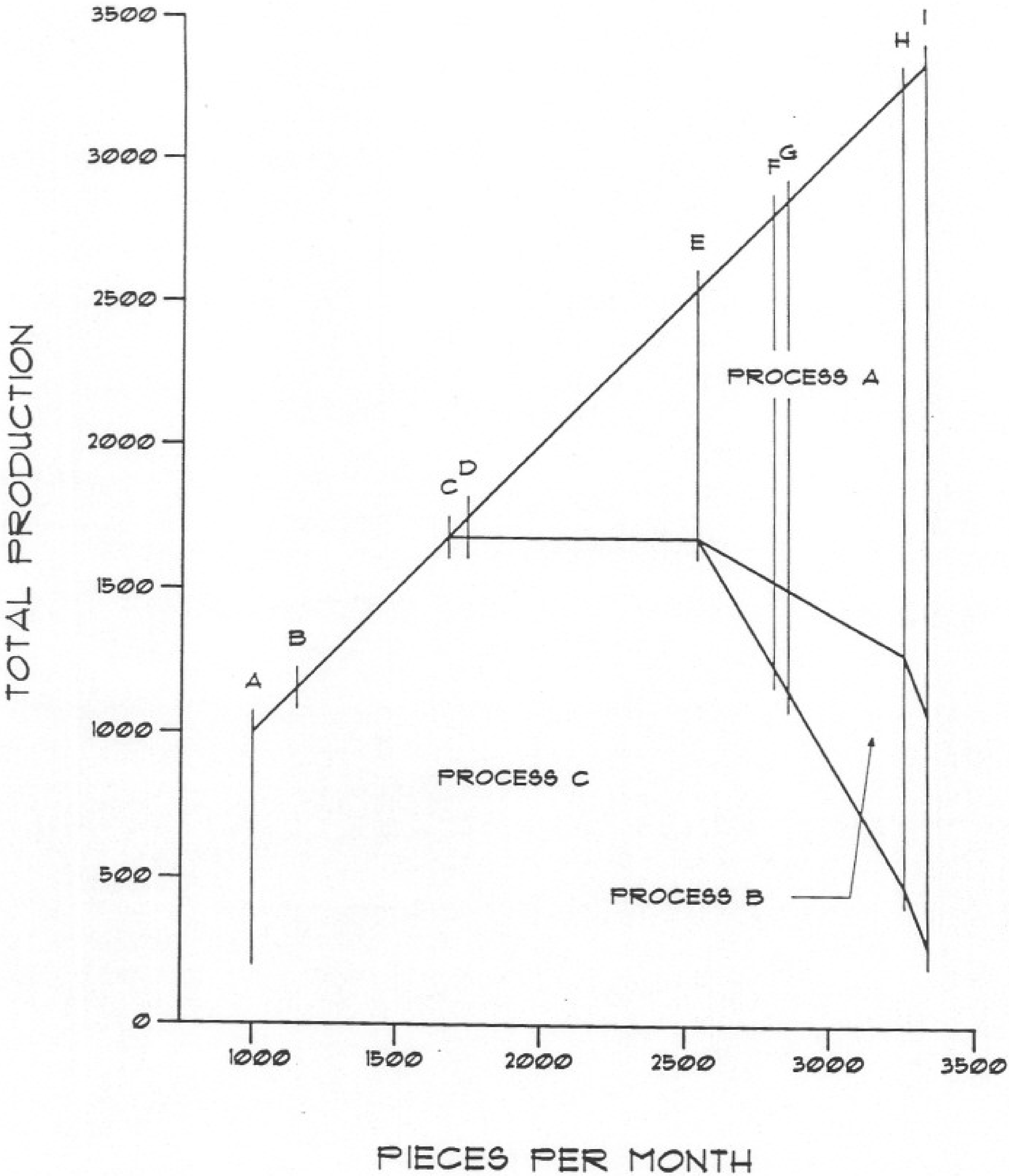
POINT H) 3258 pieces per month (LINDO Run #12).

The quantity of Process Option B parts has now reached the limit imposed by the Furnace 2 Centrifuge constraint. Further increase in production quantity must utilize Furnace 1, which means Process Option A. As the program continues to prescribe more Process Option B parts and fewer Process Option C parts to accommodate the Wax Assembly overtime constraint, we will now see excess capacity for Furnace 2. (Enter slack variable for row 9 - Furnace 2 constraint, exit slack variable for row 10 - Furnace 2 Centrifuge constraint).

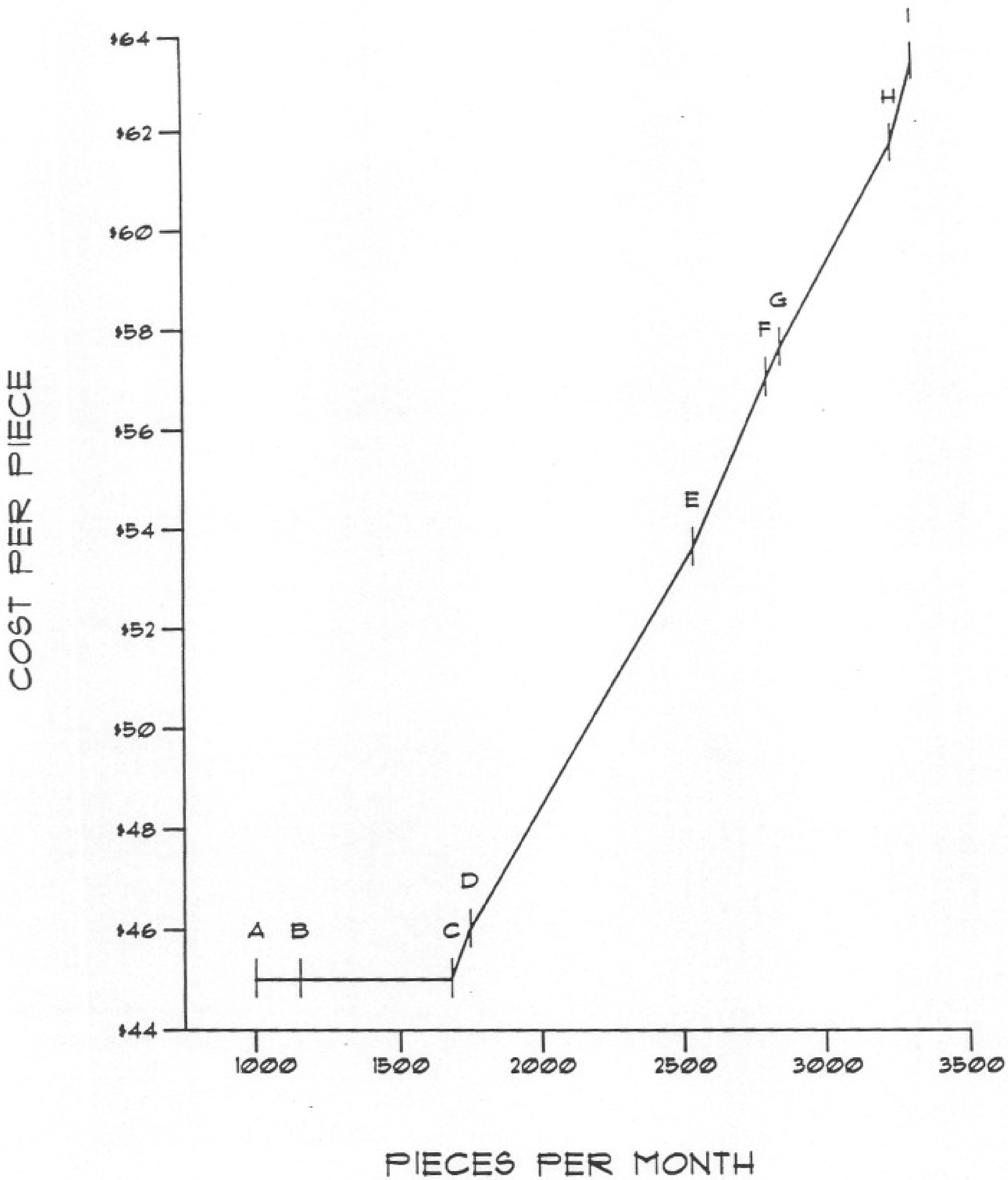
POINT I) 3338 pieces per month (LINDO Run #13).

Finally, with the production load driven to the Hand-Dip Investing processes (Options A and B), all the available Hand-Dip Investing overtime available is being used. No more product can be shifted from Process Option A to Process Option B (which would give us more pieces per allowable mold) because there is no more Furnace 2 Centrifuge processing capacity available. Similarly Process Option C quantities cannot be increased since this process requires the highest rate of Wax Assembly hours per piece.

We have reached our capacity limits for Wax Assembly overtime, Hand-Dip Investing overtime, and Furnace 2 Centrifuge. 3338 pieces per month is the maximum production capacity.



PROCESS TYPE MAP



PRODUCT UNIT COST

XII. CONCLUSION

The current plant capacity is sufficient to produce the projected sales volume. The cost to manufacture increases with volume which will require a great deal of precision in the marketing projections. Since a lower cost is possible at lower volumes, an overestimate of the sales volume may result in a high bid. Additionally, an underestimation of the sales volume will result in a low quote and eroding profit margins.

The simplest short term fix would be to add ~~additional~~ wax assembly labor. This would be effective up to the full utilization of furnace #1. Clearly, the furnace capacity is a significant constraint. While PCC has authorized the capital package to add additional furnace capacity, this is a long lead time item. The likely increase in volume of the studied product line is insufficient to support a high utilization of the new furnace.

PCC should only accept this product line if sufficient profit is available at the projected volume plus some safety margin. Additionally, strong consideration needs to be given to the customer service aspect of not having any emergency extra capacity.

In summary, this analysis has identified a clearer strategy for decision-making and a more comprehensive approach to accepting new product. As the company progresses toward 100% capacity, similar analyses will be more necessary.

LINDO
Run # 1

```
MIN      1380 X1 + 2496 X2 + 4320 X3 + 8 X4 + 8 X5 + 24 X6
SUBJECT TO
     ASSY)   3 X1 + 5 X2 + 20 X3 - X4 <=    360
  INVHAND)   X1 + X2 - X5 <=    70
 INVFRAME)   X3 - X6 <=    12
   ASSYOT)   X4 <=    120
  INVHDOT)   X5 <=    60
  INVFROT)   X6 <=    24
       F1)   0.3 X1 <=    34
       F2)   0.6 X2 + 0.8 X3 <=    14
   F2CENT)   0.6 X2 <=    10
   DEMAND)   20 X1 + 48 X2 + 96 X3 >=    3000
END
GIN         X1
GIN         X2
GIN         X3

LP OPTIMUM FOUND AT STEP     47

        OBJECTIVE FUNCTION VALUE

        1)     177484.937

 VARIABLE         VALUE          REDUCED COST
       X1        78.749985          0.000000
       X2        10.625000          0.000000
       X3         9.531250          0.000000
       X4       120.000000          0.000000
       X5        19.374985          0.000000
       X6         0.000000         24.000000


      ROW   SLACK OR SURPLUS     DUAL PRICES
    ASSY)         0.000000       145.249863
 INVHAND)         0.000000         8.000000
INVFRAME)         2.468749         0.000000
  ASSYOT)         0.000000       137.249863
 INVHDOT)        40.625000         0.000000
 INVFROT)        24.000000         0.000000
      F1)        10.375005         0.000000
      F2)         0.000000      1911.244630
  F2CENT)         3.624999         0.000000
  DEMAND)         0.000000       -91.187469

NO. ITERATIONS=      47
BRANCHES=     7 DETERM.= -1.024E   2
SET        X3 TO <=          9 AT     1, BND=   -178107.19     TWIN=-0.10000000E+31
SET        X2 TO <=         11 AT     2, BND=   -178388.75     TWIN= -178692.75
SET        X1 TO >=         81 AT     3, BND=   -178600.00     TWIN=-0.10000000E+31
SET        X2 TO >=         11 AT     4, BND=   -178676.00     TWIN= -178600.00
SET        X3 TO >=          9 AT     5, BND=   -179236.00     TWIN= -178676.00

NEW INTEGER SOLUTION OF     179236.000      AT BRANCH      12 PIVOT      64
```

```
        OBJECTIVE FUNCTION VALUE

        1)      179236.000

  VARIABLE         VALUE          REDUCED COST
        X1       81.000000        1412.000000
        X2       11.000000        2544.000000
        X3        9.000000        4480.000000
        X4      118.000000           0.000000
        X5       22.000000           0.000000
        X6        0.000000          24.000000


       ROW   SLACK OR SURPLUS     DUAL PRICES
     ASSY)        0.000000           8.000000
  INVHAND)        0.000000           8.000000
 INVFRAME)        3.000000           0.000000
   ASSYOT)        2.000000           0.000000
  INVHDOT)       38.000000           0.000000
  INVFROT)       24.000000           0.000000
       F1)        9.700012           0.000000
       F2)        0.200002           0.000000
   F2CENT)        3.400001           0.000000
   DEMAND)       12.000000           0.000000

NO. ITERATIONS=        64
BRANCHES=    12 DETERM.= -1.000E  0
BOUND ON OPTIMUM:  178600.0
FLIP        X3 TO <=          9 AT     5 WITH BND=    -178676.00
DELETE        X3 AT LEVEL      5
FLIP        X2 TO <=         10 AT     4 WITH BND=    -178600.00
SET        X1 TO >=         83 AT     5, BND=  -179303.94      TWIN=-0.10000000E+31
DELETE        X1 AT LEVEL      5
DELETE        X2 AT LEVEL      4
DELETE        X1 AT LEVEL      3
FLIP        X2 TO >=         12 AT     2 WITH BND=    -178692.75
SET        X3 TO <=          8 AT     3, BND=  -179278.38      TWIN=-0.10000000E+31
DELETE        X3 AT LEVEL      3
DELETE        X2 AT LEVEL      2
DELETE        X3 AT LEVEL      1
ENUMERATION COMPLETE. BRANCHES=     14 PIVOTS=     83

LAST INTEGER SOLUTION IS THE BEST FOUND
RE-INSTALLING BEST SOLUTION...

        OBJECTIVE FUNCTION VALUE

        1)      179236.000

  VARIABLE         VALUE          REDUCED COST
        X1       81.000000        1412.000000
        X2       11.000000        2544.000000
        X3        9.000000        4480.000000
        X4      118.000000           0.000000
        X5       22.000000           0.000000
```

X6	0.000000	24.000000

ROW	SLACK OR SURPLUS	DUAL PRICES
ASSY)	0.000000	8.000000
INVHAND)	0.000000	8.000000
INVFRAME)	3.000000	0.000000
ASSYOT)	2.000000	0.000000
INVHDOT)	38.000000	0.000000
INVFROT)	24.000000	0.000000
F1)	9.700012	0.000000
F2)	0.200002	0.000000
F2CENT)	3.400001	0.000000
DEMAND)	12.000000	0.000000

NO. ITERATIONS= 85
BRANCHES= 14 DETERM.= -1.000E 0

RANGES IN WHICH THE BASIS IS UNCHANGED:

OBJ COEFFICIENT RANGES

VARIABLE	CURRENT COEF	ALLOWABLE INCREASE	ALLOWABLE DECREASE
X1	1380.000000	INFINITY	1412.000000
X2	2496.000000	INFINITY	2544.000000
X3	4320.000000	INFINITY	4480.000000
X4	8.000000	INFINITY	8.000000
X5	8.000000	INFINITY	8.000000
X6	24.000000	INFINITY	24.000000

RIGHTHAND SIDE RANGES

ROW	CURRENT RHS	ALLOWABLE INCREASE	ALLOWABLE DECREASE
ASSY	360.000000	118.000000	2.000000
INVHAND	70.000000	22.000000	38.000000
INVFRAME	12.000000	INFINITY	3.000000
ASSYOT	120.000000	INFINITY	2.000000
INVHDOT	60.000000	INFINITY	38.000000
INVFROT	24.000000	INFINITY	24.000000
F1	34.000000	INFINITY	9.700012
F2	14.000000	INFINITY	0.200002
F2CENT	10.000000	INFINITY	3.400001
DEMAND	3000.000000	12.000000	INFINITY

LINDO
Run #2

```
MIN     1380 X1 + 2496 X2 + 4320 X3 + 8 X4 + 8 X5 + 24 X6
SUBJECT TO
     ASSY)   3 X1 + 5 X2 + 20 X3 - X4 <=    360
  INVHAND)   X1 + X2 - X5 <=    70
 INVFRAME)   X3 - X6 <=    12
   ASSYOT)   X4 <=    120
  INVHDOT)   X5 <=    60
  INVFROT)   X6 <=    24
       F1)   0.3 X1 <=    34
       F2)   0.6 X2 + 0.8 X3 <=    20
   F2CENT)   0.6 X2 <=    10
   DEMAND)   20 X1 + 48 X2 + 96 X3 >=    3000
END
GIN          X1
GIN          X2
GIN          X3

LP OPTIMUM FOUND AT STEP       0

        OBJECTIVE FUNCTION VALUE

        1)      166931.375

 VARIABLE          VALUE            REDUCED COST
       X1        52.857132            0.000000
       X2        16.666656            0.000000
       X3        11.904762            0.000000
       X4       120.000000            0.000000
       X5         0.000000            8.000000
       X6         0.000000           24.000000


      ROW   SLACK OR SURPLUS     DUAL PRICES
     ASSY)        0.000000        411.427734
  INVHAND)        0.476194          0.000000
 INVFRAME)        0.095238          0.000000
   ASSYOT)        0.000000        403.427734
  INVHDOT)       60.000000          0.000000
  INVFROT)       24.000000          0.000000
       F1)       18.142853          0.000000
       F2)        0.476191          0.000000
   F2CENT)        0.000000       2868.561280
   DEMAND)        0.000000       -130.714188

NO. ITERATIONS=        0
BRANCHES=    0 DETERM.=-67.200E  0
SET        X2 TO <=           16 AT     1, BND=   -168092.56      TWIN=-0.10000000E+31
SET        X3 TO <=           11 AT     2, BND=   -169569.56      TWIN=-0.10000000E+31
SET        X1 TO >=           59 AT     3, BND=   -169639.94      TWIN=-0.10000000E+31
SET        X2 TO >=           16 AT     4, BND=   -169665.31      TWIN= -169639.94
SET        X3 TO >=           11 AT     5, BND=   -169852.00      TWIN= -169665.31

NEW INTEGER SOLUTION OF     169852.000      AT BRANCH       5 PIVOT        8
```

```
        OBJECTIVE FUNCTION VALUE

        1)     169852.000

  VARIABLE          VALUE           REDUCED COST
        X1        59.000000         1412.000000
        X2        16.000000         2544.000000
        X3        11.000000         4480.000000
        X4       117.000000            0.000000
        X5         5.000000            0.000000
        X6         0.000000           24.000000


       ROW   SLACK OR SURPLUS      DUAL PRICES
     ASSY)        0.000000            8.000000
  INVHAND)        0.000000            8.000000
 INVFRAME)        1.000000            0.000000
   ASSYOT)        3.000000            0.000000
  INVHDOT)       55.000000            0.000000
  INVFROT)       24.000000            0.000000
       F1)       16.300003            0.000000
       F2)        1.600001            0.000000
   F2CENT)        0.400001            0.000000
   DEMAND)        4.000000            0.000000

NO. ITERATIONS=        8
BRANCHES=     5 DETERM.= -1.000E  0
BOUND ON OPTIMUM:  169639.9
FLIP        X3 TO <=          10 AT     5 WITH BND=     -169665.31
DELETE        X3 AT LEVEL      5
FLIP        X2 TO <=          15 AT     4 WITH BND=     -169639.94
DELETE        X2 AT LEVEL      4
DELETE        X1 AT LEVEL      3
DELETE        X3 AT LEVEL      2
DELETE        X2 AT LEVEL      1
ENUMERATION COMPLETE. BRANCHES=     5 PIVOTS=     21

LAST INTEGER SOLUTION IS THE BEST FOUND
RE-INSTALLING BEST SOLUTION...

        OBJECTIVE FUNCTION VALUE

        1)     169852.000

  VARIABLE          VALUE           REDUCED COST
        X1        59.000000         1412.000000
        X2        16.000000         2544.000000
        X3        11.000000         4480.000000
        X4       117.000000            0.000000
        X5         5.000000            0.000000
        X6         0.000000           24.000000


       ROW   SLACK OR SURPLUS      DUAL PRICES
     ASSY)        0.000000            8.000000
```

INVHAND)	0.000000	8.000000
INVFRAME)	1.000000	0.000000
ASSYOT)	3.000000	0.000000
INVHDOT)	55.000000	0.000000
INVFROT)	24.000000	0.000000
F1)	16.300003	0.000000
F2)	1.600001	0.000000
F2CENT)	0.400001	0.000000
DEMAND)	4.000000	0.000000

NO. ITERATIONS= 23
BRANCHES= 5 DETERM.= -1.000E 0

LINDO
Run # 3

```
MIN     1380 X1 + 2496 X2 + 5174 X3 + 8 X4 + 8 X5 + 24 X6
SUBJECT TO
     ASSY)   3 X1 + 5 X2 + 20 X3 - X4 <=   360
  INVHAND)   X1 + X2 - X5 <=   70
 INVFRAME)   X3 - X6 <=   12
   ASSYOT)   X4 <=   120
  INVHDOT)   X5 <=   60
  INVFROT)   X6 <=   24
       F1)   0.3 X1 <=   34
       F2)   0.6 X2 + 0.8 X3 <=   14
   F2CENT)   0.6 X2 <=   10
   DEMAND)   20 X1 + 48 X2 + 96 X3 >=   3000
END

LP OPTIMUM FOUND AT STEP      7

        OBJECTIVE FUNCTION VALUE

        1)     185624.625

  VARIABLE        VALUE          REDUCED COST
        X1       78.749985          0.000000
        X2       10.625000          0.000000
        X3        9.531250          0.000000
        X4      120.000000          0.000000
        X5       19.374985          0.000000
        X6        0.000000         24.000000


       ROW   SLACK OR SURPLUS     DUAL PRICES
     ASSY)        0.000000         45.171799
  INVHAND)        0.000000          8.000000
 INVFRAME)        2.468749          0.000000
   ASSYOT)        0.000000         37.171799
  INVHDOT)       40.625000          0.000000
  INVFROT)       24.000000          0.000000
       F1)       10.375005          0.000000
       F2)        0.000000       1544.297360
   F2CENT)        3.624999          0.000000
   DEMAND)        0.000000        -76.175781

NO. ITERATIONS=       7

RANGES IN WHICH THE BASIS IS UNCHANGED:

                              OBJ COEFFICIENT RANGES
VARIABLE         CURRENT        ALLOWABLE        ALLOWABLE
                  COEF          INCREASE         DECREASE
      X1      1380.000000       INFINITY        198.249588
      X2      2496.000000    1411.928960        237.899689
      X3      5174.000000     317.199463         INFINITY
      X4         8.000000      37.171799         INFINITY
      X5         8.000000       INFINITY          8.000000
      X6        24.000000       INFINITY         24.000000
```

RIGHTHAND SIDE RANGES

ROW	CURRENT RHS	ALLOWABLE INCREASE	ALLOWABLE DECREASE
ASSY	360.000000	21.066666	38.666672
INVHAND	70.000000	13.374985	40.625000
INVFRAME	12.000000	INFINITY	2.468749
ASSYOT	120.000000	21.066666	38.666672
INVHDOT	60.000000	INFINITY	40.625000
INVFROT	24.000000	INFINITY	24.000000
F1	34.000000	INFINITY	10.375005
F2	14.000000	5.391299	7.377786
F2CENT	10.000000	INFINITY	3.624999
DEMAND	3000.000000	257.777588	140.444412

THE TABLEAU

ROW	(BASIS)	X1	X2	X3	X4
1	ART	0.000	0.000	0.004	0.000
ASSY	X3	0.000	0.000	1.000	0.000
INVHAND	X5	0.000	0.000	0.000	0.000
INVFRAME	SLK 4	0.000	0.000	0.000	0.000
ASSYOT	X4	0.000	0.000	0.000	1.000
INVHDOT	SLK 6	0.000	0.000	0.000	0.000
INVFROT	SLK 7	0.000	0.000	0.000	0.000
F1	SLK 8	0.000	0.000	0.000	0.000
F2	X2	0.000	1.000	0.000	0.000
F2CENT	SLK 10	0.000	0.000	0.000	0.000
DEMAND	X1	1.000	0.000	0.000	0.000

ROW	X5	X6	SLK 2	SLK 3	SLK 4
1	0.000	24.000	45.172	8.000	0.000
ASSY	0.000	0.000	0.117	0.000	0.000
INVHAND	1.000	0.000	-0.344	-1.000	0.000
INVFRAME	0.000	-1.000	-0.117	0.000	1.000
ASSYOT	0.000	0.000	0.000	0.000	0.000
INVHDOT	0.000	0.000	0.344	1.000	0.000
INVFROT	0.000	1.000	0.000	0.000	0.000
F1	0.000	0.000	0.056	0.000	0.000
F2	0.000	0.000	-0.156	0.000	0.000
F2CENT	0.000	0.000	0.094	0.000	0.000
DEMAND	0.000	0.000	-0.188	0.000	0.000

ROW	SLK 5	SLK 6	SLK 7	SLK 8	SLK 9
1	37.172	0.000	0.000	0.000	1544.297
ASSY	0.117	0.000	0.000	0.000	0.430
INVHAND	-0.344	0.000	0.000	0.000	-3.594
INVFRAME	-0.117	0.000	0.000	0.000	-0.430
ASSYOT	1.000	0.000	0.000	0.000	0.000
INVHDOT	0.344	1.000	0.000	0.000	3.594
INVFROT	0.000	0.000	1.000	0.000	0.000
F1	0.056	0.000	0.000	1.000	1.406
F2	-0.156	0.000	0.000	0.000	1.094

F2CENT	0.094	0.000	0.000	0.000	-0.656
DEMAND	-0.188	0.000	0.000	0.000	-4.688

ROW	SLK 10	SLK 11	
1	0.00E+00	76.	-[illegible].19E+06
ASSY	0.000	0.018	9.531
INVHAND	0.000	-0.102	19.375
INVFRAME	0.000	-0.018	2.469
ASSYOT	0.000	0.000	120.000
INVHDOT	0.000	0.102	40.625
INVFROT	0.000	0.000	24.000
F1	0.000	0.023	10.375
F2	0.000	-0.023	10.625
F2CENT	1.000	0.014	3.625
DEMAND	0.000	-0.078	78.750

LINDO
Run #4

```
MIN     1380 X1 + 2496 X2 + 4320 X3 + 8 X4 + 8 X5 + 24 X6
SUBJECT TO
      ASSY)   3 X1 + 5 X2 + 20 X3 - X4 <=    360
   INVHAND)   X1 + X2 - X5 <=    70
  INVFRAME)   X3 - X6 <=    12
    ASSYOT)   X4 <=    120
   INVHDOT)   X5 <=    60
   INVFROT)   X6 <=    24
        F1)   0.3 X1 <=    34
        F2)   0.6 X2 + 0.8 X3 <=    14
    F2CENT)   0.6 X2 <=    10
    DEMAND)   20 X1 + 48 X2 + 96 X3 >=    1000
END

LP OPTIMUM FOUND AT STEP       10

        OBJECTIVE FUNCTION VALUE

        1)      44999.9961

  VARIABLE        VALUE          REDUCED COST
        X1         0.000000        480.000000
        X2         0.000000        336.000000
        X3        10.416666          0.000000
        X4         0.000000          8.000000
        X5         0.000000          8.000000
        X6         0.000000         24.000000


       ROW   SLACK OR SURPLUS     DUAL PRICES
     ASSY)       151.666656          0.000000
  INVHAND)        70.000000          0.000000
 INVFRAME)         1.583333          0.000000
   ASSYOT)       120.000000          0.000000
  INVHDOT)        60.000000          0.000000
  INVFROT)        24.000000          0.000000
       F1)        34.000000          0.000000
       F2)         5.666667          0.000000
   F2CENT)        10.000000          0.000000
   DEMAND)         0.000000        -45.000000

NO. ITERATIONS=        10

RANGES IN WHICH THE BASIS IS UNCHANGED:

                            OBJ COEFFICIENT RANGES
VARIABLE          CURRENT        ALLOWABLE        ALLOWABLE
                   COEF          INCREASE         DECREASE
      X1       1380.000000       INFINITY        480.000000
      X2       2496.000000       INFINITY        336.000000
      X3       4320.000000     672.000000       4320.000000
      X4          8.000000       INFINITY          8.000000
      X5          8.000000       INFINITY          8.000000
      X6         24.000000       INFINITY         24.000000
```

RIGHTHAND SIDE RANGES

ROW	CURRENT RHS	ALLOWABLE INCREASE	ALLOWABLE DECREASE
ASSY	360.000000	INFINITY	151.666656
INVHAND	70.000000	INFINITY	70.000000
INVFRAME	12.000000	INFINITY	1.583333
ASSYOT	120.000000	INFINITY	120.000000
INVHDOT	60.000000	INFINITY	60.000000
INVFROT	24.000000	INFINITY	24.000000
F1	34.000000	INFINITY	34.000000
F2	14.000000	INFINITY	5.666667
F2CENT	10.000000	INFINITY	10.000000
DEMAND	1000.000000	152.000000	1000.000000

VAR OUT		VAR IN		PIVOT ROW	RHS VAL	DUAL PRICE BEFORE PIVOT	OBJ VAL
					1000.00	-45.0000	45000.0
SLK	4		X6	4	1152.00	-45.0000	51840.0
SLK	9		X1	9	1680.00	-45.2500	75731.9
SLK	2		X4	2	1746.67	-69.0000	80331.9
SLK	5		X2	5	2546.67	-70.2000	136492.
SLK	3		X5	3	2809.23	-89.9531	160110.
	X6	SLK	4	4	2859.56	-90.7656	164678.
SLK	10	SLK	9	10	3257.78	-91.1875	200991.
SLK	6	ART		6	3338.67	-132.143	211680.
					3500.00	-INFINITY	INFEASIBLE

LINDO
Run #5

```
MIN     1380 X1 + 2496 X2 + 4320 X3 + 8 X4 + 8 X5 + 24 X6
SUBJECT TO
    ASSY)   3 X1 + 5 X2 + 20 X3 - X4 <=   360
 INVHAND)   X1 + X2 - X5 <=    70
INVFRAME)   X3 - X6 <=    12
  ASSYOT)   X4 <=    120
 INVHDOT)   X5 <=    60
 INVFROT)   X6 <=    24
      F1)   0.3 X1 <=    34
      F2)   0.6 X2 + 0.8 X3 <=    14
  F2CENT)   0.6 X2 <=    10
  DEMAND)   20 X1 + 48 X2 + 96 X3 >=    1000
END

LP OPTIMUM FOUND AT STEP       1

        OBJECTIVE FUNCTION VALUE

        1)     44999.9961

 VARIABLE        VALUE          REDUCED COST
       X1         0.000000        480.000000
       X2         0.000000        336.000000
       X3        10.416666          0.000000
       X4         0.000000          8.000000
       X5         0.000000          8.000000
       X6         0.000000         24.000000


      ROW   SLACK OR SURPLUS     DUAL PRICES
    ASSY)       151.666656          0.000000
 INVHAND)        70.000000          0.000000
INVFRAME)         1.583333          0.000000
  ASSYOT)       120.000000          0.000000
 INVHDOT)        60.000000          0.000000
 INVFROT)        24.000000          0.000000
      F1)        34.000000          0.000000
      F2)         5.666667          0.000000
  F2CENT)        10.000000          0.000000
  DEMAND)         0.000000        -45.000000

NO. ITERATIONS=         1

RANGES IN WHICH THE BASIS IS UNCHANGED:

                           OBJ COEFFICIENT RANGES
VARIABLE         CURRENT          ALLOWABLE         ALLOWABLE
                  COEF            INCREASE          DECREASE
      X1       1380.000000        INFINITY         480.000000
      X2       2496.000000        INFINITY         336.000000
      X3       4320.000000       672.000000       4320.000000
      X4          8.000000        INFINITY           8.000000
      X5          8.000000        INFINITY           8.000000
      X6         24.000000        INFINITY          24.000000
```

RIGHTHAND SIDE RANGES

ROW	CURRENT RHS	ALLOWABLE INCREASE	ALLOWABLE DECREASE
ASSY	360.000000	INFINITY	151.666656
INVHAND	70.000000	INFINITY	70.000000
INVFRAME	12.000000	INFINITY	1.583333
ASSYOT	120.000000	INFINITY	120.000000
INVHDOT	60.000000	INFINITY	60.000000
INVFROT	24.000000	INFINITY	24.000000
F1	34.000000	INFINITY	34.000000
F2	14.000000	INFINITY	5.666667
F2CENT	10.000000	INFINITY	10.000000
DEMAND	1000.000000	152.000000	1000.000000

LINDO
Run #6

```
MIN      1380 X1 + 2496 X2 + 4320 X3 + 8 X4 + 8 X5 + 24 X6
SUBJECT TO
     ASSY)   3 X1 + 5 X2 + 20 X3 - X4 <=    360
  INVHAND)   X1 + X2 - X5 <=    70
 INVFRAME)   X3 - X6 <=    12
   ASSYOT)   X4 <=    120
  INVHDOT)   X5 <=    60
  INVFROT)   X6 <=    24
       F1)   0.3 X1 <=    34
       F2)   0.6 X2 + 0.8 X3 <=    14
   F2CENT)   0.6 X2 <=    10
   DEMAND)   20 X1 + 48 X2 + 96 X3 >=    1153
END

LP OPTIMUM FOUND AT STEP       1

        OBJECTIVE FUNCTION VALUE

        1)     51885.2461

  VARIABLE        VALUE          REDUCED COST
        X1        0.000000        475.000000
        X2        0.000000        324.000000
        X3       12.010416          0.000000
        X4        0.000000          8.000000
        X5        0.000000          8.000000
        X6        0.010417          0.000000


       ROW   SLACK OR SURPLUS     DUAL PRICES
     ASSY)      119.791656          0.000000
  INVHAND)       70.000000          0.000000
 INVFRAME)        0.000000         24.000000
   ASSYOT)      120.000000          0.000000
  INVHDOT)       60.000000          0.000000
  INVFROT)       23.989578          0.000000
       F1)       34.000000          0.000000
       F2)        4.391666          0.000000
   F2CENT)       10.000000          0.000000
   DEMAND)        0.000000        -45.250000

NO. ITERATIONS=        1

RANGES IN WHICH THE BASIS IS UNCHANGED:

                               OBJ COEFFICIENT RANGES
VARIABLE         CURRENT        ALLOWABLE        ALLOWABLE
                  COEF          INCREASE         DECREASE
      X1      1380.000000       INFINITY        475.000000
      X2      2496.000000       INFINITY        324.000000
      X3      4320.000000      648.000000      4344.000000
      X4         8.000000       INFINITY          8.000000
      X5         8.000000       INFINITY          8.000000
      X6        24.000000      648.000000        24.000000
```

RIGHTHAND SIDE RANGES

ROW	CURRENT RHS	ALLOWABLE INCREASE	ALLOWABLE DECREASE
ASSY	360.000000	INFINITY	119.791656
INVHAND	70.000000	INFINITY	70.000000
INVFRAME	12.000000	0.010417	23.989578
ASSYOT	120.000000	INFINITY	120.000000
INVHDOT	60.000000	INFINITY	60.000000
INVFROT	24.000000	INFINITY	23.989578
F1	34.000000	INFINITY	34.000000
F2	14.000000	INFINITY	4.391666
F2CENT	10.000000	INFINITY	10.000000
DEMAND	1153.000000	527.000000	1.000000

LINDO
Run #7

```
MIN      1380 X1 + 2496 X2 + 4320 X3 + 8 X4 + 8 X5 + 24 X6
SUBJECT TO
     ASSY)   3 X1 + 5 X2 + 20 X3 - X4 <=   360
  INVHAND)   X1 + X2 - X5 <=   70
 INVFRAME)   X3 - X6 <=   12
   ASSYOT)   X4 <=   120
  INVHDOT)   X5 <=   60
  INVFROT)   X6 <=   24
       F1)   0.3 X1 <=   34
       F2)   0.6 X2 + 0.8 X3 <=   14
   F2CENT)   0.6 X2 <=   10
   DEMAND)   20 X1 + 48 X2 + 96 X3 >=   1681
END

LP OPTIMUM FOUND AT STEP      1

       OBJECTIVE FUNCTION VALUE

       1)     75800.9375

 VARIABLE        VALUE          REDUCED COST
       X1        0.049995          0.000000
       X2        0.000000        893.999756
       X3       17.500000          0.000000
       X4        0.000000          8.000000
       X5        0.000000          8.000000
       X6        5.500001          0.000000


      ROW   SLACK OR SURPLUS     DUAL PRICES
     ASSY)       9.849994          0.000000
  INVHAND)      69.949997          0.000000
 INVFRAME)       0.000000         24.000000
   ASSYOT)     120.000000          0.000000
  INVHDOT)      60.000000          0.000000
  INVFROT)      18.499985          0.000000
       F1)      33.985001          0.000000
       F2)       0.000000       2850.000000
   F2CENT)      10.000000          0.000000
   DEMAND)       0.000000        -69.000000

NO. ITERATIONS=        1

RANGES IN WHICH THE BASIS IS UNCHANGED:

                             OBJ COEFFICIENT RANGES
VARIABLE        CURRENT        ALLOWABLE        ALLOWABLE
                  COEF          INCREASE         DECREASE
      X1     1380.000000        INFINITY       475.000000
      X2     2496.000000        INFINITY       893.999756
      X3     4320.000000     1191.999760         INFINITY
      X4        8.000000        INFINITY         8.000000
      X5        8.000000        INFINITY         8.000000
      X6       24.000000     1191.999760        24.000000
```

RIGHTHAND SIDE RANGES

ROW	CURRENT RHS	ALLOWABLE INCREASE	ALLOWABLE DECREASE
ASSY	360.000000	INFINITY	9.849994
INVHAND	70.000000	INFINITY	69.949997
INVFRAME	12.000000	5.500001	18.499985
ASSYOT	120.000000	INFINITY	120.000000
INVHDOT	60.000000	INFINITY	60.000000
INVFROT	24.000000	INFINITY	18.499985
F1	34.000000	INFINITY	33.985001
F2	14.000000	0.008332	4.400001
F2CENT	10.000000	INFINITY	10.000000
DEMAND	1681.000000	65.666626	0.999900

LINDO
Run #8

```
MIN     1380 X1 + 2496 X2 + 4320 X3 + 8 X4 + 8 X5 + 24 X6
SUBJECT TO
     ASSY)   3 X1 + 5 X2 + 20 X3 - X4 <=   360
  INVHAND)   X1 + X2 - X5 <=   70
 INVFRAME)   X3 - X6 <=   12
   ASSYOT)   X4 <=   120
  INVHOOT)   X5 <=   60
  INVFROT)   X6 <=   24
       F1)   0.3 X1 <=   34
       F2)   0.6 X2 + 0.8 X3 <=   14
   F2CENT)   0.6 X2 <=   10
   DEMAND)   20 X1 + 48 X2 + 96 X3 >=   1747
END
```

LP OPTIMUM FOUND AT STEP 1

OBJECTIVE FUNCTION VALUE

1) 80355.3750

VARIABLE	VALUE	REDUCED COST
X1	3.349995	0.000000
X2	0.000000	842.799316
X3	17.500000	0.000000
X4	0.050006	0.000000
X5	0.000000	8.000000
X6	5.500001	0.000000

ROW	SLACK OR SURPLUS	DUAL PRICES
ASSY)	0.000000	8.000000
INVHAND)	66.649994	0.000000
INVFRAME)	0.000000	24.000000
ASSYOT)	119.949982	0.000000
INVHOOT)	60.000000	0.000000
INVFROT)	18.499985	0.000000
F1)	32.994995	0.000000
F2)	0.000000	2793.999020
F2CENT)	10.000000	0.000000
DEMAND)	0.000000	-70.199997

NO. ITERATIONS= 1

RANGES IN WHICH THE BASIS IS UNCHANGED:

VARIABLE	CURRENT COEF	OBJ COEFFICIENT RANGES ALLOWABLE INCREASE	ALLOWABLE DECREASE
X1	1380.000000	INFINITY	465.666504
X2	2496.000000	INFINITY	842.799316
X3	4320.000000	1123.732420	INFINITY
X4	8.000000	131.687393	8.000000
X5	8.000000	INFINITY	8.000000
X6	24.000000	1123.732420	24.000000

RIGHTHAND SIDE RANGES

ROW	CURRENT RHS	ALLOWABLE INCREASE	ALLOWABLE DECREASE
ASSY	360.000000	0.050006	119.949992
INVHAND	70.000000	INFINITY	66.649994
INVFRAME	12.000000	5.500001	18.499995
ASSYOT	120.000000	INFINITY	119.949982
INVHDOT	60.000000	INFINITY	60.000000
INVFROT	24.000000	INFINITY	18.499985
F1	34.000000	INFINITY	32.994975
F2	14.000000	0.558332	0.007144
F2CENT	10.000000	INFINITY	10.000000
DEMAND	1747.000000	799.666504	0.333372

LINDO
Run #9

```
MIN     1380 X1 + 2496 X2 + 4320 X3 + 8 X4 + 8 X5 + 24 X6
SUBJECT TO
     ASSY)   3 X1 + 5 X2 + 20 X3 - X4 <=   360
  INVHAND)   X1 + X2 - X5 <=   70
 INVFRAME)   X3 - X6 <=   12
   ASSYOT)   X4 <=   120
  INVHDOT)   X5 <=   60
  INVFROT)   X6 <=   24
       F1)   0.3 X1 <=   34
       F2)   0.6 X2 + 0.8 X3 <=   14
   F2CENT)   0.6 X2 <=   10
   DEMAND)   20 X1 + 48 X2 + 96 X3 >=   2544
END
```

LP OPTIMUM FOUND AT STEP 0

OBJECTIVE FUNCTION VALUE

1) 136304.750

VARIABLE	VALUE	REDUCED COST
X1	43.199982	0.000000
X2	0.000000	842.799316
X3	17.500000	0.000000
X4	119.599991	0.000000
X5	0.000000	8.000000
X6	5.500001	0.000000

ROW	SLACK OR SURPLUS	DUAL PRICES
ASSY)	0.000000	8.000000
INVHAND)	26.800003	0.000000
INVFRAME)	0.000000	24.000000
ASSYOT)	0.399994	0.000000
INVHDOT)	60.000000	0.000000
INVFROT)	18.499985	0.000000
F1)	21.039993	0.000000
F2)	0.000000	2793.999020
F2CENT)	10.000000	0.000000
DEMAND)	0.000000	-70.199997

NO. ITERATIONS= 0

RANGES IN WHICH THE BASIS IS UNCHANGED:

		OBJ COEFFICIENT RANGES	
VARIABLE	CURRENT COEF	ALLOWABLE INCREASE	ALLOWABLE DECREASE
X1	1380.000000	INFINITY	465.666504
X2	2496.000000	INFINITY	842.799316
X3	4320.000000	1123.732420	INFINITY
X4	8.000000	131.687393	8.000000
X5	8.000000	INFINITY	8.000000
X6	24.000000	1123.732420	24.000000

RIGHTHAND SIDE RANGES

ROW	CURRENT RHS	ALLOWABLE INCREASE	ALLOWABLE DECREASE
ASSY	360.000000	119.599991	0.399994
INVHAND	70.000000	INFINITY	26.800003
INVFRAME	12.000000	5.500001	18.499985
ASSYOT	120.000000	INFINITY	0.399994
INVHDOT	60.000000	INFINITY	60.000000
INVFROT	24.000000	INFINITY	18.499985
F1	34.000000	INFINITY	21.039993
F2	14.000000	0.057142	4.400001
F2CENT	10.000000	INFINITY	10.000000
DEMAND	2544.000000	2.666628	797.333252

LINDO
Run #10

```
MIN      1380 X1 + 2496 X2 + 4320 X3 + 8 X4 + 8 X5 + 24 X6
SUBJECT TO
     ASSY)   3 X1 + 5 X2 + 20 X3 - X4 <=    360
  INVHAND)   X1 + X2 - X5 <=    70
 INVFRAME)   X3 - X6 <=    12
   ASSYOT)   X4 <=    120
  INVHDOT)   X5 <=    60
  INVFROT)   X6 <=    24
       F1)   0.3 X1 <=    34
       F2)   0.6 X2 + 0.8 X3 <=    14
   F2CENT)   0.6 X2 <=    10
   DEMAND)   20 X1 + 48 X2 + 96 X3 >=    2810
END
```

LP OPTIMUM FOUND AT STEP 2

OBJECTIVE FUNCTION VALUE

1) 160180.250

VARIABLE	VALUE	REDUCED COST
X1	63.906235	0.000000
X2	6.171875	0.000000
X3	12.871094	0.000000
X4	120.000000	0.000000
X5	0.078122	0.000000
X6	0.871094	0.000000

ROW	SLACK OR SURPLUS	DUAL PRICES
ASSY)	0.000000	142.437393
INVHAND)	0.000000	8.000000
INVFRAME)	0.000000	24.000000
ASSYOT)	0.000000	134.437393
INVHDOT)	59.921875	0.000000
INVFROT)	23.128891	0.000000
F1)	14.828129	0.000000
F2)	0.000000	1900.932130
F2CENT)	6.296874	0.000000
DEMAND)	0.000000	-90.765610

NO. ITERATIONS= 2

RANGES IN WHICH THE BASIS IS UNCHANGED:

		OBJ COEFFICIENT RANGES	
VARIABLE	CURRENT COEF	ALLOWABLE INCREASE	ALLOWABLE DECREASE
X1	1380.000000	INFINITY	405.531982
X2	2496.000000	1737.994870	860.399902
X3	4320.000000	1147.200200	INFINITY
X4	8.000000	134.437393	INFINITY
X5	8.000000	INFINITY	8.000000
X6	24.000000	1147.200200	24.000000

RIGHTHAND SIDE RANGES

ROW	CURRENT RHS	ALLOWABLE INCREASE	ALLOWABLE DECREASE
ASSY	360.000000	0.227264	7.433340
INVHAND	70.000000	0.078122	59.921875
INVFRAME	12.000000	0.871094	23.128891
ASSYOT	120.000000	0.227264	7.433340
INVHDOT	60.000000	INFINITY	59.921875
INVFROT	24.000000	INFINITY	23.128891
F1	34.000000	INFINITY	14.828129
F2	14.000000	0.021738	2.027273
F2CENT	10.000000	INFINITY	6.296874
DEMAND	2810.000000	49.555573	0.769201

LINDO
Run #11

```
MIN      1380 X1 + 2496 X2 + 4320 X3 + 8 X4 + 8 X5 + 24 X6
SUBJECT TO
    ASSY)   3 X1 + 5 X2 + 20 X3 - X4 <=    360
 INVHAND)   X1 + X2 - X5 <=    70
INVFRAME)   X3 - X6 <=    12
  ASSYOT)   X4 <=    120
 INVHDOT)   X5 <=    60
 INVFROT)   X6 <=    24
      F1)   0.3 X1 <=    34
      F2)   0.6 X2 + 0.9 X3 <=    14
  F2CENT)   0.6 X2 <=    10
  DEMAND)   20 X1 + 48 X2 + 96 X3 >=    2860
END

LP OPTIMUM FOUND AT STEP        1

       OBJECTIVE FUNCTION VALUE

       1)     164718.687

 VARIABLE        VALUE           REDUCED COST
       X1        67.812495           0.000000
       X2         7.343750           0.000000
       X3        11.992188           0.000000
       X4       120.000000           0.000000
       X5         5.156246           0.000000
       X6         0.000000          24.000000


      ROW   SLACK OR SURPLUS     DUAL PRICES
    ASSY)         0.000000        145.249863
 INVHAND)         0.000000          8.000000
INVFRAME)         0.007812          0.000000
  ASSYOT)         0.000000        137.249863
 INVHDOT)        54.943750          0.000000
 INVFROT)        24.000000          0.000000
      F1)        13.656254          0.000000
      F2)         0.000000       1911.244630
  F2CENT)         5.593749          0.000000
  DEMAND)         0.000000        -91.187469

NO. ITERATIONS=        1

RANGES IN WHICH THE BASIS IS UNCHANGED:

                              OBJ COEFFICIENT RANGES
VARIABLE        CURRENT          ALLOWABLE          ALLOWABLE
                 COEF            INCREASE           DECREASE
      X1      1380.000000         INFINITY          407.732178
      X2      2496.000000       1747.423580         878.399658
      X3      4320.000000       1171.199950           INFINITY
      X4         9.000000        137.249863           INFINITY
      X5         8.000000         INFINITY            8.000000
      X6        24.000000         INFINITY           24.000000
```

RIGHTHAND SIDE RANGES

ROW	CURRENT RHS	ALLOWABLE INCREASE	ALLOWABLE DECREASE
ASSY	360.000000	0.066664	59.666687
INVHAND	70.000000	5.156246	54.843750
INVFRAME	12.000000	INFINITY	0.007812
ASSYOT	120.000000	0.066664	59.666687
INVHDOT	60.000000	INFINITY	54.843750
INVFROT	24.000000	INFINITY	24.000000
F1	34.000000	INFINITY	13.656254
F2	14.000000	0.018181	6.714285
F2CENT	10.000000	INFINITY	5.593749
DEMAND	2860.000000	397.777588	0.444424

LINDO
Run #12

```
MIN     1380 X1 + 2496 X2 + 4320 X3 + 8 X4 + 8 X5 + 24 X6
SUBJECT TO
     ASSY)   3 X1 + 5 X2 + 20 X3 - X4 <=    360
  INVHAND)   X1 + X2 - X5 <=    70
 INVFRAME)   X3 - X6 <=    12
   ASSYOT)   X4 <=    120
  INVHDOT)   X5 <=    60
  INVFROT)   X6 <=    24
       F1)   0.3 X1 <=    34
       F2)   0.6 X2 + 0.8 X3 <=    14
   F2CENT)   0.6 X2 <=    10
   DEMAND)   20 X1 + 48 X2 + 96 X3 >=    3258
END

LP OPTIMUM FOUND AT STEP       1

       OBJECTIVE FUNCTION VALUE

       1)     201020.437

 VARIABLE         VALUE          REDUCED COST
       X1       98.928558          0.000000
       X2       16.666656          0.000000
       X3        4.994047          0.000000
       X4      120.000000          0.000000
       X5       45.595230          0.000000
       X6        0.000000         24.000000


      ROW   SLACK OR SURPLUS     DUAL PRICES
     ASSY)        0.000000        418.285889
  INVHAND)        0.000000          8.000000
 INVFRAME)        7.005952          0.000000
   ASSYOT)        0.000000        410.285999
  INVHDOT)       14.404765          0.000000
  INVFROT)       24.000000          0.000000
       F1)        4.321434          0.000000
       F2)        0.004762          0.000000
   F2CENT)        0.000000       2912.382810
   DEMAND)        0.000000       -132.142914

NO. ITERATIONS=        1

RANGES IN WHICH THE BASIS IS UNCHANGED:

                              OBJ COEFFICIENT RANGES
VARIABLE         CURRENT          ALLOWABLE         ALLOWABLE
                  COEF            INCREASE          DECREASE
      X1      1380.000000         INFINITY         407.733398
      X2      2496.000000       1747.430180         INFINITY
      X3      4320.000000       2297.601070         INFINITY
      X4         9.000000        410.285889         INFINITY
      X5         8.000000         INFINITY          8.000000
      X6        24.000000         INFINITY         24.000000
```

RIGHTHAND SIDE RANGES

ROW	CURRENT RHS	ALLOWABLE INCREASE	ALLOWABLE DECREASE
ASSY	360.000000	0.033333	16.805557
INVHAND	70.000000	45.595230	14.404765
INVFRAME	12.000000	INFINITY	7.005952
ASSYOT	120.000000	0.033333	16.805557
INVHDOT	60.000000	INFINITY	14.404765
INVFROT	24.000000	INFINITY	24.000000
F1	34.000000	INFINITY	4.321434
F2	14.000000	INFINITY	0.004762
F2CENT	10.000000	0.003125	2.016669
DEMAND	3258.000000	80.666687	0.222219

```
MIN     1380 X1 + 2496 X2 + 4320 X3 + 8 X4 + 8 X5 + 24 X6
SUBJECT TO
     ASSY)   3 X1 + 5 X2 + 20 X3 - X4 <=    360
  INVHAND)   X1 + X2 - X5 <=    70
 INVFRAME)   X3 - X6 <=    12
   ASSYOT)   X4 <=    120
   INVHDOT)  X5 <=    60
   INVFROT)  X6 <=    24
       F1)   0.3 X1 <=    34
       F2)   0.6 X2 + 0.8 X3 <=    14
    F2CENT)  0.6 X2 <=    10
    DEMAND)  20 X1 + 48 X2 + 96 X3 >=    3338
END
```

LINDO
Run #13

LP OPTIMUM FOUND AT STEP 0

OBJECTIVE FUNCTION VALUE

1) 211591.875

VARIABLE	VALUE	REDUCED COST
X1	113.214279	0.000000
X2	16.666656	0.000000
X3	2.851191	0.000000
X4	120.000000	0.000000
X5	59.880936	0.000000
X6	0.000000	24.000000

ROW	SLACK OR SURPLUS	DUAL PRICES
ASSY)	0.000000	418.285889
INVHAND)	0.000000	8.000000
INVFRAME)	9.148808	0.000000
ASSYOT)	0.000000	410.285889
INVHDOT)	0.119051	0.000000
INVFROT)	24.000000	0.000000
F1)	0.035721	0.000000
F2)	1.719047	0.000000
F2CENT)	0.000000	2912.382810
DEMAND)	0.000000	-132.142914

NO. ITERATIONS= 0

RANGES IN WHICH THE BASIS IS UNCHANGED:

VARIABLE	CURRENT COEF	OBJ COEFFICIENT RANGES ALLOWABLE INCREASE	ALLOWABLE DECREASE
X1	1380.000000	INFINITY	407.733398
X2	2496.000000	1747.430180	INFINITY
X3	4320.000000	2297.601070	INFINITY
X4	8.000000	410.285889	INFINITY
X5	8.000000	INFINITY	8.000000
X6	24.000000	INFINITY	24.000000

RIGHTHAND SIDE RANGES

ROW	CURRENT RHS	ALLOWABLE INCREASE	ALLOWABLE DECREASE
ASSY	360.000000	12.033332	0.138893
INVHAND	70.000000	59.880936	0.119051
INVFRAME	12.000000	INFINITY	9.148808
ASSYOT	120.000000	12.033332	0.138893
INVHDOT	60.000000	INFINITY	0.119051
INVFROT	24.000000	INFINITY	24.000000
F1	34.000000	INFINITY	0.035721
F2	14.000000	INFINITY	1.719047
F2CENT	10.000000	1.128124	0.016670
DEMAND	3338.000000	0.666685	80.222183

LP OPTIMUM FOUND AT STEP 10

OBJECTIVE FUNCTION VALUE

1) 44999.9961

VARIABLE	VALUE	REDUCED COST
X1	0.000000	480.000000
X2	0.000000	336.000000
X3	10.416666	0.000000
X4	0.000000	8.000000
X5	0.000000	8.000000
X6	0.000000	24.000000

ROW	SLACK OR SURPLUS	DUAL PRICES
ASSY)	151.666656	0.000000
INVHAND)	70.000000	0.000000
INVFRAME)	1.583333	0.000000
ASSYOT)	120.000000	0.000000
INVHDOT)	60.000000	0.000000
INVFROT)	24.000000	0.000000
F1)	34.000000	0.000000
F2)	5.666667	0.000000
F2CENT)	10.000000	0.000000
DEMAND)	0.000000	-45.000000

NO. ITERATIONS= 10