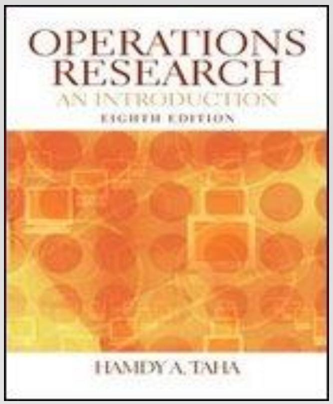
Chapter 2:
Modeling with Linear Programming & sensitivity analysis



Hamdy A. Taha, Operations Research: An introduction, 8th Edition

Mjdah Al Shehri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Mute ur call

LINEAR PROGRAMMING (LP)

-In mathematics, **linear programming (LP)** is a technique for optimization of a linear objective function, subject to linear equality and linear inequality constraints.

-Linear programming determines the way to achieve the best outcome (such as maximum profit or lowest cost) in a given mathematical model and given some list of requirements represented as linear equations.

Mathematical formulation of Linear Programming model:

Step 1

- Study the given situation
- Find the key decision to be made
- Identify the decision variables of the problem

Step 2

- Formulate the objective function to be optimized

Step 3

- Formulate the constraints of the problem

Step 4

- Add non-negativity restrictions or constraints

The objective function , the set of constraints and the non-negativity restrictions together form an LP model.

TWO-VARIABLE LP MODEL

EXAMPLE:

“ THE GALAXY INDUSTRY PRODUCTION”

- Galaxy manufactures two toy models:
  - Space Ray.
  - Zapper.
- Resources are limited to
  - 1200 pounds of special plastic.
  - 40 hours of production time per week.

- Marketing requirement
  - Total production cannot exceed 800 dozens.
  - Number of dozens of Space Rays cannot exceed number of dozens of Zappers by more than 450.
- Technological input
  - Space Rays requires 2 pounds of plastic and 3 minutes of labor per dozen.
  - Zappers requires 1 pound of plastic and 4 minutes of labor per dozen.

- Current production plan calls for:
  - Producing as much as possible of the more profitable product, Space Ray ($8 profit per dozen).
  - Use resources left over to produce Zappers ($5 profit per dozen).

- The current production plan consists of:

  Space Rays = 550 dozens

  Zapper = 100 dozens

  Profit = 4900 dollars per week

A Linear Programming Model can provide an intelligent solution to this problem

SOLUTION

- Decisions variables:
  - X1 = Production level of Space Rays (in dozens per week).
  - X2 = Production level of Zappers (in dozens per week).
- Objective Function:
  - Weekly profit, to be maximized

The Linear Programming Model

Max $8X1 + 5X2$ (Weekly profit)

subject to

$2X1 + 1X2 <= 1200$ (Plastic)

$3X1 + 4X2 <= 2400$ (Production Time)

$X1 + X2 <= 800$ (Total production)

$X1 - X2 <= 450$ (Mix)

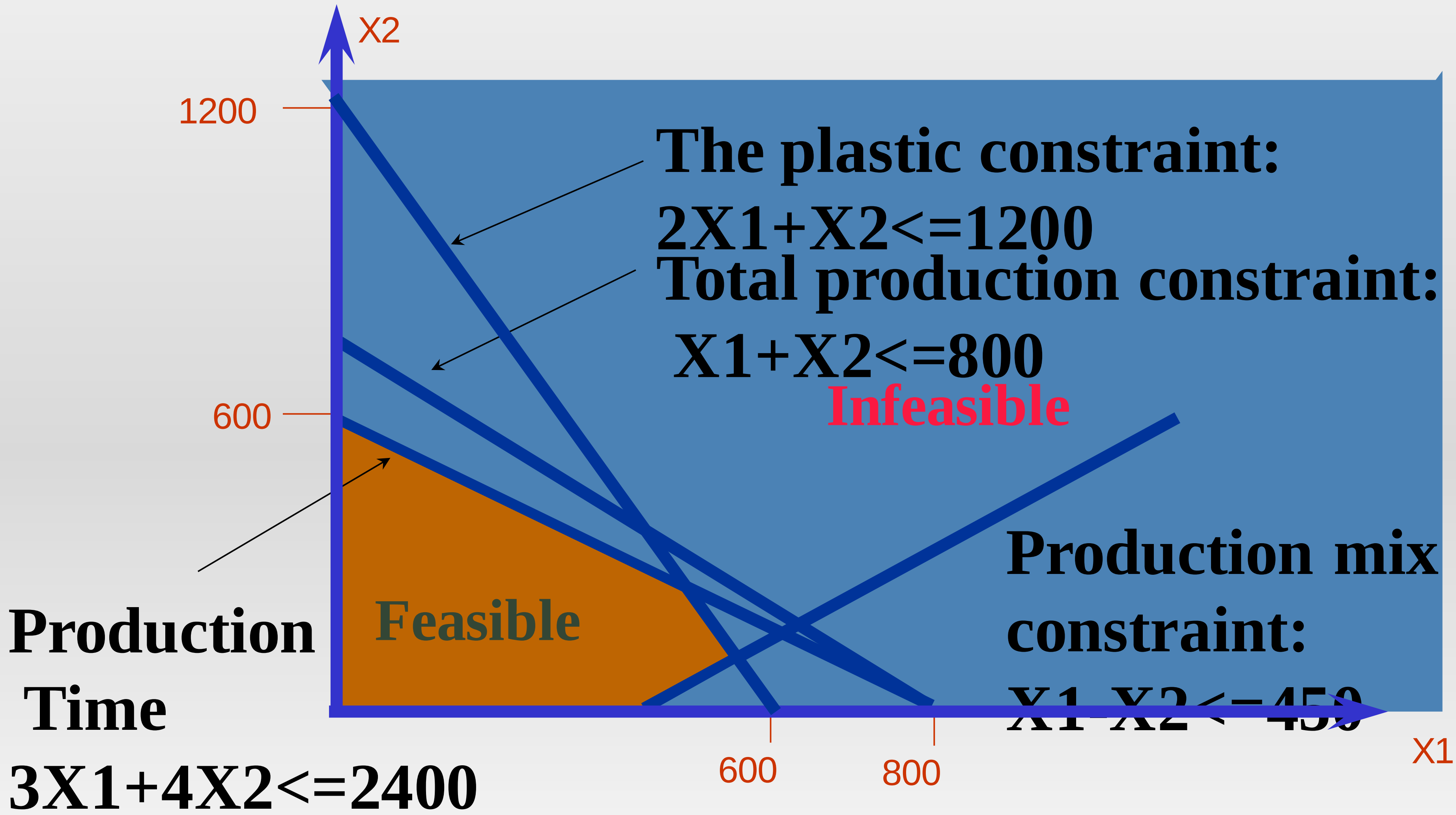
$X_j >= 0, \; j = 1,2$ (Nonnegativity)

Feasible Solutions for Linear Programs

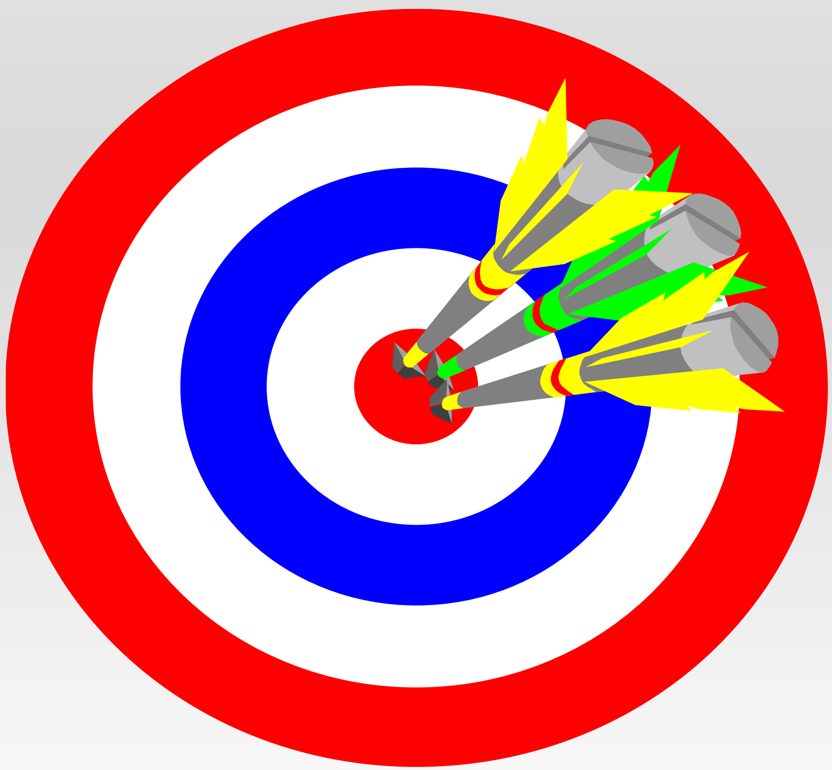
- The set of all points that satisfy all the constraints of the model is called

FEASIBLE REGION

Using a graphical presentation we can represent all the constraints, the objective function, and the three types of feasible points.


X2
1200
600
The plastic constraint:
2X1+X2<=1200
Total production constraint:
X1+X2<=800
Infeasible
Production mix
constraint:
X1-X2<=450
Feasible
Production
Time
3X1+4X2<=2400
600
800
X1

Solving Graphically for an Optimal Solution

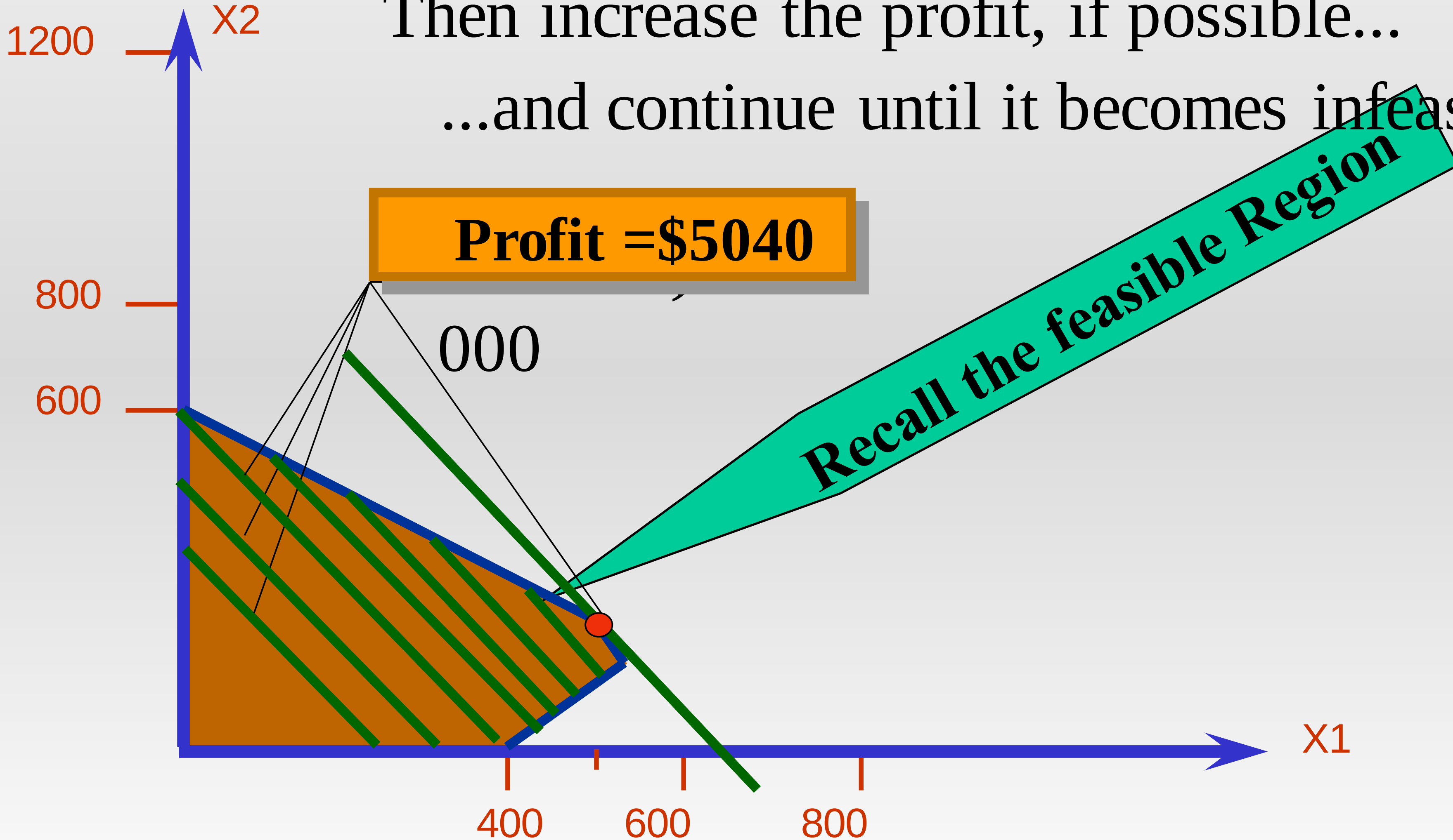


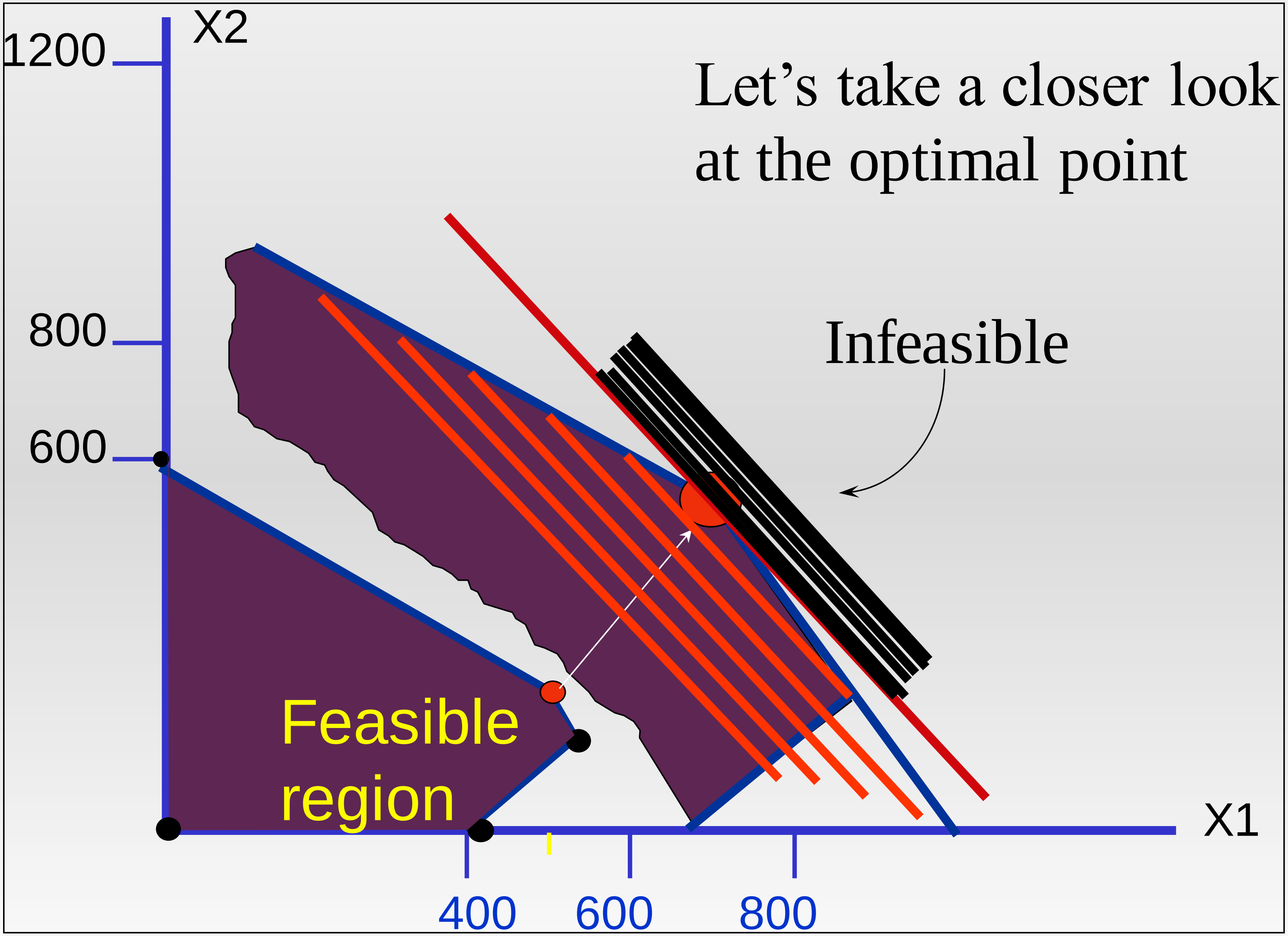
We now demonstrate the search for an optimal solution

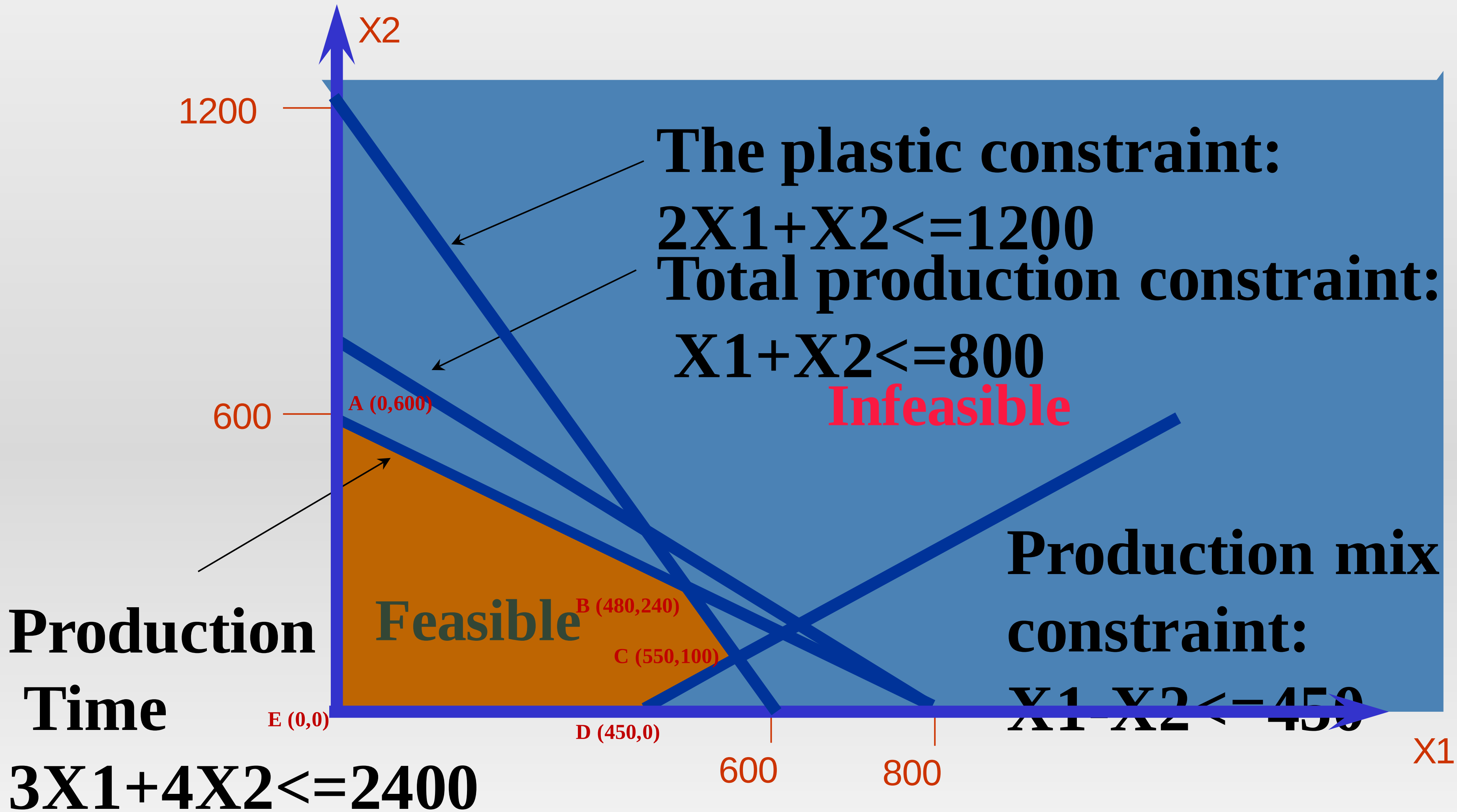
Start at some arbitrary profit, say profit = $2,000...

Then increase the profit, if possible...

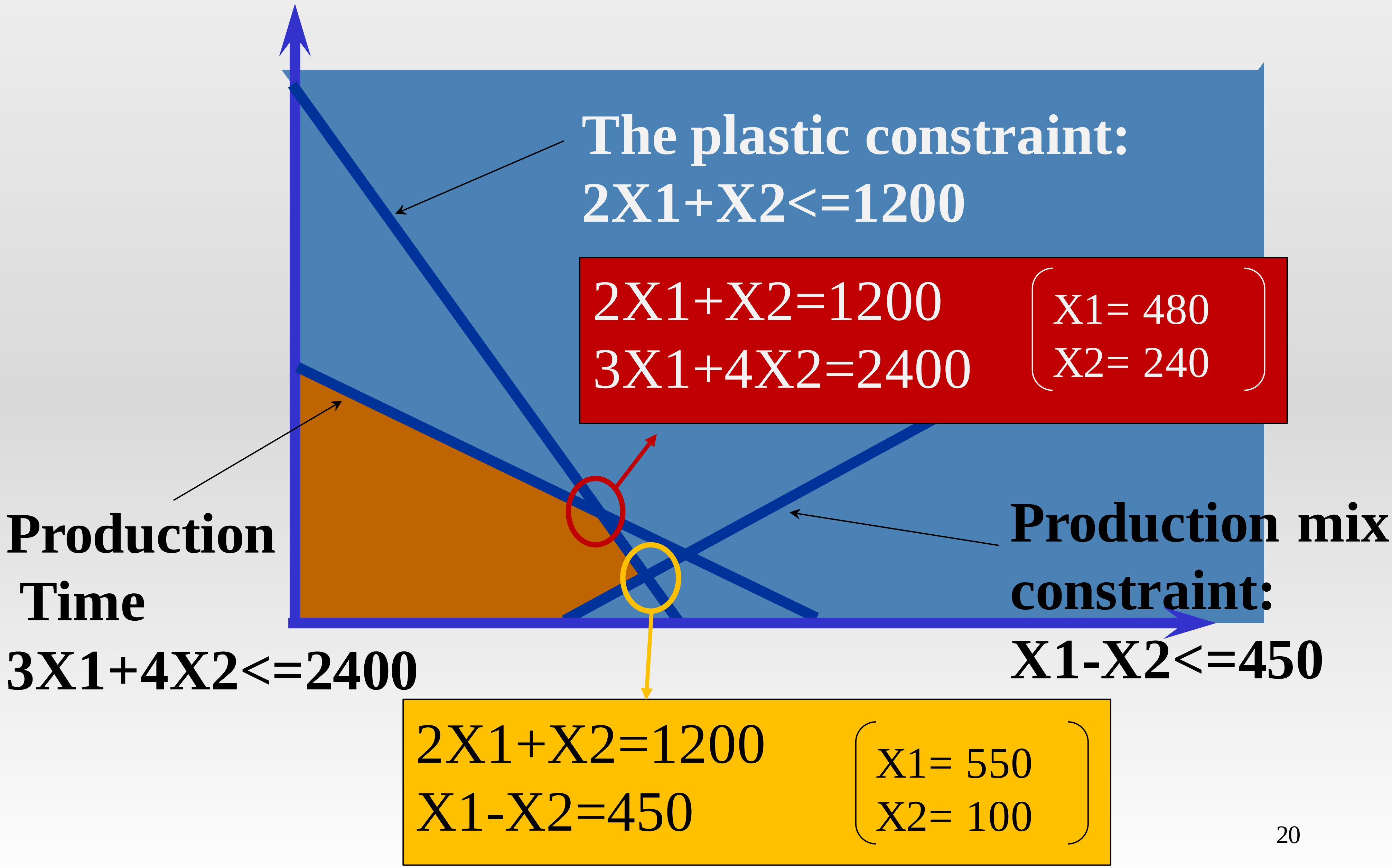
...and continue until it becomes infeasil




X2
1200
800
600
Let's take a closer look at the optimal point
Infeasible
Feasible region
X1
400
600
800


X2
1200
600
The plastic constraint:
2X1+X2<=1200
Total production constraint:
X1+X2<=800
Infeasible
A (0,600)
Production mix
constraint:
X1-X2<=450
Feasible
B (480,240)
C (550,100)
Production
Time
3X1+4X2<=2400
E (0,0)
D (450,0)
600
800
X1

- To determine the value for X1 and X2 at the optimal point, the two equations of the binding constraint must be solved.


The plastic constraint:
2X1+X2<=1200
2X1+X2=1200
3X1+4X2=2400
X1= 480
X2= 240
Production
Time
3X1+4X2<=2400
Production mix
constraint:
X1-X2<=450
2X1+X2=1200
X1-X2=450
X1= 550
X2= 100

By Compensation on :

Max 8X1 + 5X2

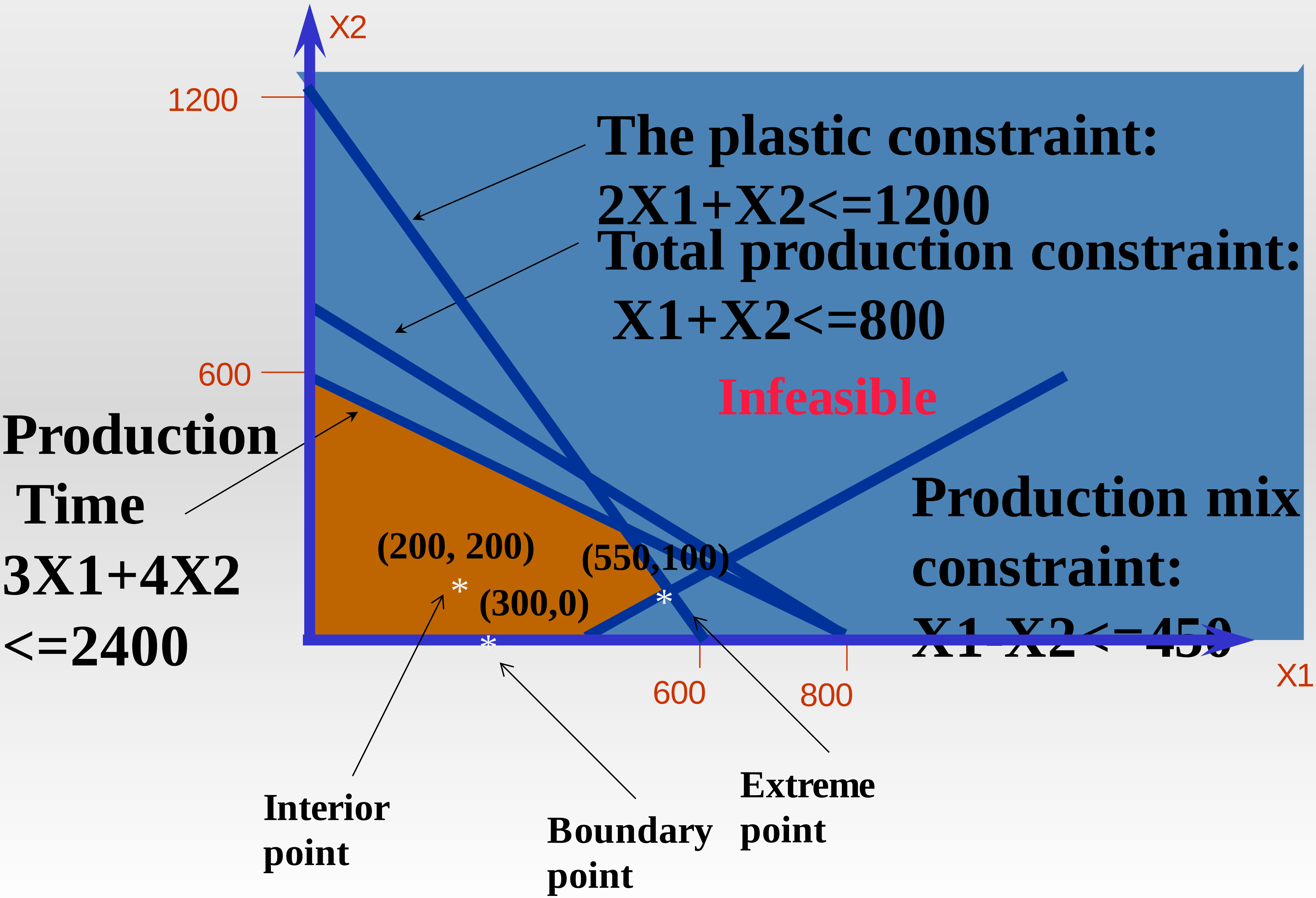
(X1, X2)	Objective fn
(0,0)	0
(450,0)	3600
(480,240)	5040
(550,100)	4900
(0,600)	3000

The maximum profit (5040) will be by producing:

Space Rays = 480 dozens, Zappers = 240 dozens

Type of feasible points

- Interior point: satisfies all constraint but non with equality.
- Boundary points: satisfies all constraints, at least one with equality
- Extreme point: satisfies all constraints, two with equality.


X2
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600
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Total production constraint:
X1+X2<=800
Infeasible
Production Time
3X1+4X2
<=2400
Production mix
constraint:
X1-X2<=450
(200, 200)
(550,100)
(300,0)
*
*
*
600
800
X1
Interior
point
Boundary
point
Extreme
point

- If a linear programming has an optimal solution , an extreme point is optimal.

Summery of graphical solution procedure

1- graph constraint to find the feasible point

2- set objective function equal to an arbitrary value so that line passes through the feasible region.

3- move the objective function line parallel to itself until it touches the last point of the feasible region .

4- solve for X1 and X2 by solving the two equation that intersect to determine this point

5- substitute these value into objective function to determine its optimal solution.

MORE EXAMPLE

Example 2.1-1 (The Reddy Mikks Company)

- Reddy Mikks produces both interior and exterior paints from two raw materials M1 and M2

	Tons of raw material per ton of		
	Exterior paint	Interior paint	Maximum daily availability (tons)
Raw material M1	6	4	24
Raw material M2	1	2	6
Profit per ton ($1000)	5	4	

-Daily demand for interior paint cannot exceed that of exterior paint by more than 1 ton

-Maximum daily demand of interior paint is 2 tons

-Reddy Mikks wants to determine the optimum product mix of interior and exterior paints that maximizes the total daily profit

Solution:

Let x_1 = tons produced daily of exterior paint

x_2 = tons produced daily of interior paint

Let z represent the total daily profit (in thousands of dollars)

Objective:

Maximize $z = 5x_1 + 4x_2$

(Usage of a raw material by both paints) $\leq$ (Maximum raw material availability)

Usage of raw material M1 per day = $6x_1 + 4x_2$ tons

Usage of raw material M2 per day = $1x_1 + 2x_2$ tons

- daily availability of raw material M1 is 24 tons
- daily availability of raw material M2 is 6 tons

Restrictions:

$6x_1 + 4x_2 \leq 24$ (raw material M1)

$x_1 + 2x_2 \leq 6$ (raw material M2)

- Difference between daily demand of interior (x_2) and exterior (x_1) paints does not exceed 1 ton,

  so $x_2 - x_1 \leq 1$

- Maximum daily demand of interior paint is 2 tons,

  so $x_2 \leq 2$

- Variables x_1 and x_2 cannot assume negative values,

  so $x_1 \geq 0$, $x_2 \geq 0$

Complete Reddy Mikks model:

Maximize $z = 5x_1 + 4x_2$ (total daily profit)

subject to

$$6x_1 + 4x_2 \leq 24 \quad \text{(raw material M1)}$$

$$x_1 + 2x_2 \leq 6 \quad \text{(raw material M2)}$$

$$x_2 - x_1 \leq 1$$

$$x_2 \leq 2$$

$$x_1 \geq 0$$

$$x_2 \geq 0$$

- Objective and the constraints are all linear functions in this example.

Properties of the LP model:

Linearity implies that the LP must satisfy three basic properties:

1) Proportionality:

- contribution of each decision variable in both the objective function and constraints to be directly proportional to the value of the variable

2) Additivity:

- total contribution of all the variables in the objective function and in the constraints to be the direct sum of the individual contributions of each variable

3) Certainty:

- All the objective and constraint coefficients of the LP model are deterministic (known constants)
- LP coefficients are average-value approximations of the probabilistic distributions
- If standard deviations of these distributions are sufficiently small , then the approximation is acceptable
- Large standard deviations can be accounted for directly by using stochastic LP algorithms or indirectly by applying sensitivity analysis to the optimum solution

Example 2.1-2
(Problem Mix Model)

- Two machines X and Y
- X is designed for 5-ounce bottles
- Y is designed for 10-ounce bottles
- X can also produce 10-ounce bottles with some loss of efficiency
- Y can also produce 5-ounce bottles with some loss of efficiency

Machine	5-ounce bottles	10-ounce bottles
X	80/min	30/min
Y	40/min	50/min

- X and Y machines can run 8 hours per day for 5 days a week
- Profit on 5-ounce bottle is 20 paise
- Profit on 10-ounce bottle is 30 paise
- Weekly production of the drink cannot exceed 500,000 ounces
- Market can utilize 30,000 (5-ounce) bottles and 8000 (10-ounce) bottles per week
- To maximize the profit

Solution:

Let X_1 = number of 5-ounce bottles to be produced per week

$X2$ = number of 10-ounce bottles to be produced per week

Objective:

Maximize profit $z = \text{Rs}\ (0.20x_1 + 0.30x_2)$

Constraints:

- Time constraint on machine X,

  $(x_1/80) + (x_2/30) \leq 8 \times 60 \times 5 = 2400$ minutes
- Time constraint on machine Y,

  $(x_1/40) + (x_2/50) \leq 8 \times 60 \times 5 = 2400$ minutes
- Weekly production of the drink cannot exceed 500,000 ounces,

  $5x_1 + 10x_2 \leq 500{,}000$ ounces
- Market demand per week,

  $x_1 \geq 30{,}000$ (5-ounce bottles)

  $x_2 \geq 8{,}000$ (10-ounce bottles)

Example 2.1-3
(Production Allocation Model)

- Two types of products A and B
- Profit of Rs.4 on type A
- Profit of Rs.5 on type B
- Both A and B are produced by X and Y machines

Products	Machine X	Machine Y
A	2 minutes	3 minutes
B	2 minutes	2 minutes

- Machine X is available for maximum 5 hours and 30 minutes during any working day

- Machine Y is available for maximum 8 hours during any working day

- Formulate the problem as a LP problem.

Solution:

Let x_1 = number of products of type A

x_2 = number of products of type B

Objective:

- Profit of Rs.4 on type A , therefore $4x_1$ will be the profit on selling x_1 units of type A
- Profit of Rs.5 on type B, therefore $5x_2$ will be the profit on selling x_2 units of type B

Total profit,

$$z = 4x_1 + 5x_2$$

Constraints:

- Time constraint on machine X,

$$2x_1 + 2x_2 \leq 330 \text{ minutes}$$

- Time constraint on machine Y,

$$3x_1 + 2x_2 \leq 480 \text{ minutes}$$

- Non-negativity restrictions are,

$$x_1 \geq 0 \text{ and } x_2 \geq 0$$

Complete LP model is,

$$\text{Maximize } z = 4x_1 + 5x_2$$

subject to

$$2x_1 + 2x_2 \leq 330 \text{ minutes}$$

$$3x_1 + 2x_2 \leq 480 \text{ minutes}$$

$$x_1 \geq 0$$

$$x_2 \geq 0$$

2.2 GRAPHICAL LP SOLUTION

The graphical procedure includes two steps:

1) Determination of the feasible solution space.
2) Determination of the optimum solution from among all the feasible points in the solution space.

2.2.1 Solution of a Maximization model

Example 2.2-1 (Reddy Mikks model)

Step 1:

1) Determination of the feasible solution space:

- Find the coordinates for all the 6 equations of the restrictions (only take the equality sign)

$$6x_1 + 4x_2 \leq 24 \quad (1)$$

$$x_1 + 2x_2 \leq 6 \quad (2)$$

$$x_2 - x_1 \leq 1 \quad (3)$$

$$x_2 \leq 2 \quad (4)$$

$$x_1 \geq 0 \quad (5)$$

$$x_2 \geq 0 \quad (6)$$

- Change all equations to equality signs

$$6x_1 + 4x_2 = 24 \qquad (1)$$

$$x_1 + 2x_2 = 6 \qquad (2)$$

$$x_2 - x_1 = 1 \qquad (3)$$

$$x_2 = 2 \qquad (4)$$

$$x_1 = 0 \qquad (5)$$

$$x_2 = 0 \qquad (6)$$

- Plot graphs of $x_1 = 0$ and $x_2 = 0$
- Plot graph of $6x_1 + 4x_2 = 24$ by using the coordinates of the equation
- Plot graph of $x_1 + 2x_2 = 6$ by using the coordinates of the equation
- Plot graph of $x_2 - x_1 = 1$ by using the coordinates of the equation
- Plot graph of $x_2 = 2$ by using the coordinates of the equation

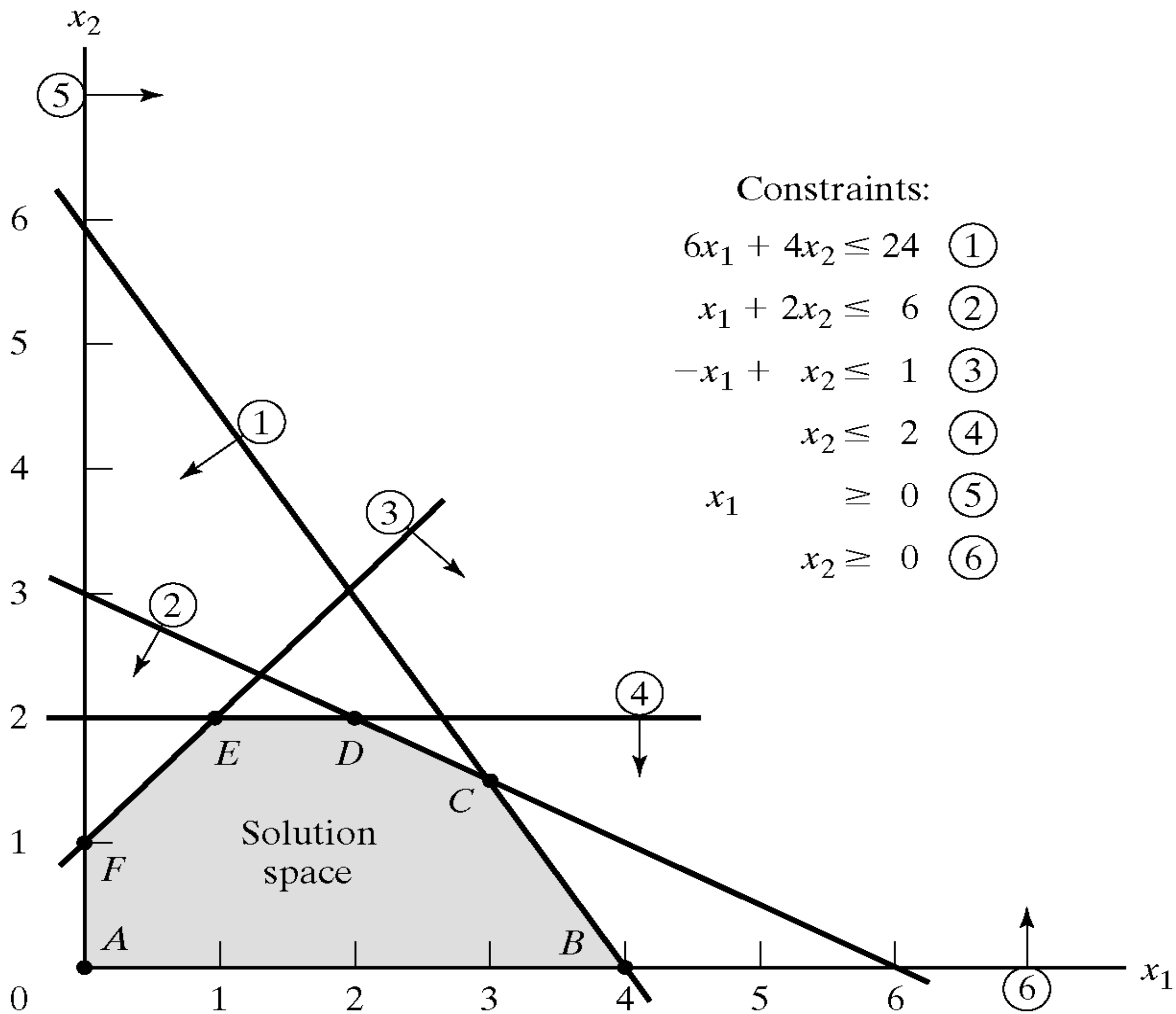


Figure 2.1

Feasible space of the Reddy Mikks model.

- Now include the inequality of all the 6 equations
- Inequality divides the (x1, x2) plane into two half spaces , one on each side of the graphed line
- Only one of these two halves satisfies the inequality
- To determine the correct side , choose (0,0) as a reference point
- If (0,0) coordinate satisfies the inequality, then the side in which (0,0) coordinate lies is the feasible half-space , otherwise the other side is
- If the graph line happens to pass through the origin (0,0) , then any other point can be used to find the feasible half-space

Step 2:

2) Determination of the optimum solution from among all the feasible points in the solution space:

- After finding out all the feasible half-spaces of all the 6 equations, feasible space is obtained by the line segments joining all the corner points A, B, C, D ,E and F
- Any point within or on the boundary of the solution space ABCDEF is feasible as it satisfies all the constraints
- Feasible space ABCDEF consists of infinite number of feasible points

- To find optimum solution identify the direction in which the maximum profit increases , that is $z = 5x1 + 4x2$
- Assign random increasing values to z , $z = 10$ and $z = 15$

$$5x1 + 4x2 = 10$$
$$5x1 + 4x2 = 15$$

- Plot graphs of above two equations
- Thus in this way the optimum solution occurs at corner point C which is the point in the solution space
- Any further increase in z that is beyond corner point C will put points outside the boundaries of ABCDEF feasible space
- Values of x_1 and x_2 associated with optimum corner point C are determined by solving the equations 1 and 2

$$6x_1 + 4x_2 = 24 \quad (1)$$
$$x_1 + 2x_2 = 6 \quad (2)$$

- $x_1 = 3$ and $x_2 = 1.5$ with $z = 5 \times 3 + 4 \times 1.5 = 21$
- So daily product mix of 3 tons of exterior paint and 1.5 tons of interior paint produces the daily profit of $21,000 .

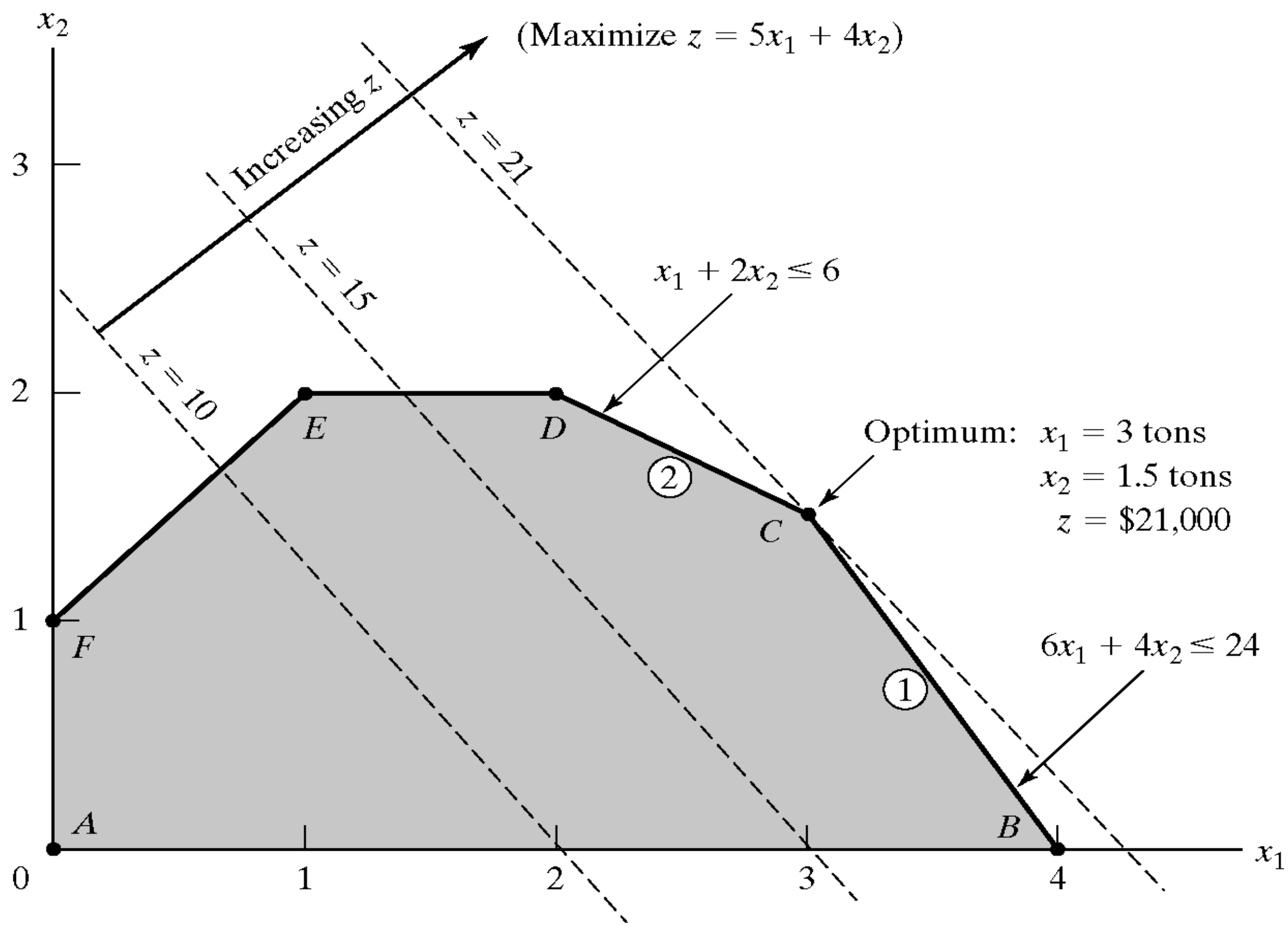


Figure 2.2
Optimum solution of the Reddy Mikks model.

- Important characteristic of the optimum LP solution is that it is always associated with a corner point of the solution space (where two lines intersect)
- This is even true if the objective function happens to be parallel to a constraint
- For example if the objective function is,

$$z = 6x_1 + 4x_2$$

- The above equation is parallel to constraint of equation 1

- So optimum occurs at either corner point B or corner point C when parallel
- Actually any point on the line segment BC will be an alternative optimum
- Line segment BC is totally defined by the corner points B and C

- Since optimum LP solution is always associated with a corner point of the solution space, so optimum solution can be found by enumerating all the corner points as below:-

Corner point	(X_1,X_2)	z	
A	(0,0)	0	
B	(4,0)	20	
C	**(3,1.5)**	**21**	**(optimum solution)**
D	(2,2)	18	
E	(1,2)	13	
F	(0,1)	4	

- As number of constraints and variables increases , the number of corner points also increases

2.2.2 Solution of a Minimization model

Example 2.2-3

- Firm or industry has two bottling plants
- One plant located at Coimbatore and other plant located at Chennai
- Each plant produces three types of drinks Coca-cola , Fanta and Thumps-up

	Number of bottles produced per day by plant at	
	Coimbatore	Chennai
Coca-cola	15,000	15,000
Fanta	30,000	10,000
Thumps-up	20,000	50,000
Cost per day (in any unit)	600	400

- Market survey indicates that during the month of April there will be a demand of 200,000 bottles of Coca-cola , 400,000 bottles of Fanta , and 440,000 bottles of Thumps-up
- For how many days each plant be run in April so as to minimize the production cost , while still meeting the market demand?

Solution:

Let x_1 = number of days to produce all the three types of bottles by plant at Coimbatore

x_2 = number of days to produce all the three types of bottles by plant at Chennai

Objective:

$$\text{Minimize } z = 600\,x_1 + 400\,x_2$$

Constraint:

$$15{,}000\,x_1 + 15{,}000\,x_2 \geq 200{,}000 \qquad (1)$$

$$30{,}000\,x_1 + 10{,}000\,x_2 \geq 400{,}000 \qquad (2)$$

$$20{,}000\,x_1 + 50{,}000\,x_2 \geq 440{,}000 \qquad (3)$$

$$x_1 \geq 0 \qquad (4)$$

$$x_2 \geq 0 \qquad (5)$$

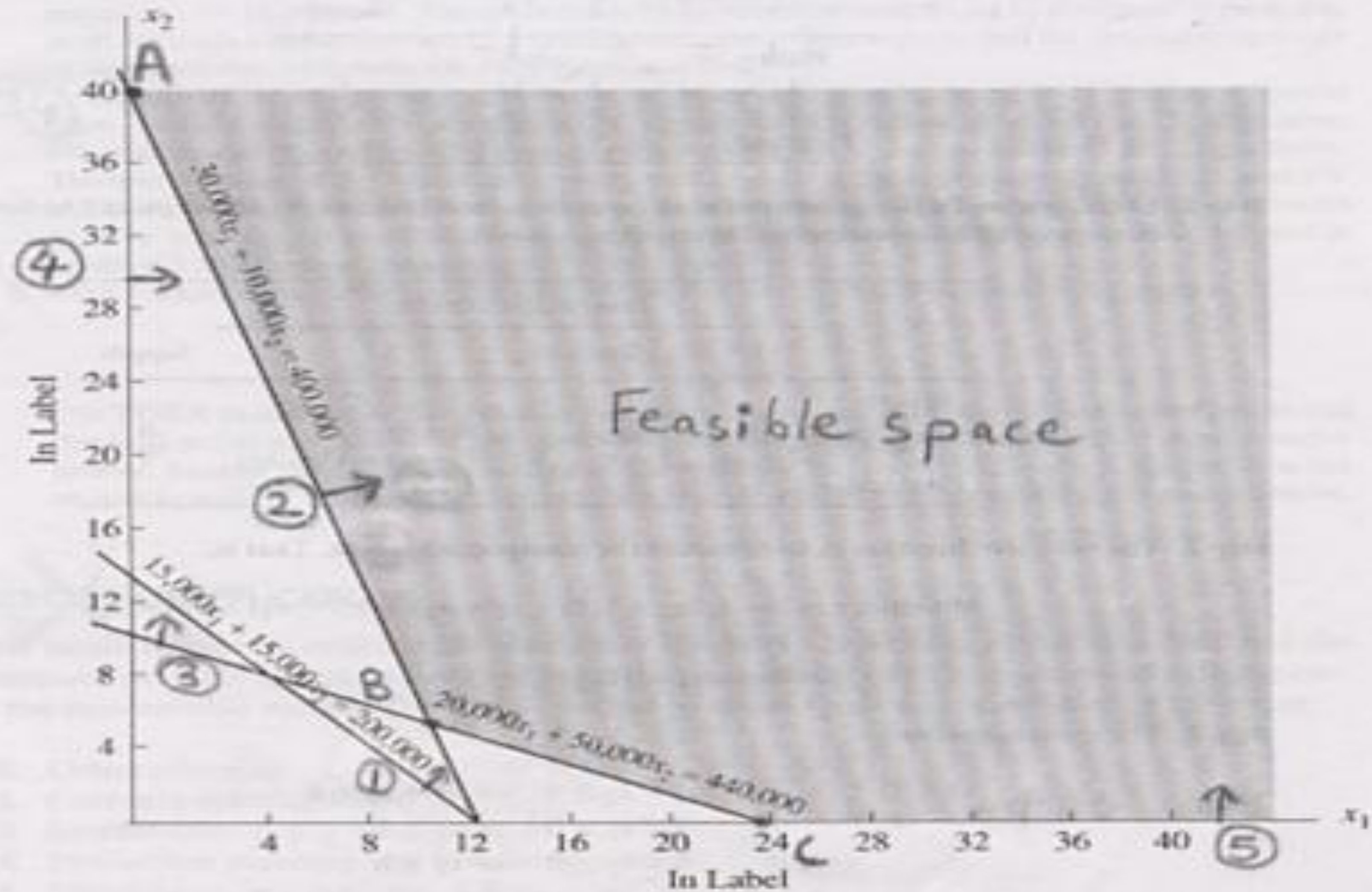


FIGURE 2.4
Graphical representation of the LP problem in Example 2.2-3.

Corner points	(x_1,x_2)	$z = 600\, x_1 + 400\, x_2$
A	(0, 40)	16000
B	(12,4)	8800
C	(22,0)	13200

- In 12 days all the three types of bottles (Coca-cola, Fanta, Thumps-up) are produced by plant at Coimbatore
- In 4 days all the three types of bottles (Coca-cola, Fanta, Thumps-up) are produced by plant at Chennai
- So minimum production cost is 8800 units to meet the market demand of all the three types of bottles (Coca-cola, Fanta, Thumps-up) to be produced in April

Sensitivity Analysis

The Role of Sensitivity Analysis of the Optimal Solution

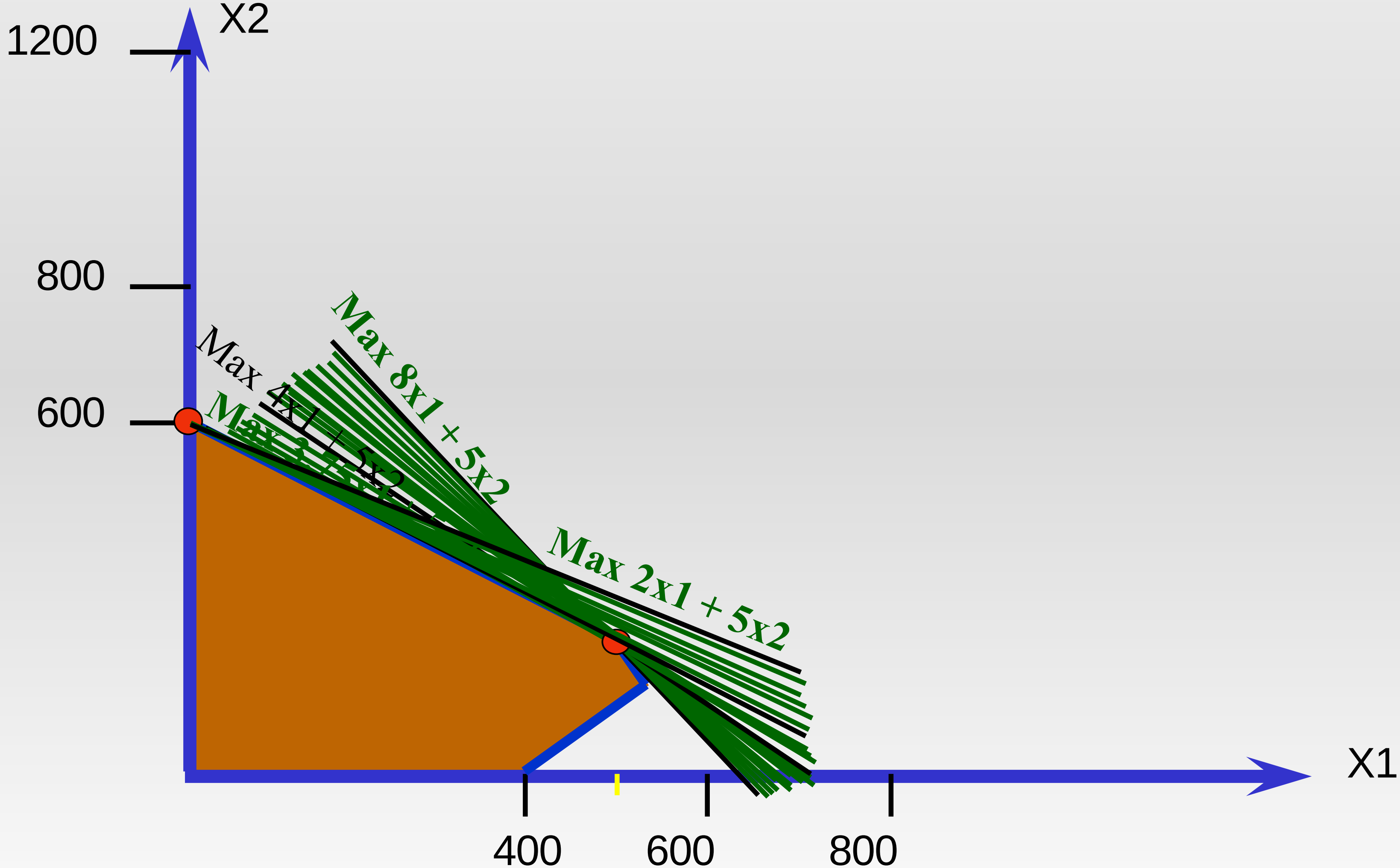
- Is the optimal solution sensitive to changes in input parameters?

The effective of this change is known as “sensitivity”

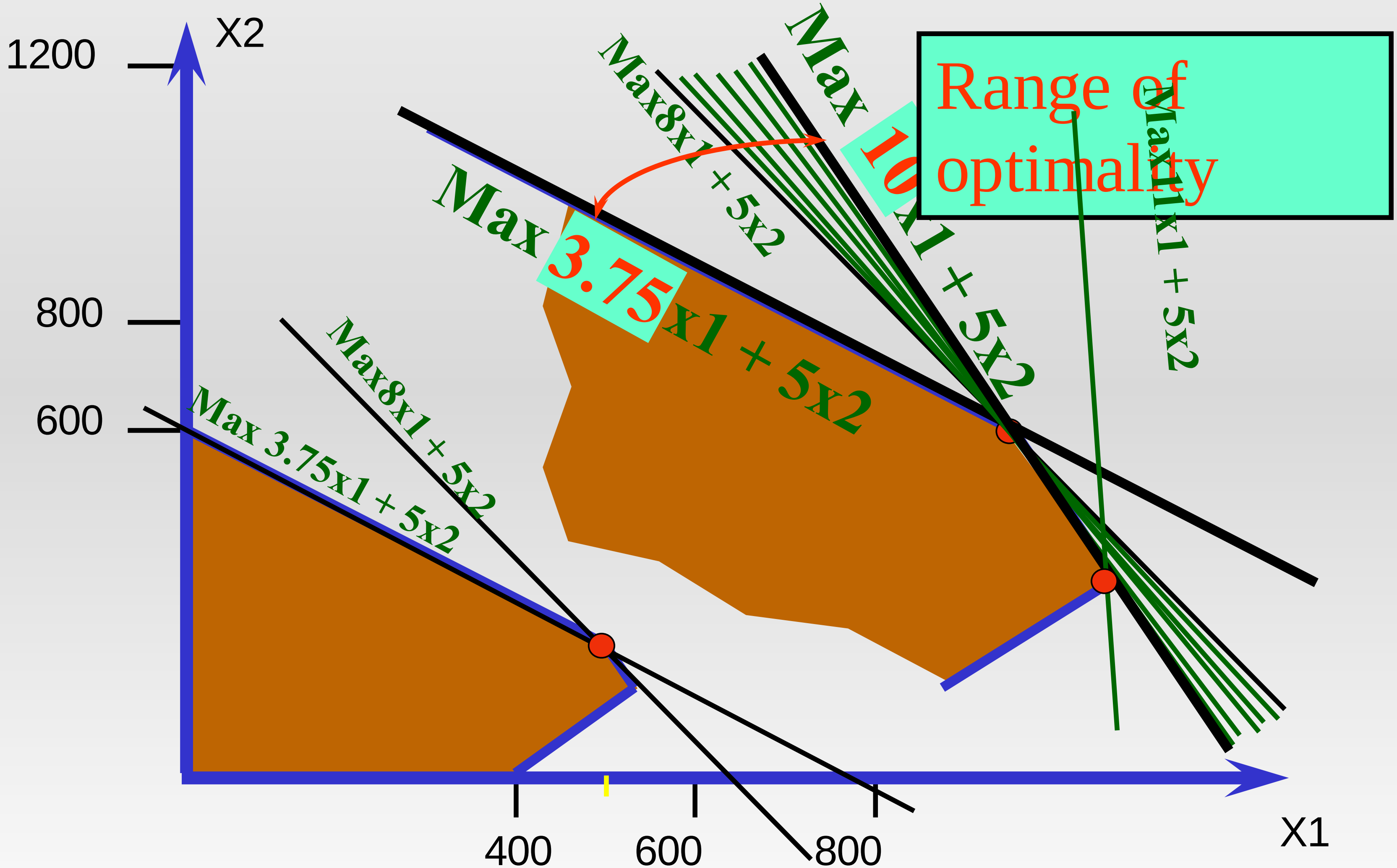
Sensitivity Analysis of Objective Function Coefficients.

- Range of Optimality
  - The optimal solution will remain unchanged as long as
    - An objective function coefficient lies within its ***range of optimality***
    - There are no changes in any other input parameters.

The effects of changes in an objective function coefficient on the optimal solution



The effects of changes in an objective function coefficients on the optimal solution



- It could be find the range of optimality for an objectives function coefficient by determining the range of values that gives a slope of the objective function line between the slopes of the binding constraints.

- The binding constraints are:

  $2X1 + X2 = 1200$

  $3X1 + 4X2 = 2400$

  The slopes are: -2/1, and -3/4 respectively.

- To find range optimality for Space Rays, and coefficient per dozen Zappers is C2= 5

Thus the slope of the objective function line can be expressed as

$$-C1/5$$

- Range of optimality for C1 is found by sloving the following for C1:

$$-2/1 \leq -C1/5 \leq -3/4$$

$$3.75 \leq C1 \leq 10$$

- Range optimality for Zapper, and coefficient per dozen space rays is $C1= 8$

Thus the slope of the objective function line can be expressed as

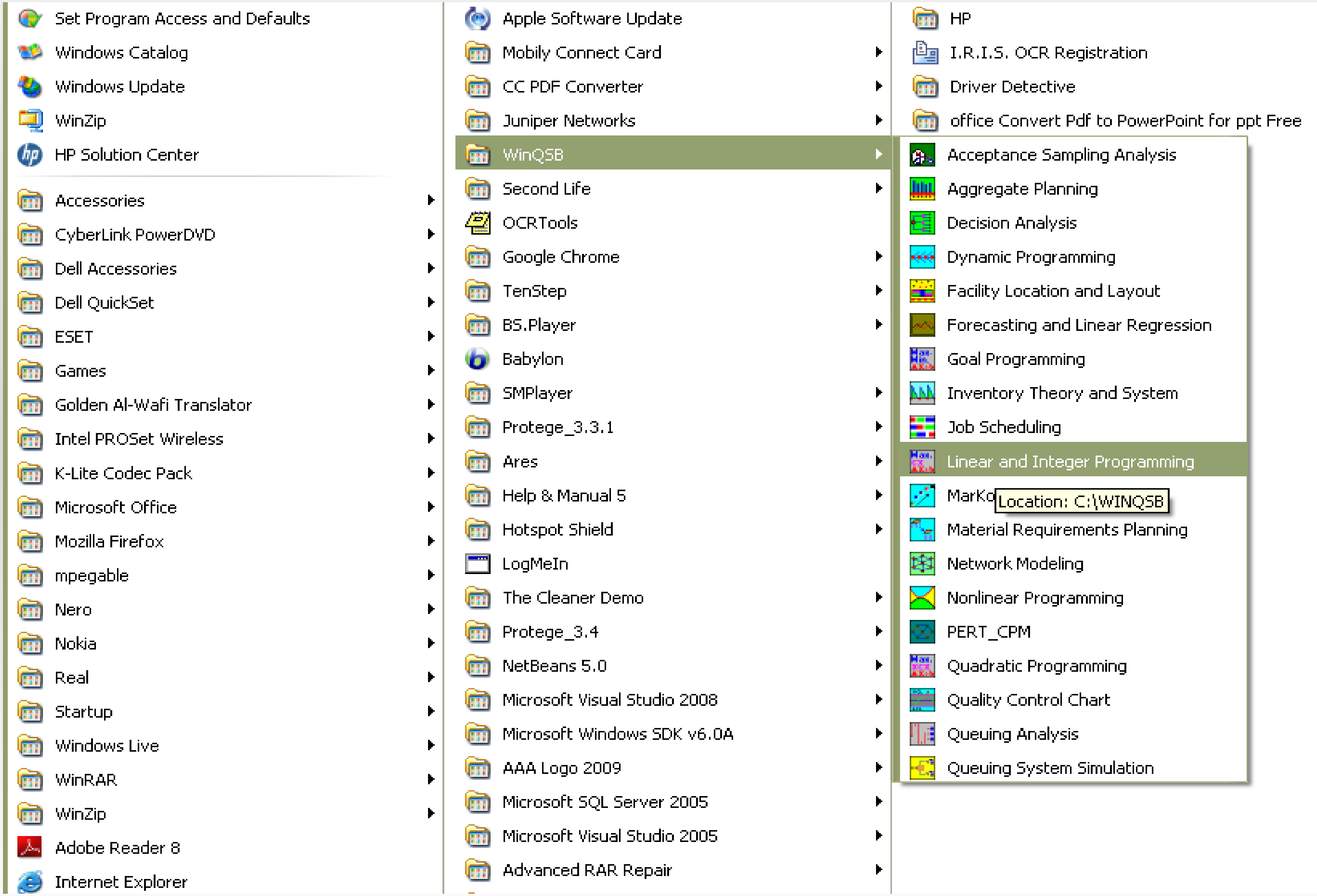
$$-8/C2$$

- Range of optimality for C2 is found by sloving the following for C2:

$$-2/1 \le -8/C2 \le -3/4$$

$$4 \le C2 \le 10.667$$

WINQSB Input Data for the Galaxy Industries Problem


Set Program Access and Defaults
Windows Catalog
Windows Update
WinZip
HP Solution Center
Accessories
CyberLink PowerDVD
Dell Accessories
Dell QuickSet
ESET
Games
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Intel PROSet Wireless
K-Lite Codec Pack
Microsoft Office
Mozilla Firefox
mpegable
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Nokia
Real
Startup
Windows Live
WinRAR
WinZip
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Second Life
OCRTools
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Decision Analysis
Dynamic Programming
Facility Location and Layout
Forecasting and Linear Regression
Goal Programming
Inventory Theory and System
Job Scheduling
Linear and Integer Programming
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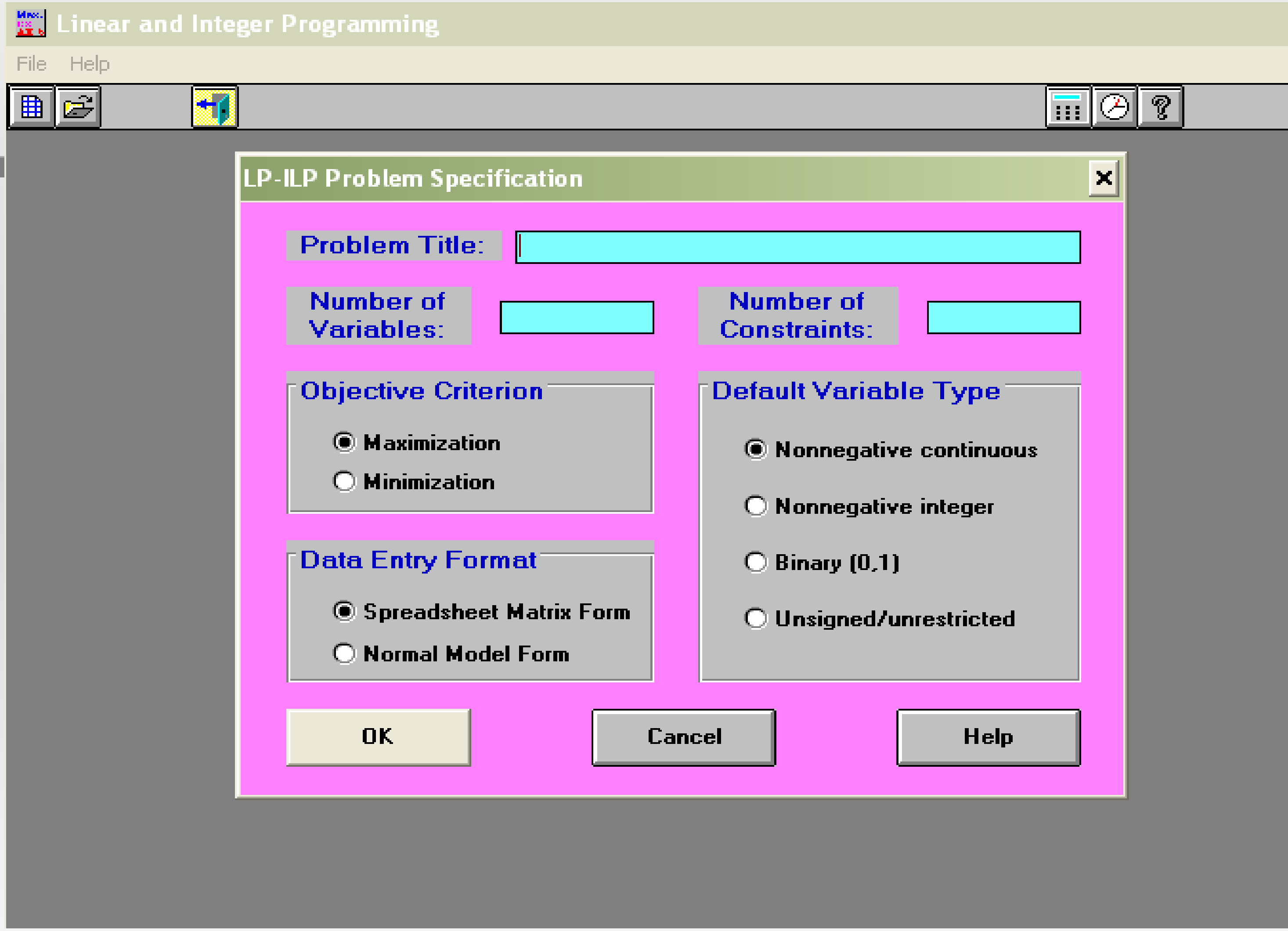
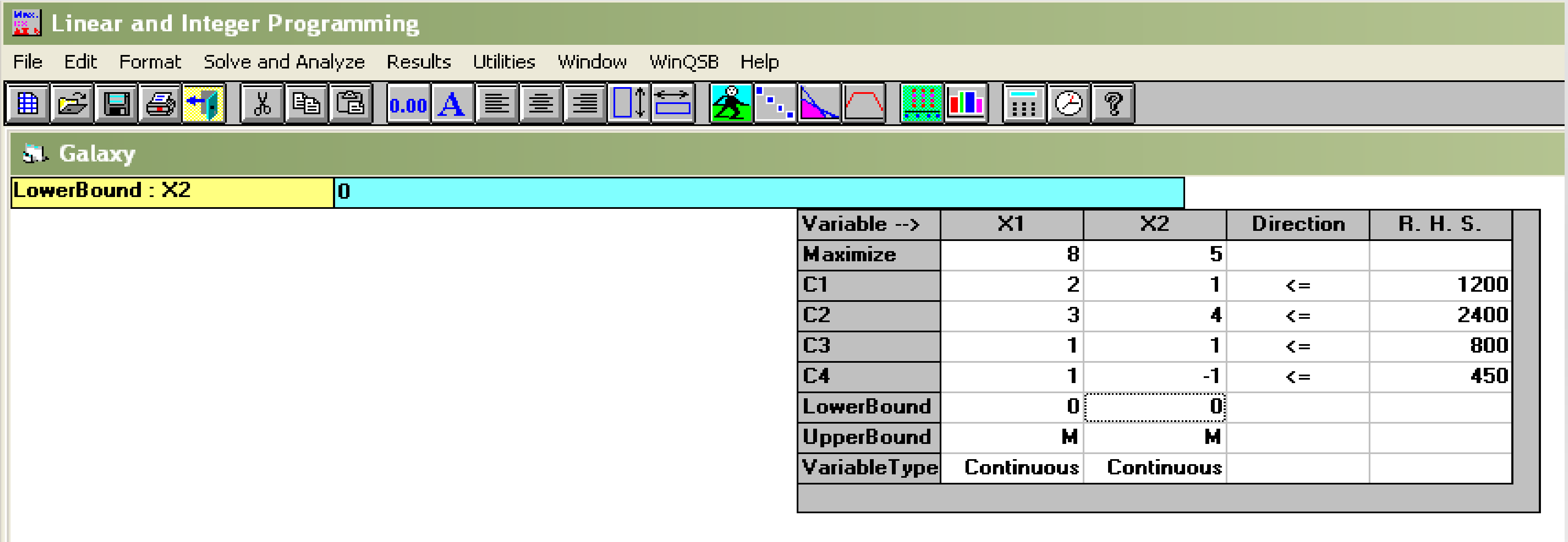
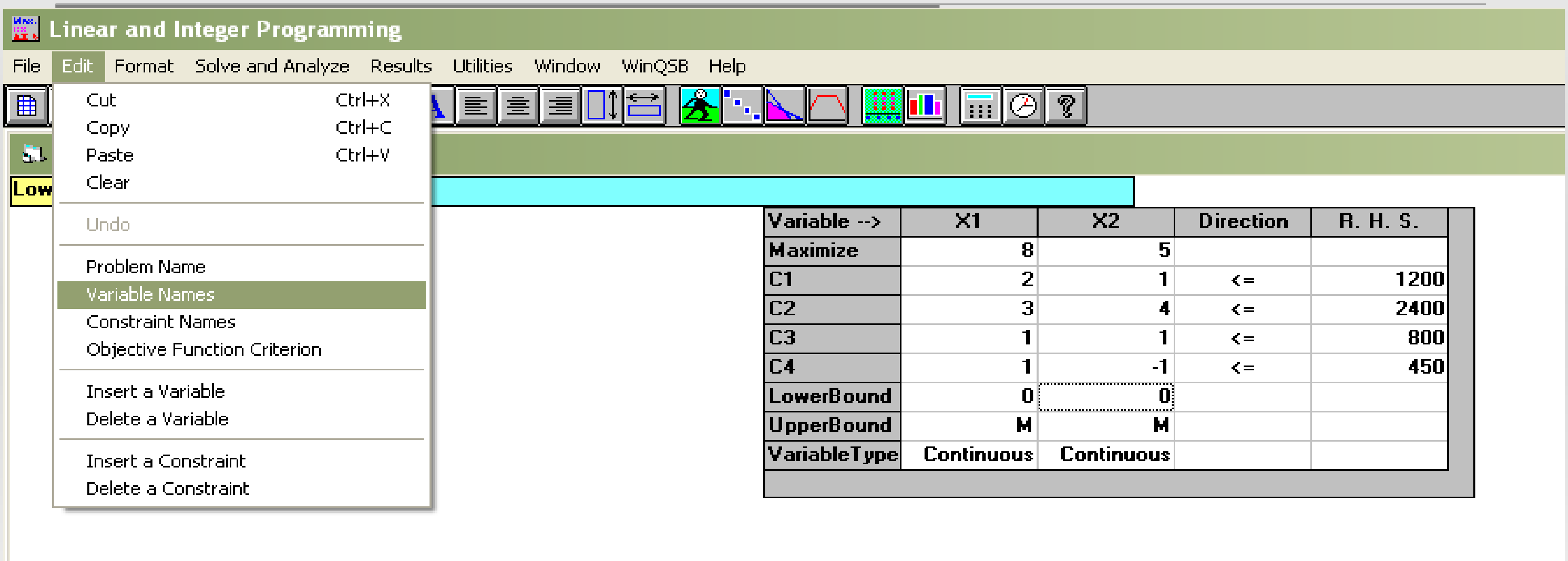
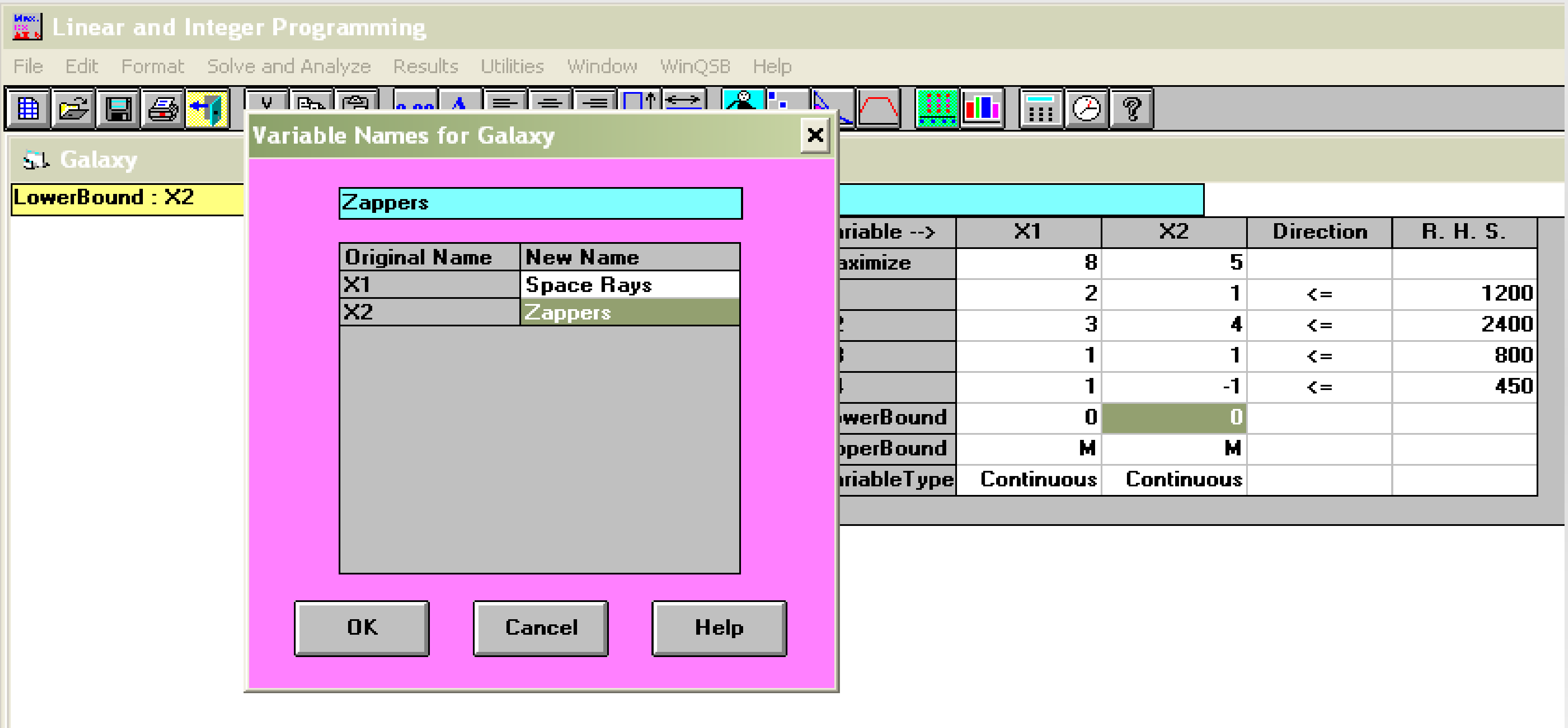
Nonlinear Programming
PERT_CPM
Quadratic Programming
Quality Control Chart
Queuing Analysis
Queuing System Simulation

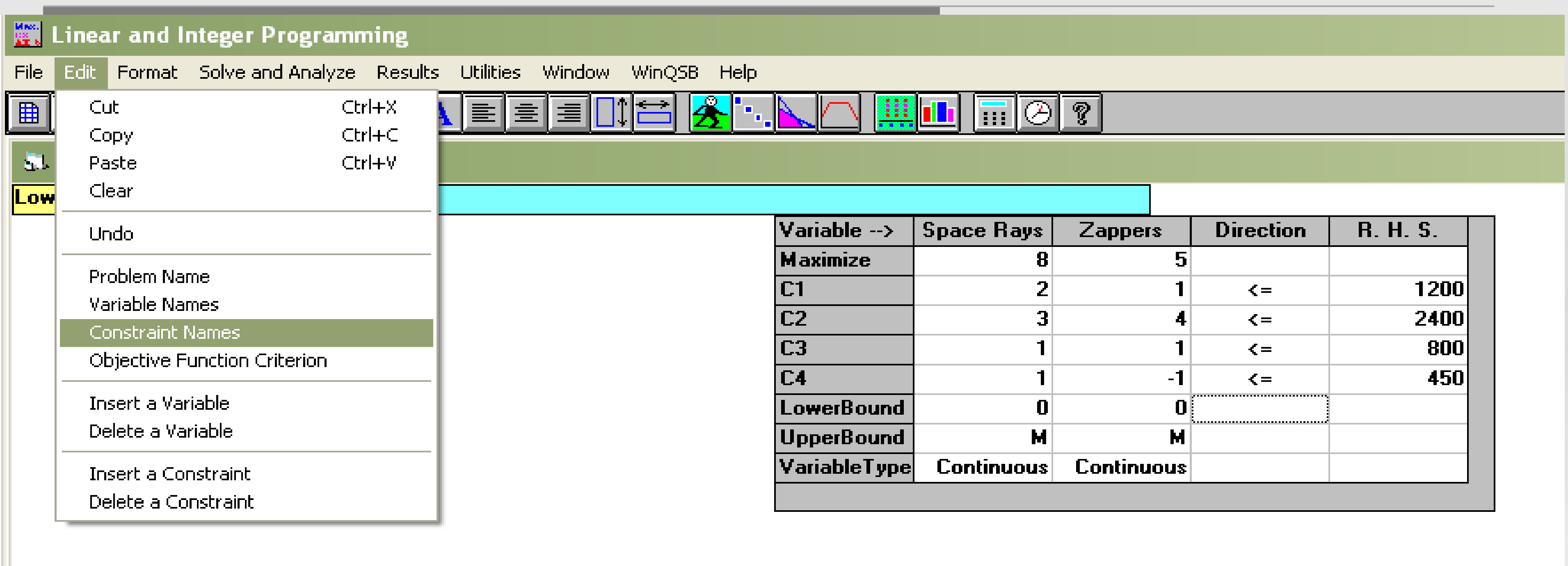

Linear and Integer Programming
File Help
LP-ILP Problem Specification
Problem Title:
Number of Variables:
Number of Constraints:
Objective Criterion
Maximization
Minimization
Default Variable Type
Nonnegative continuous
Nonnegative integer
Binary (0,1)
Unsigned/unrestricted
Data Entry Format
Spreadsheet Matrix Form
Normal Model Form
OK
Cancel
Help

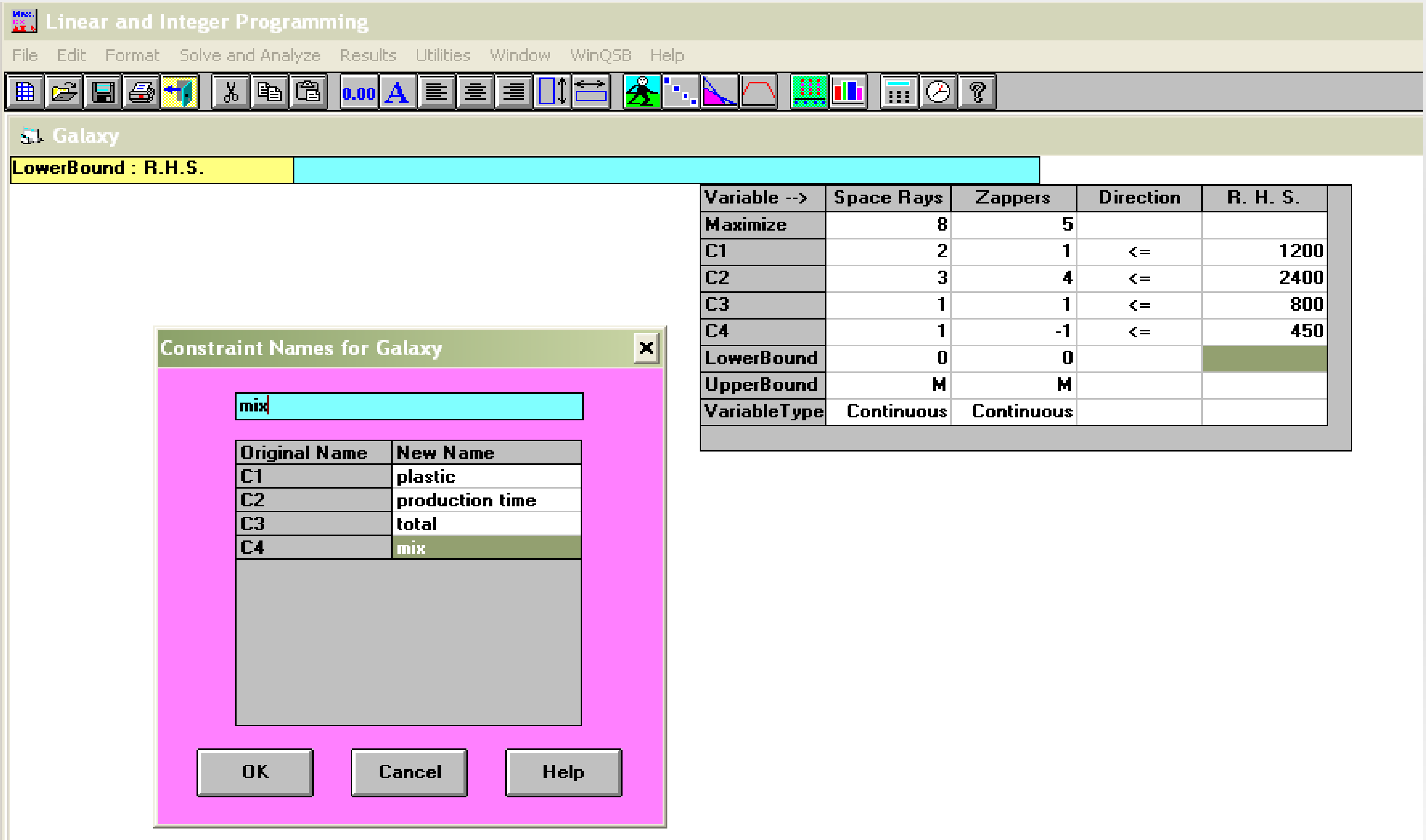


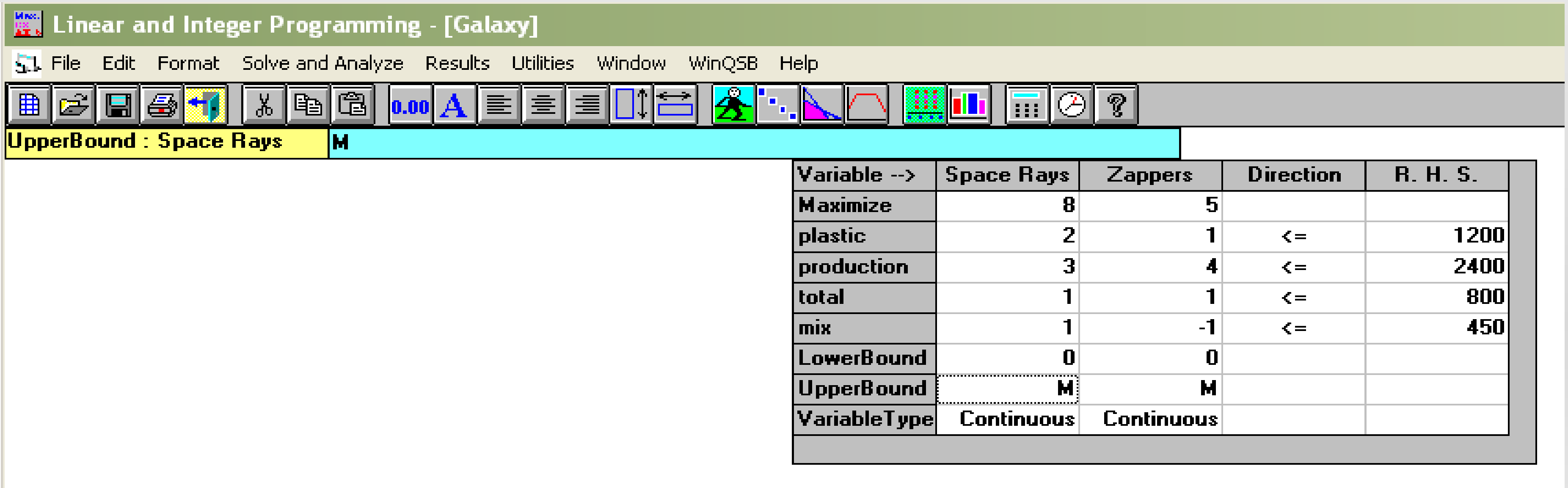
Variable -->	X1	X2	Direction	R. H. S.
Maximize	8	5		
C1	2	1	<=	1200
C2	3	4	<=	2400
C3	1	1	<=	800
C4	1	-1	<=	450
LowerBound	0	0		
UpperBound	M	M		
VariableType	Continuous	Continuous		


Linear and Integer Programming
File Edit Format Solve and Analyze Results Utilities Window WinQSB Help
Cut Ctrl+X
Copy Ctrl+C
Paste Ctrl+V
Clear
Undo
Problem Name
Variable Names
Constraint Names
Objective Function Criterion
Insert a Variable
Delete a Variable
Insert a Constraint
Delete a Constraint
Low
Variable --> | X1 | X2 | Direction | R. H. S.
Maximize | 8 | 5 | |
C1 | 2 | 1 | <= | 1200
C2 | 3 | 4 | <= | 2400
C3 | 1 | 1 | <= | 800
C4 | 1 | -1 | <= | 450
LowerBound | 0 | 0 | |
UpperBound | M | M | |
VariableType | Continuous | Continuous | |

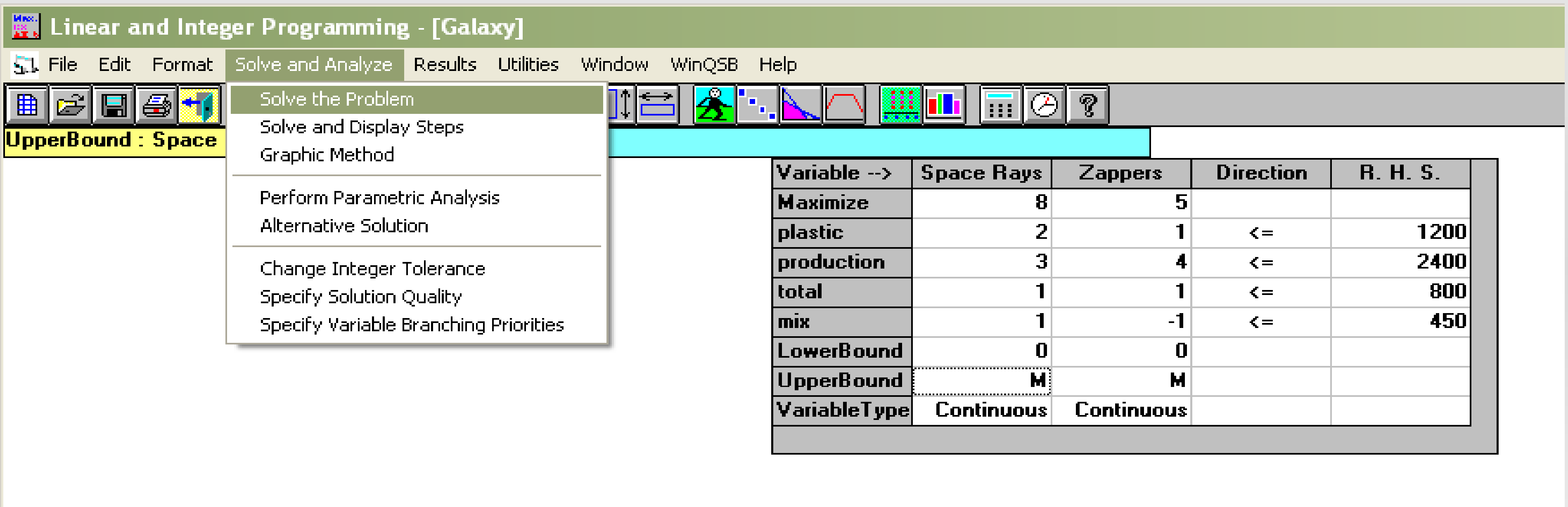

Linear and Integer Programming
File Edit Format Solve and Analyze Results Utilities Window WinQSB Help
Galaxy
LowerBound : X2
Variable Names for Galaxy
Zappers
Original Name
New Name
X1
Space Rays
X2
Zappers
OK
Cancel
Help
X1
X2
Direction
R. H. S.
8
5
2
1
<=
1200
3
4
<=
2400
1
1
<=
800
1
-1
<=
450
0
0
M
M
Continuous
Continuous


Linear and Integer Programming
File Edit Format Solve and Analyze Results Utilities Window WinQSB Help
Cut Ctrl+X
Copy Ctrl+C
Paste Ctrl+V
Clear
Undo
Problem Name
Variable Names
Constraint Names
Objective Function Criterion
Insert a Variable
Delete a Variable
Insert a Constraint
Delete a Constraint
Low
Variable --> Space Rays Zappers Direction R. H. S.
Maximize 8 5
C1 2 1 <= 1200
C2 3 4 <= 2400
C3 1 1 <= 800
C4 1 -1 <= 450
LowerBound 0 0
UpperBound M M
VariableType Continuous Continuous

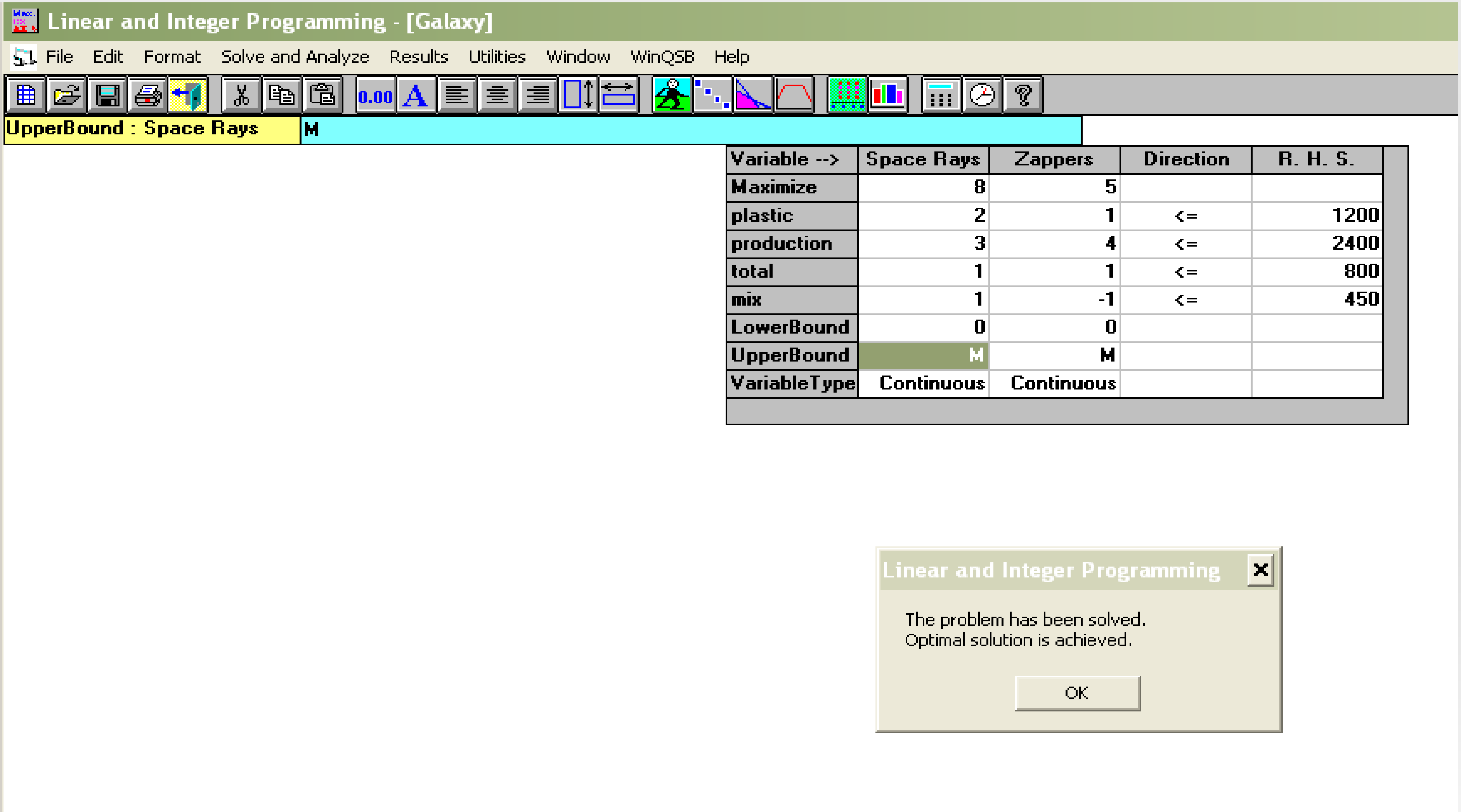

Linear and Integer Programming
File Edit Format Solve and Analyze Results Utilities Window WinQSB Help
0.00
Galaxy
LowerBound : R.H.S.
Variable --> | Space Rays | Zappers | Direction | R. H. S.
Maximize | 8 | 5
C1 | 2 | 1 | <= | 1200
C2 | 3 | 4 | <= | 2400
C3 | 1 | 1 | <= | 800
C4 | 1 | -1 | <= | 450
LowerBound | 0 | 0
UpperBound | M | M
VariableType | Continuous | Continuous
Constraint Names for Galaxy
mix
Original Name | New Name
C1 | plastic
C2 | production time
C3 | total
C4 | mix
OK
Cancel
Help



Variable -->	Space Rays	Zappers	Direction	R. H. S.
Maximize	8	5		
plastic	2	1	<=	1200
production	3	4	<=	2400
total	1	1	<=	800
mix	1	-1	<=	450
LowerBound	0	0		
UpperBound	M	M		
VariableType	Continuous	Continuous		



Variable -->	Space Rays	Zappers	Direction	R. H. S.
Maximize	8	5		
plastic	2	1	<=	1200
production	3	4	<=	2400
total	1	1	<=	800
mix	1	-1	<=	450
LowerBound	0	0		
UpperBound	M	M		
VariableType	Continuous	Continuous		



Variable -->	Space Rays	Zappers	Direction	R. H. S.
Maximize	8	5		
plastic	2	1	<=	1200
production	3	4	<=	2400
total	1	1	<=	800
mix	1	-1	<=	450
LowerBound	0	0		
UpperBound	M	M		
VariableType	Continuous	Continuous		

Linear and Integer Programming

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Combined Report for Galaxy

	21:52:32		Friday	October	30	2009		
	Decision Variable	Solution Value	Unit Cost or Profit c(j)	Total Contribution	Reduced Cost	Basis Status	Allowable Min. c(j)	Allowable Max. c(j)
1	Space Rays	480.0000	8.0000	3,840.0000	0	basic	3.7500	10.0000
2	Zappers	240.0000	5.0000	1,200.0000	0	basic	4.0000	10.6667
	Objective	Function	(Max.) =	5,040.0000				
	Constraint	Left Hand Side	Direction	Right Hand Side	Slack or Surplus	Shadow Price	Allowable Min. RHS	Allowable Max. RHS
1	plastic	1,200.0000	<=	1,200.0000	0	3.4000	600.0000	1,350.0000
2	production time	2,400.0000	<=	2,400.0000	0	0.4000	2,050.0000	2,800.0000
3	total	720.0000	<=	800.0000	80.0000	0	720.0000	M
4	mix	240.0000	<=	450.0000	210.0000	0	240.0000	M