

Linear Programming¹

1) A Person wants to decide the constituents amount of diet² which will fulfill his daily requirements of Proteins, Fats and Carbohydrates at a Minimum cost. The choice is to be made from four different types of foods. The yields per unit of those food are given below. Formulate Linear programming Model

Food type	Yield per unit			Cost per unit (Rs) ³
	Proteins	Fats	Carbohydrates	
1	3	2	6	45
2	4	2	4	40
3	8	7	7	85
4	6	5	4	65
Minimum Requirement	800	200	700	

Solution:⁴

Let X_1 Amount of Type1 food to be taken, Let X_2 Amount of Type2 to be taken, Let X_3 Amount of Type3 to be taken, Let X_4 Amount of Type4 to be taken,

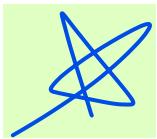
$Z_{\min} = 45X_1 + 40X_2 + 85X_3 + 65X_4$ ----Objective Equation⁶

$3X_1 + 4X_2 + 8X_3 + 6X_4 \geq 800$ [Protein constrain]⁷

$2X_1 + 2X_2 + 7X_3 + 5X_4 \geq 200$ [Fats constrain]⁸

$6X_1 + 4X_2 + 7X_3 + 4X_4 \geq 700$ [Carbohydrates constrain]⁹

$X_1 \geq 0, X_2 \geq 0, X_3 \geq 0, X_4 \geq 0$ { Non negative Constrain}¹⁰



1

Linear Programming ²

- 1) Old Hens can be bought for Rs. 300 each , Young one cost Rs. 500 each, Old Hen lay 3 eggs per week and young ones lay 5 eggs per week, Each egg being worth 6 Rs. A hen costs of Rs. 15 for feed. If a person has only 15000 to spend on the hens, How many of each kind should he buy to get a profit of more than 600 Rs. Per week Assuming that he cannot house more than 30 hens. Formulate Linear programming Model ³

Solution: ⁴

Let X be the number of Old Hens to be brought, ⁵

Let Y be the number of Young Hens to be brought ⁶

	Old Hen	Young Hen	⁷
Cost	300	500	
Egg	3 Egg per week	5 Egg per week	
Feed	15 Rs.	15 Rs.	
Each Egg	6	6	

Selling price ⁸

$$Z_{\text{Max}} = SP - CP = ⁹$$

since objective was not defined, i.e max. profit or minimize cost..we calc. ¹⁰ profit by this

$$= (6*3)X + (6*5)Y - 15*X - 15*Y \quad \{15* X indicate feed\} ¹¹$$

$$= 18X + 30Y - 15X - 15Y$$

$$Z_{\text{Max}} = 3X + 15Y \quad \text{---Objective Equation} ¹²$$

$$300X + 500Y \leq 15000 \quad [\text{Cost constrain}]$$

$$X + Y \leq 30 \quad [\text{Space constrain}]$$

$$X \geq 0, Y \geq 0 \quad [\text{Non Negative}]$$

$$3X + 15Y \geq 600 \quad [\text{Income Constrain}]$$

Linear Programming¹

1) A farmer has a 100 acre farm, He can sell all the Tomatoes, Onion, Radishes he can raise, The price he can obtain is Rs.5 per kg Tomatoes, Rs.10 per kg Onion, Rs. 8 per kg for Radish, The average yield per acre is 2000 kg of Tomatoes, 3000 kg Onion, 1000 kg of Radish, Fertilizer is available at RS.5 per Kg, Amount of fertilizer require for each Tomatoe, Onion-100 Kg per acre, 50 Kg for Radish, Labour require for cultivating per acre is 5 man day for Tomatoes, 6 man day for Onion, 5 man day for Radish. A total 400 mans are available at Rs.500 per day. Formulate Linear programming Model.

Solution:³

	Tomatoes	Onion	Radish	⁴
Selling Price	Rs.5 per kg	Rs.10 per kg	Rs. 8 per kg	
Yield	2000kg/Acre	3000kg/Acre	1000kg/Acre	
Fertilizer	100kg/Acre	100kg/Acre	50kg/Acre	
Cultivating	5 Man/Acre	20 Man/Acre	5 Man/Acre	

Fertilizer rate: 5 Rs/kg⁵

Each Labour Cost: Rs.500 per Day⁶

X ₁	X ₂	X ₃	⁷
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Let X₁ be the number of acres to be used for growing Tomatoe.⁸

Let X₂ be the numbe of acrs to be used for growing Onion.⁹

Let X₃ be the numbe of acrs to be used for growing Radishes.¹⁰

$$Z_{\max} = (2000*5) X_1 + (3000*10) X_2 + (1000*8) X_3 - (100*5) X_1^{11} - (100*5) X_2 - (50*5) X_3 - (500*5) X_1^{12} - (20*500) X_2 - (500*5) X_3^{12}$$

profit = SP-CP

$$= 10000X_1 + 30000 X_2 + 8000 X_3 - 500 X_1 - 500 X_2 - 250 X_3 - 2500 X_1^{\textcolor{red}{1}} \\ - 10000 X_2 - 2500 X_3$$

$$Z_{\max} = 7000 X_1 + 19500 X_2 + 5250 X_3 \quad \{ \text{Objective equation} \}^{\textcolor{red}{2}}$$

Constraints:³

$$5 X_1 + 20 X_2 + 5 X_3 \leq 400 \quad \{ \text{Labour Constraint} \}^{\textcolor{red}{4}}$$

$$X_1 + X_2 + X_3 \leq 100 \quad \{ \text{Land Constraint} \}$$

$$X_1 \geq 0, X_2 \geq 0, X_3 \geq 0 \quad \{ \text{Non negative Constraint} \}$$



2) A hospital has the following minimal daily requirement of nurses

Period	Clock time	Minimal Number of Nurses Required
1	6 AM to 10 AM	2
2	10 AM to 2 PM	7
3	2 PM to 6 PM	15
4	6 PM to 10 PM	8
5	10 PM to 2 AM	20
6	2 AM to 6 AM	6

Nurses report to the hospital at the beginning of each period and work for 8 consecutive hours. The hospital wants to determine the minimal number of nurses to be employed so that there is sufficient number of nurses available for each period. Formulate this as Linear programming problem

Solution: ³

Let $X_1, X_2, X_3, X_4, X_5, X_6$ number of nurses to be appointed for period 1,2,3,4,5,6 respectively.

Objective equation: $Z_{\min} = X_1 + X_2 + X_3 + X_4 + X_5 + X_6$ ⁵

Constraints ⁶

$$X_1 + X_2 \geq 7$$
 ⁷

$$X_2 + X_3 \geq 15$$
 ⁸

$$X_3 + X_4 \geq 8$$
 ⁹

$$X_4 + X_5 \geq 20$$
 ¹⁰

$$X_5 + X_6 \geq 6$$
 ¹¹

$$X_6 + X_1 \geq 2$$
 ¹²

$$X_1 \geq 0, X_2 \geq 0, X_3 \geq 0, X_4 \geq 0, X_5 \geq 0, X_6 \geq 0,$$
 ¹³

Linear Programming ¹

1) Consider the following problem faced by a production planner in ²
a soft drink plant. He has 2 bottling machines A and B. A is
assigned for 8-ounce bottle and B is assigned for 16-ounce bottle.
The following data are available

Machine A	8ounce bottle	16ounce bottle ³
-----------	---------------	-----------------------------

A	100/ Minute	40/Minute ⁴
---	-------------	------------------------

B	60/Minute	75/Minute ⁵
---	-----------	------------------------

The machines can be run for 8-hours per day, 5 days a week, Profit ⁶
on 8 ounce bottle is 15 paise and on 16 ounce bottle is 25 paise.
Weekly production of the drink cannot exceed 300000 ounces
and the market can obserb 25000 eight ounce bottle and 7000
sixteen ouce bottles per week. The planner wishes to maximize
his profit, of course, to all the production and marketing
constraints. Formulate Linear programming model.

Solution ⁷

Let X_1 be the number of 8 Ounce bottle to be produced on ⁸
Machine A, X_2 be the number of 16 ounce bottle to be produced
on Machine A.

Let Y_1 be the number of 8 ounce bottle to be produced on B, Y_2 ⁹
be the number of 16 ounce bottle to be produced on B.

$$Z_{\max} = (X_1 + Y_1) 0.15 + (X_2 + Y_2) 0.25 \quad [\text{Objective equation}] ¹⁰$$

1 Min----100 products then 1 product $\frac{1}{100}$ duration requires ¹¹

Similarley for X_1 products $\frac{X_1}{100}$ [8 Ounce bottles]

1 Min---- 40 products 1 product $\frac{1}{40}$ duration requires ¹

Similarley for X_2 products $\frac{X_2 [16 \text{ Ounce bottles}]}{40}$ ²

$$\frac{X_1}{100} + \frac{X_2}{40} \leq 5*8*60 \quad \frac{Y_1}{60} + \frac{Y_2}{75} \leq 5*8*60 \quad ^3$$

$$\frac{2X_1 + 5X_2}{200} \leq 2400 \quad ^4$$

$$2X_1 + 5X_2 \leq 480000$$

$X_1 + Y_1 \geq 25000$ [Market Constrain 8 ounce bottle] ⁵

$X_2 + Y_2 \geq 7000$ [Market Constrain 16 ounce bottle] ⁶

$$8(X_1 + Y_1) + 16(X_2 + Y_2) \leq 300000 \quad ^7$$

$$X_1 \geq 0, X_2 \geq 0, Y_1 \geq 0, Y_2 \geq 0 \quad ^8$$



- 11) 2) A manufacture of a line of patent medicines is preparing a ⁹ production plan on medicines A and B. There are sufficient ingredient available to make 20,000 bottles of A and 40000 bottles of B but there are only 45000 bottles into which both the medicines can be put. Further more it take 3 hours to prepare enough materials to fill 1000 bottles of A, it take 1 hour to prepare enough materials to fill 1000 bottles of B and there are 66 hours available for this operations. The profit is Rs.8 per bottle for A and Rs.7 per bottle for B. Formulate the linear programming model

Solution: Let x be the number of A type medicine to be produced ¹⁰
Let y be the number of B type medicine to be produced

$$Z_{\max} = 8x + 7y \text{ [objective]} \quad 1$$

$$x \leq 20000 \text{ [Bottle A constraint]}$$

$$y \leq 40000 \text{ [Bottle B constraint]}$$

$$x+y \leq 45000 \text{ [Together]}$$

2

$$\frac{3}{1000} * x = \frac{3x}{1000}$$

3

$$\frac{1}{1000} * y = \frac{y}{1000}$$

$$\frac{3x}{1000} + \frac{3y}{1000} \leq 66 \text{ hrs} \quad \text{Hours constrain}$$

$$X \geq 0, Y \geq 0$$

Linear Programming ¹

Q1) A firm can produce 3 types of cloth A,B,C. 3 kinds of wool required for it, ²
Red wool,green wool, and blue wool.

One unit length of type A cloth needs 2 yards of red Wool and 3 yards of blue ³ wool.one unit of length of type B cloth need 3 yard of red wool, 2 yards of green wool and 2 yards of blue wool. One unit of type c cloth needs 5 yards of green wool and 4 yards of blue wool. The firm has a stock of only 8 yards of red wool, 10 yads of green wool, and 15 yards of blue wool. It is assumed that the income obtained from one unit length of type A cloth is Rs 3, of type B cloth is Rs.5, of type C cloth is Rs. 4. Formulate the problem as a linear programming problem

Solution: ⁴

Let X_1 be the number of Type A cloth to be produced ⁵

Let X_2 be the number of Type B cloth to be produced ⁶

Let X_3 be the number of Type C cloth to be produced ⁷

Z_{max} = $3X_1 + 5X_2 + 4X_3$ ----Objective Equation ⁸

	Red	Green	Blue	⁹
Type A	2 Yard	----	3 Yard	
Type B	3 Yard	2 Yard	2 Yard	
Type C	-----	5 Yard	4 Yard	

Availability ¹⁰ **8 Yard** ¹¹ **10 Yard** ¹² **15 Yard** ¹³

$2X_1 + 3X_2 \leq 8$ {Red Wool Constrain} ¹⁴

$2X_1 + 5X_3 \leq 10$ {Green Wool Constrin} ¹⁵

$3X_1 + 2X_2 + 4X_3 \leq 15$ { Blue Wool Constrain} ¹⁶

$X_1 \geq 0, X_2 \geq 0, X_3 \geq 0$ { Non negative Constrain} ¹⁷

Q2) A firm Produce 3 Products,these products are processed in 3 different machine. The time required to manufacture one unit of each product and the daily capacity of machine 3 machine given below 1

Machine	P1	P2	P3	Machine capacity
M1	2	8	2	940 Min/day
M2	4	---	8	970 Min/day
M3	2	5	--	430 Min/day

Profit of product P1,P2,P3 are RS 4, Rs 8, Rs 6 Write a linear programming 3 model to the given problem

Solution: 4

Let a be the number of Type P1 Product to be produced 5

Let b be the number of Type P2Product to be produced 6

Let c be the number of Type P3 Product to be produced 7

$Z_{\max} = 4a + 8b + 6c$ ----Objective Equation 8

$2a + 8b + 2c \leq 940$ { Machine P1 constrain} 9

$4a + 8c \leq 970$ { Machine P2 constrain} 10

$2a + 5b \leq 430$ { Machine P3 constrain} 11

$a \geq 0, b \geq 0, c \geq 0$ { Non negative Constrain} 12

Q3) A farmer has 1000 acres of land on which he grown corn,wheat, and soyabeans. Each acre of corn cost Rs. 100 for preparation, requires 7 man days of work and yields a profit of Rs 30. An acre of wheat costs Rs 120 to prepare, requires 10 man day of work and yields profit of Rs.40, An acre of soyabean costs Rs 70 to prepare requires 8 man days of work and yields of profit Rs.20, If the farmer has Rs. 100000 for preparation and can count on 8000 man days work, formulate the L.P model to allocate the number of acres to each crop to maximize the total profit 1

Solution: 2

Let X_1 be the land to be used to cultivating Corn 3

Let X_2 be the land to be used to cultivating Wheat 4

Let X_3 be the land to be used to cultivating Soyabean 5

$Z_{\max} = 30X_1 + 40X_2 + 20X_3$ ----Objective Equation 6

	<u>Preparation cost</u>	<u>Labour</u>	7
Corn	100 RS. per Acre	7 Man days per Acre	
Wheat	120 Rs. per Acre	10 Man days per Acre	
Soyabean	70 RS.per Acre	80Man days per Acre	

Availability 8 **100000 RS** 9 **8000 Mans Available** 10

Acres available: **1000** 11

$100X_1 + 120X_2 + 70X_3 \leq 100000$ { Preparation cost constrain} 12

$7X_1 + 10X_2 + 8X_3 \leq 8000$ {Labour constrain} 13

$X_1 + X_2 + X_3 \leq 1000$ { Acres constrain} 14

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- 1) A computer manufacturing company purchases components parts and make 2models of moniters A and B. The components are assembled by the company to produce model A and B. Model A requires 28 hours of labour to assemble from component part, while model B requires 42 hours. After assembly each monitor is tested in inspection department. Model A requires 12 hours of inspection time while B requires 6 hours. The company employs 400 peoples in the assembly department, each working 7 hours a day, 6 days a week. 100 peoples are presently employed in the inspection department, each working 8 hours a day, 6 days a week. Currently wages rate are Rs. 50 per hour in assembly and Rs.75 per hour in inspection. Model A cost 1850 and Model B cost Rs.3250 to produce. Currently two models sell for Rs. 6400 and Rs. 8300. The supplier of these chip can provide no more than 660 in any one working week 2

<u>Solution:</u>	Monitor A	Monitor B	3
Component Cost	1850	3250	
Assemble Cost	1400	2100	
Inspection Cost	900	450	
<hr/>			
Cost Price	4150	5800	
<hr/>			
Selling price	6400	8300	
<hr/>			
Profit	6400-4150= 2250	8300-5800=2500	

Let X be the number of type A to be produced, 4

Let Y be the number of type B to be produced 5

$Z_{\max} = 2250 X + 2500 Y$ [Objective equation] 6

Assemble for per monitor A 7

type requires 28 hour labour,
1 hour labour cost for
assemble =50

for 28 hours = $28 \times 50 = 1400$

Type B requires 42 hour 8
labour for assemble

For 42 hours = $42 \times 50 = 2100$ 9

Inspection cost per hour=75 10

Type A—12= $12 \times 75 = 900$ 11

Type B--- 6= $6 \times 75 = 450$ 12

	Monitor A	Monitor B	Employees	working	total day	Total hour	13
Assemble	28 hours	42hours	400	7 hour/day	6	$400 \times 7 \times 6 = 16800$	
Inspection	12 hours	6 hours	100	8 hour/day	8	$100 \times 8 \times 6 = 4800$	

One Monitor Type A require 28 hour for assemble, So X monitor requires $X \times 28 = 28 X$ 14

One Monitor Type B require 42 hour for assemble, So Y monitor requires $Y \times 42 = 42 Y$ 15

Available hour in assemble department = 16800 28X + 42Y <= 16800 [Assemble constraint] 16

Similarly 17

One Monitor Type A require 12 hour for inspection, So X monitor requires $X \times 12 = 12 X$ 18

One Monitor Type B require 6 hour for assemble, So Y monitor requires $Y \times 6 = 6 Y$ 19

Available hour in assemble department = 4800 12X + 6Y <= 4800 [Inspection dept. hour constrain] 20

Chip available 660 21

Assume that 1 monitor require 1 chip of any type X number of Type A require X number of chip, Y number of type B requires Y number of chip 22

$X + Y <= 660$ [Chip Constarin] X >= 0, Y >= 0 [Non negative Constraint] 23

- 2) A confectionery company mixes 3 types of toffees **ingredients** to form one kg of toffee packs. The pack is sold at Rs. 170, The 3 types of toffees **ingredients** cost Rs.200, Rs.100 and Rs.50 per kg. The mixture must contain at least 0.3kg of the first type of toffees and the weight of first two types of toffees **almost** be equal to the weight of third type. Determine the optimal mix for maximum profit 1

Solution : Let X, Y,Z be the number of KG ingredients of 3 types is mixed to prepare 1 KG 2 toffees

$$Z_{\max} = 170 - 200 * X - 100 * Y - 50 * Z \text{ [Objective equation]} \quad 3$$

$$X >= 0.30 \text{ [First type ingredients constrain]} \quad 4$$

$$X + Y <= Z \text{ [type1 and 2 almost equal to third type]} \quad 5$$

$$X + Y + Z = 1 \text{ [To add all that to form only 1 kg, not exceed or less than 1]} \quad 6$$

$$X >= 0, Y >= 0, Z >= 0 \quad 7$$

Simplex Method¹

Q1) $Z_{\text{Max}} = 3X_1 + 4X_2$ 2
 $X_1 + X_2 \leq 4$ 3
 $X_1 - X_2 \leq 2$ 4

Solution: $Z_{\text{max}} - 3X_1 - 4X_2 = 0$ 5
 $X_1 + X_2 + S_1 = 4$ 6
 $X_1 - X_2 + S_2 = 2$ 7

Basic Variable: Unique, Unit, Positive Co-efficient : S_1, S_2, Z_{Max} 8

↓

Basic variable	X_1	X_2	S_1	S_2	Z_{Max}	RHS	$\text{Ratio} = \frac{\text{RHS}}{PC}$
S_1	1	1	1	0	0	4	$\frac{4}{1} = 4$
S_2	1	-1	0	1	0	2	$\frac{2}{-1} = -2$
Z_{Max}	-3	-4	0	0	1	0	

Pivoting Column [P C] = Entering variable [E V] = Maximum Negative in Z_{Max} $x_2 = -4$ 10

Pivoting Row [P R]= Leaving Variable [LV]= Minimum Positive Ratio = 4 11

Pivoting Element =Intersecting of Row and Column= 1 12

New Pivoting Row= $X_2 = \frac{1}{\text{PE}} * \text{Old Row}$ 13

$$X_2 = \frac{1}{1} * [1, 1, 1, 0, 0, 4] \quad \text{14}$$

$$X_2 = [1, 1, 1, 0, 0, 4] \quad \text{15}$$

Key Element for $S_2 = -1$ 16

New Row $S_2 = -\text{Key} * \text{NPR} + \text{Old row}$ 17 18
 $= -(-1) [1, 1, 1, 0, 0, 4] + [1, -1, 0, 1, 0, 2]$
 $= 1 [1, 1, 1, 0, 0, 4] + [1, -1, 0, 1, 0, 2]$
 $= [1, 1, 1, 0, 0, 4] + [1, -1, 0, 1, 0, 2]$
 $= [1+1, 1-1, 1+0, 0+1, 0+0, 4+2]$
 $= [2, 0, 1, 1, 0, 6]$

Simplex Method¹

Key Element for $Z_{\text{Max}} = -4$ ²

$$\begin{aligned}
 Z_{\text{Max}} &= -\text{Key} * \text{NPR} + \text{Old row} & 3 \\
 &= -(-4) \begin{bmatrix} 1, 1, 1, 0, 0, 4 \end{bmatrix} + \begin{bmatrix} -3, -4, 0, 0, 1, 0 \end{bmatrix} \\
 &= 4 \begin{bmatrix} 1, 1, 1, 0, 0, 4 \end{bmatrix} + \begin{bmatrix} -3, -4, 0, 0, 1, 0 \end{bmatrix} \\
 &= \begin{bmatrix} 4, 4, 4, 0, 0, 16 \end{bmatrix} + \begin{bmatrix} -3, -4, 0, 0, 1, 0 \end{bmatrix} \\
 &= \begin{bmatrix} 4-3, 4-4, 4+0, 0+0, 0+1, 16+0 \end{bmatrix} \\
 &= \begin{bmatrix} 1 & 0 & 4 & 0 & 1 & 16 \end{bmatrix}
 \end{aligned}$$

Basic variable	X ₁	X ₂	S ₁	S ₂	Z _{Max}	RHS	Ratio = $\frac{RHS}{PC}$
X ₂	1	1	1	0	0	4	
S ₂	2	0	1	1	0	6	
Z _{Max}	1	0	4	0	1	16	

Stop the Process because there is no negative in Z_{max} row. ⁵

$$\begin{array}{ll}
 1X_2 = 4 & 1Z_{\text{Max}} = 16 \quad 6 \\
 \boxed{X_2 = 4} & \boxed{Z_{\text{Max}} = 16} \quad 7
 \end{array}$$

There is no X₁ is present in Basic Variable Column So X₁=0 ⁸

Verification: ⁹

$$\begin{array}{lll}
 X_1 + X_2 \leq 4 & 10 & Z_{\text{Max}} = 3X_1 + 4X_2 \quad 12 \\
 0 + 4 \leq 4 & 13 & = 3(0) + 4(4) \quad 15 \\
 4 \leq 4 & 16 & = 0 + 16 \quad 18 \\
 & & Z_{\text{Max}} = 16 \quad 19
 \end{array}
 \begin{array}{ll}
 X_1 - X_2 \leq 2 & 11 \\
 0 - 4 \leq 2 & 14 \\
 -4 \leq 2 & 17
 \end{array}$$

Simplex Method ¹

Q4) $Z_{\min} = X_1 - 3X_2 + 2X_3$ ² ³

$$3X_1 - X_2 + 3X_3 \leq 7$$

$$4X_1 + 3X_2 + 8X_3 \leq 10$$

$$-2X_1 + 4X_2 \leq 12$$

Solution : $3X_1 - X_2 + 3X_3 + S_1 = 7$ ⁴

$$4X_1 + 3X_2 + 8X_3 + S_2 = 10$$
 ⁵

$$-2X_1 + 4X_2 + S_3 = 12$$

Convert Z_{\min} to Z_{\max} ⁶

I.e. $Z_{\max} = -Z_{\min}$ ⁷

$$Z_{\max} = -[X_1 - 3X_2 + 2X_3]$$
 ⁸

$$Z_{\max} = -X_1 + 3X_2 - 2X_3$$
 ⁹

$$Z_{\max} + X_1 - 3X_2 + 2X_3 = 0$$
 ¹⁰

I. B.F.S. ¹¹

Let $X_1 = 0, X_2 = 0, X_3 = 0$, then $S_1 = 7, S_2 = 10, S_3 = 12$ ¹²

Basic variable : Unique, Unit, +ve Co-efficient ¹³

S_1, S_2, S_3, Z_{\max} ¹⁴



B.V	X_1	X_2	X_3	S_1	S_2	S_3	Z_{\max}	RHS	Ratio=RHS/P.C
S_1	3	-1	3	1	0	0	0	7	$7/-1 = -7$
S_2	4	3	8	0	1	0	0	10	$10/3$
S_3	-2	4	0	0	0	1	0	12	3
Z_{\max}	1	-3	2	0	0	0	1	0	

Simplex Method¹

Pivoting Element [P.E] = Intersting of row and column = 4²

$$\begin{aligned}
 \text{New Pivoting row} &= \frac{1}{PE} * [\text{Old row}]^3 & 4 \\
 &= \frac{1}{4} \left[-2, 4, 0, 0, 0, 1, 0, 12 \right] \\
 &= \left[-\frac{1}{2}, 1, 0, 0, 0, \frac{1}{4}, 0, 3 \right]
 \end{aligned}$$

Key element for $S_1 = -1$ ⁵

$$\begin{aligned}
 \text{New row } S_1 &= -\text{Key} * \text{NPR} + \text{Old row}^6 & 7 \\
 &= -(-1) \left[\frac{-1}{2}, 1, 0, 0, 0, \frac{1}{4}, 0, 3 \right] + \left[3, -1, 3, 1, 0, 0, 0, 7 \right] \\
 &= 1 \left[\frac{-1}{2}, 1, 0, 0, 0, \frac{1}{4}, 0, 3 \right] + \left[3, -1, 3, 1, 0, 0, 0, 7 \right] \\
 &= \left[-\frac{1}{2}, 1, 0, 0, 0, \frac{1}{4}, 0, 3 \right] + \left[3, -1, 3, 1, 0, 0, 0, 7 \right] \\
 &= \left[-\frac{1}{2} + 3, 1 - 1, 0 + 3, 0 + 1, 0 + 0, \frac{1}{4} + 0, 0 + 0, 3 + 7 \right] \\
 &= \left[\frac{5}{2}, 0, 3, 1, 0, \frac{1}{4}, 0, 10 \right]
 \end{aligned}$$

Key element for $S_2 = 3$ ⁸

$$\begin{aligned}
 \text{New row } S_2 &= -\text{Key} * \text{NPR} + \text{old row}^9 & 10 \\
 &= -3 \left[-\frac{1}{2}, 1, 0, 0, 0, \frac{1}{4}, 0, 3 \right] + \left[4, 3, 8, 0, 1, 0, 0, 10 \right] \\
 &= \left[\frac{3}{2}, -3, 0, 0, 0, -\frac{3}{4}, 0, -9 \right] + \left[4, 3, 8, 0, 1, 0, 0, 10 \right]
 \end{aligned}$$