

# MAT168 HW2

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**(1)(2)**

Please refer to the written part attached below in this PDF.

**(3)**

## Optimal Dictionary

$$\zeta = 13 - 3x_2 - x_4 - x_6$$

$$x_3 = 1 + x_2 + 3x_4 - 2x_6$$

$$x_1 = 2 - 2x_2 - 2x_4 + x_6$$

$$x_5 = 1 + 5x_2 + 2x_4$$

## Given

$$B = \{3, 1, 5\}, N = \{2, 4, 6\}$$

$$c = [5, 4, 3, 0, 0, 0]$$

$$z_N^* = \begin{bmatrix} 3 \\ 1 \\ 1 \end{bmatrix}$$

$$B = \begin{bmatrix} 1 & 3 & -2 \\ -2 & -2 & 1 \\ 5 & 2 & 0 \end{bmatrix}$$

## Constraint Equations

$$B^{-1}N = \begin{bmatrix} 1 & 3 & -2 \\ -2 & -2 & 1 \\ 5 & 2 & 0 \end{bmatrix}$$

## Range for $c_2$

### Setup

$$\Delta c = [0, 1, 0, 0, 0, 0]$$

$$\Delta c_B^T = [0, 0, 0]$$

$$\Delta c_N^T = [1, 0, 0]$$

Please note the indices for these variables correspond to:

$$\Delta c = \{1, 2, 3, 4, 5, 6\}$$

$$\Delta c_B^T = B = \{3, 1, 5\}$$

$$\Delta c_N^T = N = \{2, 4, 6\}$$

### Calculate $\Delta z_N$

$$\Delta z_N = (B^{-1}N)^T \Delta c_B - \Delta c_N$$

$$\Delta z_N = \begin{bmatrix} 1 & 3 & -2 \\ -2 & -2 & 1 \\ 5 & 2 & 0 \end{bmatrix}^T \begin{bmatrix} 0 \\ 0 \\ 0 \end{bmatrix} - \begin{bmatrix} 1 \\ 0 \\ 0 \end{bmatrix}$$

$$\Delta z_N = \begin{bmatrix} -1 \\ 0 \\ 0 \end{bmatrix}$$

### Solve for $t$

Since  $z_N^* + t\Delta z_N \geq 0$ :

$$\begin{bmatrix} 3 \\ 1 \\ 1 \end{bmatrix} + t \begin{bmatrix} -1 \\ 0 \\ 0 \end{bmatrix} \geq \begin{bmatrix} 0 \\ 0 \\ 0 \end{bmatrix}$$

Then:

$$3 - t \geq 0$$

$$t \leq 3$$

$$t \in (-\infty, 3]$$

## Range for $c_3$

### Setup

$$\Delta c = [0, 0, 1, 0, 0, 0]$$

$$\Delta c_B^T = [1, 0, 0]$$

$$\Delta c_N^T = [0, 0, 0]$$

Please note the indices for these variables correspond to:

$$\Delta c = \{1, 2, 3, 4, 5, 6\}$$

$$\Delta c_B^T = B = \{3, 1, 5\}$$

$$\Delta c_N^T = N = \{2, 4, 6\}$$

### Calculate $\Delta z_N$

$$\Delta z_N = (B^{-1}N)^T \Delta c_B - \Delta c_N$$

$$\Delta z_N = \begin{bmatrix} 1 & 3 & -2 \\ -2 & -2 & 1 \\ 5 & 2 & 0 \end{bmatrix}^T \begin{bmatrix} 1 \\ 0 \\ 0 \end{bmatrix} - \begin{bmatrix} 0 \\ 0 \\ 0 \end{bmatrix}$$

$$\Delta z_N = \begin{bmatrix} 1 & -2 & 5 \\ 3 & -2 & 2 \\ -2 & 1 & 0 \end{bmatrix} \begin{bmatrix} 1 \\ 0 \\ 0 \end{bmatrix}$$

$$\Delta z_N = \begin{bmatrix} 1 \\ 3 \\ -2 \end{bmatrix}$$

## Solve for $t$

Since  $z_N^* + t\Delta z_N \geq 0$ :

$$\begin{bmatrix} 3 \\ 1 \\ 1 \end{bmatrix} + t \begin{bmatrix} 1 \\ 3 \\ -2 \end{bmatrix} \geq \begin{bmatrix} 0 \\ 0 \\ 0 \end{bmatrix}$$

Then:

$$3 + t \geq 0$$

$$t \geq -3$$

$$1 + 3t \geq 0$$

$$t \geq \frac{-1}{3}$$

$$1 - 2t \geq 0$$

$$t \leq \frac{1}{2}$$

$$t \in \left[ \frac{-1}{3}, \frac{1}{2} \right]$$

(4)

## Constraints

The production facilities can produce 11k units per month. Let  $\{x\}_1^3$  be the packages shipped from San Francisco and  $\{x\}_4^6$  be the packages shipped from Sacramento.

$$x_1 + x_2 + x_3 \leq 11$$

$$x_4 + x_5 + x_6 \leq 11$$

We have to meet the demand at the destinations which is 10k at Davis, 8k at Winters, and 4k at Woodland. Let  $x_1, x_4$  be the packages shipped to Davis. Let  $x_2, x_5$  be the packages shipped to Winters. Let  $x_3, x_6$  be the packages shipped to Woodland.

$$x_1 + x_4 \geq 10$$

$$x_2 + x_5 \geq 8$$

$$x_3 + x_6 \geq 4$$

## Objective Function

We want to minimize cost of both facilities. Let vector  $c$  be the cost to ship.

$$\min c^T x$$

$$\min 10x_1 + 8x_2 + 12x_3 + 4x_4 + 11x_5 + 6x_6$$

## Online Solver

We used this online solver: <https://online-optimizer.appspot.com>

### Input

```
var x1 >= 0;  
var x2 >= 0;  
var x3 >= 0;  
var x4 >= 0;  
var x5 >= 0;  
var x6 >= 0;  
  
minimize z: 10*x1 + 8*x2 + 12*x3 + 4*x4 + 11*x5 + 6*x6;  
  
subject to c11: x1 + x2 + x3 <= 11;  
subject to c12: x4 + x5 + x6 <= 11;  
subject to c13: x1 + x4 >= 10;  
subject to c14: x2 + x5 >= 8;  
subject to c15: x3 + x6 >= 4;  
  
end;
```

### Output Model Overview

Label	Value
Problem type	Linear optimization
Objective	Minimize z
Optimal objective value	146
Solver Status	Optimal
Total number of variables	6
Continuous variables	6
Number of constraints	6
Non-binary nonzero coefficients	18

## Output Model Variables

Variable	Type	Value	Value bounds	Status	Reduced obj coef	Obj coef tol interval
x1	Real	3	[0, Inf]	Basic	0	[-1, Inf]
x2	Real	8	[0, Inf]	Basic	0	[-6, Inf]
x3	Real	0	[0, Inf]	At lower bound	0	
x4	Real	7	[0, Inf]	Basic	0	
x5	Real	0	[0, Inf]	At lower bound	9	
x6	Real	4	[0, Inf]	Basic	0	

## Output Model Constraints

Name	Lhs value	Rhs bounds	Slack	Status	Dual value	Rhs tol interval
c11	11	[-Inf, 11]	0	Basic	0	
c12	11	[-Inf, 11]	0	At upper bound	-6	[11, 14]
c13	10	[10, Inf]	0	At lower bound	10	[7, 10]
c14	8	[8, Inf]	0	At lower bound	8	[0, 8]
c15	4	[4, Inf]	0	At lower bound	12	[1, 4]

## Output Model Log Messages

Reading model section from editor.mod ...

16 lines were read

Generating z...

Generating c11...

Generating c12...

Generating c13...

Generating c14...

Generating c15...

Model has been successfully generated

Scaling...

A: min—aij— = 1 max—aij— = 12 ratio = 12

GM: min—aij— = 0.7681450856702011 max—aij— = 1.3018373985007101 ratio = 1.6947806121350972

EQ: min—aij— = 0.6030226891555273 max—aij— = 1 ratio = 1.6583123951777

Solving the model using the simplex optimizer

GLPK Simplex Optimizer, v4.49

6 rows, 6 columns, 18 non-zeros

Preprocessing...

5 rows, 6 columns, 12 non-zeros

Scaling...

A: min—aij— = 1 max—aij— = 1 ratio = 1

Problem data seem to be well scaled

Constructing initial basis...

Size of triangular part = 5  
0: obj = 0 infeas = 22 (0)  
\*4: obj = 209 infeas = 0 (0)  
\*6: obj = 146 infeas = 0 (0)  
OPTIMAL SOLUTION FOUND

## Collaboration

All collaborators are listed (in alphabetical order) below:

- Melody
- Sterling
- Zhongning

## Academic Integrity

On my personal integrity as a student and member of the UCD community, I have not given, nor received and unauthorized assistance on this assignment.

Signature: Andrew Jowe

## Written Parts

See below.

$$\textcircled{1} \quad \begin{aligned} & \max 2x_1 - 6x_2 + 0x_3 \\ & -x_1 - x_2 - x_3 \leq -2 \\ & 2x_1 - x_2 + x_3 \leq 1 \end{aligned}$$

Aux Problem

$$\begin{aligned} & \max -x_0 \\ & -x_1 - x_2 - x_3 - x_0 \leq -2 \\ & 2x_1 - x_2 + x_3 - x_0 \leq 1 \end{aligned}$$

$$x_0^* = b = \begin{bmatrix} -2 \\ 1 \end{bmatrix}$$

$$z_N^* = -c_N = \begin{bmatrix} 1 \\ 0 \\ 0 \\ 0 \end{bmatrix}$$

$$N = \{0, 1, 2, 3\} \quad B = \{4, 5\}$$

$$B = \begin{bmatrix} 1 & 0 \\ 0 & 1 \end{bmatrix}$$

$$N = \begin{bmatrix} -1 & 1 & 4 & 1 \\ -1 & 2 & 1 & 1 \end{bmatrix}$$

It 2

2:  $i = 4$

3:  $\Delta z_N = - (B^{-1}N)^T e_i$

$$= - \begin{bmatrix} -1 & -1 & -1 & -1 \\ -1 & 2 & -1 & 1 \end{bmatrix}^T \begin{bmatrix} 1 \\ 0 \end{bmatrix}$$

$$= \begin{bmatrix} 1 \\ 1 \\ 1 \end{bmatrix}$$

4:  $(\max \xi | y_1, y_0, y_0, y_0)_3^{-1}$

$$\xi_3 = 1$$

5:  $j = 0$

6:  $\Delta x_B = B^{-1}N e_j$

$$= \begin{bmatrix} -1 & -1 & -1 & -1 \\ -1 & 2 & -1 & 1 \end{bmatrix} \begin{bmatrix} 1 \\ 0 \\ 0 \\ 0 \end{bmatrix}$$

$$= \begin{bmatrix} -1 \\ -1 \end{bmatrix}$$

7:  $t = -y_{-1} = 2$

8:  $x_0^* = t$

$$x_0^* = 2$$

$$x_B^* = x_0^* - t \Delta x_B$$

$$x_0^* = \begin{bmatrix} -2 \\ 1 \end{bmatrix} - 2 \begin{bmatrix} -1 \\ -1 \end{bmatrix} = \begin{bmatrix} 0 \\ 3 \end{bmatrix}$$

$$z_1^* = 5$$

$$z_4^* = 1$$

$$z_N^* = z_N^* - 5\Delta z_N$$

$$z_N^* = \begin{bmatrix} 1 \\ 0 \\ 0 \\ 0 \end{bmatrix} - \begin{bmatrix} 1 \\ 1 \\ 1 \\ 1 \end{bmatrix} = \begin{bmatrix} 0 \\ -1 \\ -1 \\ -1 \end{bmatrix}$$

$$q, B = \{0, 5\}, N = \{4, 1, 2, 3\}$$

$$x_B^* = \begin{bmatrix} 2 \\ 3 \end{bmatrix} \quad z_N^* = \begin{bmatrix} 1 \\ -1 \\ -1 \\ -1 \end{bmatrix}$$

$$B = \begin{bmatrix} -1 & 0 \\ -1 & 1 \end{bmatrix} \quad N = \begin{bmatrix} 1 & 4 & 4 & 1 \\ 0 & 2 & 1 & 1 \end{bmatrix}$$

I E 2  $\rightarrow$  primal simplex

$$2: j=1$$

$$3: \Delta x_B = B^{-1} N e_j$$

$$= \begin{bmatrix} -1 & 0 \\ -1 & 1 \end{bmatrix}^{-1} \begin{bmatrix} 1 & 4 & 4 & 1 \\ 0 & 2 & 1 & 1 \end{bmatrix} \begin{bmatrix} 0 \\ 1 \\ 0 \\ 0 \end{bmatrix}$$

$$\left[ \begin{array}{cc|cc} -1 & 0 & 1 & 0 \\ -1 & 1 & 0 & 1 \end{array} \right] \xrightarrow{R_1}$$

$$\left[ \begin{array}{cc|cc} 1 & 0 & -1 & 0 \\ -1 & 1 & 0 & 1 \end{array} \right] \xrightarrow{R_2 + R_1}$$

$$\left[ \begin{array}{cc|cc} 1 & 0 & -1 & 0 \\ 0 & 1 & -1 & 1 \end{array} \right]$$

$$= \left[ \begin{array}{c} -1 \\ -1 \end{array} \right] \left[ \begin{array}{cccc} 1 & 4 & 4 & 4 \\ 0 & 2 & 4 & 1 \end{array} \right] \left[ \begin{array}{c} 0 \\ 1 \\ 0 \\ 0 \end{array} \right]$$

$$\hat{=} \left[ \begin{array}{cccc} -1 & 1 & 1 & 1 \\ -1 & 3 & 0 & 2 \end{array} \right] \left[ \begin{array}{c} 0 \\ 1 \\ 0 \\ 0 \end{array} \right]$$

$$= \left[ \begin{array}{c} 1 \\ 3 \end{array} \right]$$

$$\text{u: } (\text{aux } \mathfrak{S}_{k_2}, 3/33)^{-1}$$

$$t = 1$$

$$s; i \geq s$$

$$6: \Delta z_n = -[B^{-1}N]^T e_i$$

$$= -\begin{bmatrix} -1 & 1 & 1 & 1 \\ -1 & 3 & 0 & 2 \end{bmatrix}^T \begin{bmatrix} 0 \\ 1 \end{bmatrix}$$

$$= \begin{bmatrix} 1 \\ -3 \\ 0 \\ -2 \end{bmatrix}$$

$$7: s = -1/3 \approx 1/3$$

$$8: x_j^* = \epsilon$$

$$x_1^* = 1$$

$$x_B^* = \begin{bmatrix} 2 \\ 3 \end{bmatrix} - \begin{bmatrix} 1 \\ 3 \end{bmatrix} = \begin{bmatrix} 1 \\ 0 \end{bmatrix}$$

$$z_i^* = s$$

$$z_5^* = y_3$$

$$z_n^* = \begin{bmatrix} 1 \\ -1 \\ -1 \\ -1 \end{bmatrix} - \frac{1}{3} \begin{bmatrix} 1 \\ -3 \\ 0 \\ -2 \end{bmatrix}$$

$$z_N^* = \begin{bmatrix} 1 \\ -1 \\ 1 \\ -1 \end{bmatrix} + \begin{bmatrix} -1/3 \\ 1 \\ 0 \\ 2/3 \end{bmatrix}$$

$$z_N^* = \begin{bmatrix} 2/3 \\ 0 \\ -1 \\ -4/3 \end{bmatrix}$$

q.  $B = \{0, 1/3\}$   $N = \{4, 5, 2, 3\}$

$$x_8^* = \begin{bmatrix} 1 \\ 1 \end{bmatrix} \quad z_N^* = \begin{bmatrix} 2/3 \\ 4/3 \\ -1 \\ -4/3 \end{bmatrix}$$

$$B = \begin{bmatrix} -1/4 \\ -1/2 \end{bmatrix} \quad N = \begin{bmatrix} 1 & 0 & 4 & -1 \\ 0 & 1 & -1 & 1 \end{bmatrix}$$

I+3  
 $\therefore j=2$

$\therefore \Delta \pi_B = B^{-1} N e_j$

$$= \begin{bmatrix} -1/4 \\ -1/2 \end{bmatrix}^{-1} \begin{bmatrix} 1 & 0 & 4 & -1 \\ 0 & 1 & -1 & 1 \end{bmatrix} \begin{bmatrix} 0 \\ 0 \\ -1 \\ 0 \end{bmatrix}$$

$$\left[ \begin{array}{cc|cc} -1 & -1 & 1 & 0 \\ -1 & 2 & 0 & 1 \end{array} \right] \xrightarrow{2R_1 + R_2}$$

$$\left[ \begin{array}{cc|cc} -3 & 0 & 2 & 1 \\ -1 & 2 & 0 & 1 \end{array} \right] \xrightarrow{-\frac{1}{3}R_1}$$

$$\left[ \begin{array}{cc|cc} 1 & 0 & -\frac{2}{3} & \frac{1}{3} \\ -1 & 2 & 0 & 1 \end{array} \right] \xrightarrow{R_2 + R_1}$$

$$\left[ \begin{array}{cc|cc} 1 & 0 & -\frac{2}{3} & \frac{1}{3} \\ -1 & 2 & 0 & 1 \end{array} \right] \xrightarrow{R_2 + R_1}$$

$$\left[ \begin{array}{cc|cc} 1 & 0 & -\frac{2}{3} & \frac{1}{3} \\ 0 & 2 & -\frac{2}{3} & \frac{2}{3} \end{array} \right] \xrightarrow{\frac{1}{2}R_2}$$

$$\left[ \begin{array}{cc|cc} 1 & 0 & -\frac{2}{3} & \frac{1}{3} \\ 0 & 1 & -\frac{1}{3} & \frac{1}{3} \end{array} \right]$$

$$= \begin{bmatrix} -\frac{2}{3} & \frac{1}{3} \\ -\frac{1}{3} & \frac{1}{3} \end{bmatrix} \begin{bmatrix} 1 & 0 & 1 & 1 \\ 0 & 1 & 1 & 1 \end{bmatrix} \begin{bmatrix} 0 \\ 0 \\ -1 \\ 0 \end{bmatrix}$$

$$= \begin{bmatrix} -\frac{2}{3} & -\frac{1}{3} & 1 & \frac{1}{3} \\ -\frac{1}{3} & \frac{1}{3} & 0 & \frac{1}{3} \end{bmatrix} \begin{bmatrix} 0 \\ 0 \\ 0 \end{bmatrix}$$

$$= \begin{bmatrix} 1 \\ 0 \end{bmatrix}$$

$$4: t = (\max \varepsilon/2, \gamma(3))^{-1}$$

$$t = 1$$

$$5: i \geq 0$$

$$6: \Delta z_i = -(\mathbf{B}^{-1} \mathbf{N})^+ e_i$$

$$= - \begin{bmatrix} -\gamma_3 & -\gamma_3 & 1 & \gamma_3 \\ -\gamma_3 & \gamma_3 & 0 & \gamma_3 \end{bmatrix}^+ \begin{bmatrix} 1 \\ 0 \end{bmatrix}$$

$$= \begin{bmatrix} \gamma_3 \\ \gamma_3 \\ -1 \\ -\gamma_3 \end{bmatrix}$$

$$7: s = \gamma_1 = 1$$

$$8: x_j^* = t$$

$$x_2^* = 1$$

$$x_0^* = \begin{bmatrix} 1 \\ 1 \end{bmatrix} - \begin{bmatrix} 5 \\ 0 \end{bmatrix} = \begin{bmatrix} 0 \\ 1 \end{bmatrix}$$

$$z_i^* = 5 \rightarrow z_0^* = 1$$

$$z_0^* = \begin{bmatrix} 2/3 \\ 4/3 \\ -1 \\ -4/3 \end{bmatrix} - \begin{bmatrix} 4/3 \\ 1/3 \\ -1 \\ -9/3 \end{bmatrix} = \begin{bmatrix} 0 \\ 0 \\ 0 \\ 0 \end{bmatrix}$$

q.  $B = \{2, 1/3\}$   $N = \{4, 15, 10, 33\}$

$$x_0^* = \begin{bmatrix} 1 \\ 1 \end{bmatrix} \quad z_N^* = \begin{bmatrix} 0 \\ 0 \\ 1 \\ 0 \end{bmatrix}$$

$$B = \begin{bmatrix} -1/4 \\ -1/2 \end{bmatrix} \quad N = \begin{bmatrix} 1 & 0 & 4 & 1 \\ 0 & 1 & 1 & 1 \end{bmatrix}$$

Done with Aux

$$y^* = C_B^T B^{-1} b$$

$$= [2 \ -6] \begin{bmatrix} -1 & 1 \\ -1 & 2 \end{bmatrix}^{-1} \begin{bmatrix} -2 \\ 1 \end{bmatrix}$$

$$= [2 \ -6] \begin{bmatrix} -4/3 & 1/3 \\ -1/3 & 4/3 \end{bmatrix} \begin{bmatrix} -2 \\ 1 \end{bmatrix}$$

$$= \begin{bmatrix} 2/3 & -8/3 \end{bmatrix} \begin{bmatrix} -2 \\ 1 \end{bmatrix}$$

$$= -4/3 - 8/3 = -4$$

$$z_n^* = \begin{bmatrix} -4/3 & 1/3 \\ -1/3 & 4/3 \end{bmatrix} \begin{bmatrix} 1 & 0 & 1 \\ 0 & 1 & 1 \end{bmatrix} \begin{bmatrix} 2 \\ -6 \\ 0 \end{bmatrix}$$

~~$\begin{bmatrix} 0 \\ 0 \end{bmatrix}$~~

$$z_n^* = \begin{bmatrix} -\frac{4}{3} & \frac{1}{3} \\ -\frac{1}{3} & \frac{4}{3} \end{bmatrix} \begin{bmatrix} 1 & 0 & 1 \\ 0 & 1 & 1 \end{bmatrix} \begin{bmatrix} 2 \\ -6 \\ 0 \end{bmatrix}$$

$$z_n^* = \begin{bmatrix} -\frac{4}{3} & -\frac{1}{3} & \frac{1}{3} \\ -\frac{1}{3} & \frac{4}{3} & \frac{2}{3} \end{bmatrix} \begin{bmatrix} 2 \\ -6 \\ 0 \end{bmatrix}$$

$$z_n^* = \begin{bmatrix} \frac{4}{3} \\ -\frac{8}{3} \\ 0 \end{bmatrix}$$

$$-\frac{4}{3} + \frac{6}{3} = \frac{2}{3}$$

$$-\frac{1}{3} - \frac{6}{3} = -\frac{7}{3}$$

$$x_B^* = \begin{bmatrix} 1 \\ 1 \end{bmatrix}$$

$$z_n^* = \begin{bmatrix} \frac{2}{3} \\ -\frac{8}{3} \\ 0 \end{bmatrix}$$

$$B = \begin{bmatrix} -1/3 \\ -1/3 \end{bmatrix} \quad N = \begin{bmatrix} 1 & 0 & 1 \\ 0 & 1 & 1 \end{bmatrix}$$

$$B = \{2, 1/3\} \quad N = \{4, 5, 3\}$$

$$2. j=3$$

$$3. \Delta x_B = B^{-1} N e_j$$

$$= \begin{bmatrix} -\frac{1}{3} & -\frac{1}{3} & \frac{1}{3} \\ -\frac{1}{3} & \frac{1}{3} & \frac{2}{3} \end{bmatrix} \begin{bmatrix} 0 \\ 0 \\ 1 \end{bmatrix}$$

$$= \begin{bmatrix} \frac{1}{3} \\ \frac{2}{3} \end{bmatrix}$$

$$4. \left( \max \left\{ \frac{1}{3}, \frac{2}{3}, 3 \right\} \right)^{-1}$$

$$t = 3/2$$

$$5. i=1$$

$$6. \Delta z_N = -(B^{-1}N)^T e_i$$

$$= - \begin{bmatrix} -\frac{1}{3} & -\frac{1}{3} & \frac{1}{3} \\ -\frac{1}{3} & \frac{1}{3} & \frac{2}{3} \end{bmatrix}^T \begin{bmatrix} 0 \\ 1 \end{bmatrix}$$

$$= \begin{bmatrix} \frac{1}{3} \\ -\frac{1}{3} \\ -\frac{2}{3} \end{bmatrix}$$

$$7. \quad s = 0 / -y_3 \approx 0$$

$$8. \quad x_j^* = t$$

$$x_3^* = 3/2$$

$$x_B^* = x_B - t \Delta x_B$$

$$= \begin{bmatrix} 1 \\ 1 \end{bmatrix} - \frac{3}{2} \begin{bmatrix} y_3 \\ y_3 \end{bmatrix}$$

$$= \begin{bmatrix} ; \\ ; \end{bmatrix} + \begin{bmatrix} -y_2 \\ -1 \end{bmatrix}$$

$$= \begin{bmatrix} y_2 \\ 0 \end{bmatrix}$$

$$z_i^* = 5$$

$$z_1^* = 0$$

$$z_n^* = z_n - s \Delta z_n$$

$$= \begin{bmatrix} y_3 \\ -y_3 \\ 0 \end{bmatrix}$$

$$9_1 \quad B = \{2, 3\} \quad N = \{4, 5, 13\}$$

$$x_B^* = \begin{bmatrix} 1/2 \\ 3/2 \end{bmatrix}$$

$$z_N^* = \begin{bmatrix} 1/3 \\ -8/3 \\ 0 \end{bmatrix}$$

$$B = \begin{bmatrix} -1 & 1 \\ -1 & 1 \end{bmatrix} \quad N = \begin{bmatrix} 1 & 0 & 1 \\ 0 & 1 & 2 \end{bmatrix}$$

$$g^* = 2(0) - 6(1/2) = -3$$

$$(2) \begin{aligned} \max & 2x_1 - 6x_2 + 0x_3 \\ \exists & -x_1 - x_2 - x_3 \leq -2 \\ & 2x_1 - x_2 + x_3 \leq 1 \end{aligned}$$

$$\begin{aligned} \max & -(-2+\mu)x_1 - (6+\mu)x_2 - (0+\mu)x_3 = 8 \\ \not\exists & x_4 = -2+\mu \stackrel{\neq 0}{=} x_1 + x_2 + x_3 \rightarrow \text{unbd} \\ & x_5 = 1+\mu \stackrel{\neq 3}{=} -2x_1 + x_2 - x_3 \rightarrow x_1 \leq \frac{3}{2} \end{aligned}$$

$$\begin{array}{ll} \mu \geq 2 & \mu \geq 2 \\ \mu \geq -6 & \mu \geq -1 \rightarrow \mu = 2 \rightarrow x_1 \text{ enters} \\ \mu \geq 0 & \end{array}$$

$x_1$  enters,  $x_5$  leaves

$$\begin{aligned} \max & -(-2+\mu)x_1 - (6+\mu)x_2 - (0+\mu)x_3 \\ \not\exists & x_4 = -2+\mu + x_1 + x_2 + x_3 \\ & x_1 = \gamma_1(1+\mu) + \gamma_2x_2 - \gamma_3x_3 - \gamma_5x_5 \end{aligned}$$

$$\begin{aligned} \max & -(-2+\mu)(\gamma_1(1+\mu) + \gamma_2x_2 - \gamma_3x_3 - \gamma_5x_5) - (6+\mu)x_2 - (0+\mu)x_3 \\ \not\exists & x_4 = -2+\mu + \gamma_1(1+\mu) + \gamma_2x_2 - \gamma_3x_3 - \gamma_5x_5 + x_2 + x_3 \\ & x_1 = \gamma_1(1+\mu) + \gamma_2x_2 - \gamma_3x_3 - \gamma_5x_5 \end{aligned}$$

$$\begin{aligned} \max & -(-2+\mu)(\gamma_1(1+\mu) + \gamma_2x_2 - \gamma_3x_3 - \gamma_5x_5) - (6+\mu)x_2 - (0+\mu)x_3 \\ & -(-1+\gamma_2\mu)x_2 - (-\gamma_3\mu)x_3 - (\gamma_5\mu)x_5 - (6+\mu)x_2 - (0+\mu)x_3 \\ \not\exists & x_4 = -3\gamma_1 + 3\gamma_2\mu + \gamma_2x_2 + \gamma_3x_3 - \gamma_5x_5 \\ & x_1 = \gamma_1(1+\mu) + \gamma_2x_2 - \gamma_3x_3 - \gamma_5x_5 \end{aligned}$$

$$\max - (-2 + \mu)(y_2 + y_3) \\ - (5 + \frac{3}{2}\mu)x_2 - (1 + \frac{1}{2}\mu)x_3 - (1 - \frac{1}{2}\mu)x_5 \\ \Rightarrow x_4 = -\frac{3}{2} + \frac{3}{2}\mu + \frac{3}{2}x_2 + y_2x_3 - y_2x_5 \\ x_1 = y_1 + \frac{1}{2}\mu + \frac{1}{2}x_2 - y_2x_3 - y_2x_5$$

$$5 + \frac{3}{2}\mu \geq 0 \quad | \quad -\frac{3}{2} + \frac{3}{2}\mu \geq 0 \rightarrow \mu \geq 1 \\ 1 + \frac{1}{2}\mu \geq 0 \quad | \quad y_2 + \frac{1}{2}\mu \geq 0 \rightarrow \mu = 1 \\ 1 - \frac{1}{2}\mu \geq 0 \rightarrow \mu \leq 2 \quad | \quad \rightarrow x_4 \text{ leaves}$$

Dual ratio test

$$(\sim) -\frac{3}{2} z_4 - (\sim) \\ z_2 = \frac{13}{2} - \frac{3}{2} z_4 + (\sim) \rightarrow z_4 \leq \frac{13}{3} \\ z_3 = \frac{3}{2} - \frac{1}{2} z_4 + (\sim) \rightarrow z_4 \leq 3 \rightarrow x_3 \text{ enters} \\ z_5 = y_2 + \frac{1}{2} z_4 + (\sim) \rightarrow \text{unbdd}$$

$x_3$  enters  $x_4$  leaves

$$\max - (-2 + \mu)(y_2 + y_3) \\ - (5 + \frac{3}{2}\mu)x_2 - (1 + \frac{1}{2}\mu)x_3 - (1 - \frac{1}{2}\mu)x_5 \\ \Rightarrow x_3 = 3 - 3\mu - 3x_2 + 2x_4 + x_5 \\ x_1 = y_1 + \frac{1}{2}\mu + \frac{1}{2}x_2 - y_2x_3 - y_2x_5$$

$$\max - (-2 + \mu)(y_2 + y_3) \\ - (5 + \frac{3}{2}\mu)x_2 - (1 + \frac{1}{2}\mu)(3 - 3\mu - 3x_2 + 2x_4 + x_5) - (1 - \frac{1}{2}\mu)x_5 \\ \Rightarrow x_3 = 3 - 3\mu - 3x_2 + 2x_4 + x_5 \\ x_1 = y_1 + \frac{1}{2}\mu + \frac{1}{2}x_2 - y_2(3 - 3\mu - 3x_2 + 2x_4 + x_5) - y_2x_5$$

$$\max - (-2 + \mu)(y_2 + y_m) - (1 + y_m)(3 - 3\mu)$$

$$- (5 + 3\mu)x_2 - (-3 - 3\mu)x_2 - (2 + \mu)x_4 - (1 + \mu)x_5 - (1 - y_m)x_5$$

$$\geq x_3 = 3 - 3\mu - 3x_2 + 2x_4 + x_5$$

$$x_1 = -1 + 2\mu + 2x_2 - x_4 - x_5$$

$$\max - (-2 + \mu)(y_2 + y_m) - (1 + y_m)(3 - 3\mu)$$

$$-2\overset{=2}{x_2} - (\overset{=3\mu}{2 + \mu})x_4 - 2\overset{=2}{x_5}$$

$$\geq x_3 = 3 - 3\mu - 3x_2 + 2x_4 + x_5$$

$$x_1 = -1 + 2\mu + 2x_2 - x_4 - x_5$$

$$\text{unbdd} \vee 3 - 3\mu \geq 0 \rightarrow \mu \leq 1 \vee$$

$$2 + \mu \geq 0 \vee -1 + 2\mu \geq 0 \rightarrow \mu \geq y_2 \rightarrow \mu = y_2$$

$$1 + y_2 \mu \geq 0 \vee \rightarrow x_1 \text{ leaves}$$

Dual ratio test

$$(m) = 0 z_1 + (\sim)$$

$$z_2 = 2 - 2z_1 \rightarrow z_1 \leq 1$$

$$z_4 = 3/2 + z_1 \rightarrow \text{unbdd} \rightarrow x_2 \text{ enters}$$

$$z_5 = 2 + z_1 \rightarrow \text{unbdd}$$

$$\max - (-2 + \mu)(y_2 + y_m) - (1 + y_m)(3 - 3\mu)$$

$$-2x_2 - (2 + \mu)x_4 - 2x_5$$

$$\geq x_3 = 3 - 3\mu - 3x_2 + 2x_4 + x_5$$

$$x_1 = y_2 - \mu + y_2 x_1 + y_2 x_4 + y_2 x_5$$

$$\max - (-2 + \mu)(1_2 + \mu) - (1 + \mu)(3 - 3\mu)$$

$$-2(1_2 - \mu + 1_2 x_1 + 1_2 x_4 + 1_2 x_5) - (2 + \mu)x_4 - 2x_5$$

$$\begin{aligned} \Rightarrow x_3 &= 3 - 3\mu - 3(1_2 - \mu + 1_2 x_1 + 1_2 x_4 + 1_2 x_5) + 2x_4 + x_5 \\ x_2 &= 1_2 - \mu + 1_2 x_1 + 1_2 x_4 + 1_2 x_5 \end{aligned}$$

$$\max - (-2 + \mu)(1_2 + \mu) - (1 + \mu)(3 - 3\mu)$$

$$-1 + 2\mu - x_1 - x_4 - x_5 - (2 + \mu)x_4 - 2x_5$$

$$\begin{aligned} \Rightarrow x_3 &= 3 - 3\mu - 3_2 + 3\mu - 3_2 x_1 - 3_2 x_4 - 3_2 x_5 + 2x_4 + x_5 \\ x_2 &= 1_2 - \mu + 1_2 x_1 + 1_2 x_4 + 1_2 x_5 \end{aligned}$$

$$\max - (-2 + \mu)(1_2 + \mu) - (1 + \mu)(3 - 3\mu) - 1 + 2\mu$$

$$-x_1 - (3 + \mu)x_4 - 3x_5$$

$$\Rightarrow x_3 = 3_2 - 3_2 x_1 + 1_2 x_4 - 1_2 x_5$$

$$x_2 = 1_2 - \mu + 1_2 x_1 + 1_2 x_4 + 1_2 x_5$$

unbdd

$$3 + \mu \geq 0 \quad \checkmark$$

unbdd

unbdd

$$1_2 - \mu \geq 0 \rightarrow \mu \leq 1_2 \quad \checkmark \rightarrow \mu = 0$$

$$\max - 3 - x_1 - (3 + \mu)x_4 - 3x_5$$

$$\Rightarrow x_3 = 3_2 - 3_2 x_1 + 1_2 x_4 - 1_2 x_5$$

$$x_2 = 1_2 + 1_2 x_1 + 1_2 x_4 + 1_2 x_5$$

$$x_1, x_4, x_5 \geq 0$$

$$x_2 = 1_2$$

$$x_3 = 3_2$$

$$y = -3$$