CHAPTER III

WEIGHTED GOAL PROGRAMMING MODEL

FORMULATION AND CALCULATION OF DIET PLANNING

3.1 INTRODUCTION

Linear goal programming is one of many techniques for dealing with the modeling, solution, and analysis of multiple and conflicting objective linear problems. This type of multiobjective linear problems requiring a goal programming solution have been expanded and defined considerably since Charnes and Cooper [1961] introduced the concept of “goal programming.” As goal programming models were improved to more accurately reflect the decision environment they were designed to model, complications inevitable arose. Once complication concerned the weighting of goals in the objective function Ignizio [1976], the problem that arose was finding a valid mean by which one calculates representative weightings. One approach to avoid this difficulty is to eliminate the mathematical weighting from the model. With this approach, a goal programming problem becomes a lexicographic problem. The goals in the lexicographic problem are not differentiated by a weighting system, but instead are ordinals ranked in order of preference.

To solve the lexicographic goal programming problem, decision makers have a choice of two approaches:
(1) the multiphase simplex methods, or

(2) the sequential linear goal programming methods.

The multiphase simplex method is basically a modified version of Danzig’s simplex method for solving linear programming minimization problems. The two most common versions of the multiphase simplex method are by Lee [1972] and Ignizio [1976, 1982].

The sequential linear goal programming method’s major feature is that it allows goal programming problems to be run on conventional linear programming computer programs. Kornbluth [1973] originally described the sequential linear goal programming algorithm, while Arthur and Ravindran [1978] improved its efficacy, and Kwak and Schniederjans [1985] gives an alternative solution.

The first solution of a diet problem using linear programming was by Smith [1959]. Anderson and Earle [1983] have done the comparative study of diet planning through linear programming and goal programming approach for daily nutritional requirements of Thais. McCann-Rugg et al. [1983] has studied the diabetic patients’ diet through interactive linear goal programming approach and gives the comparative results with classical manual. Selection of diets by quantitative techniques is becoming increasingly common. The most popular technique is linear programming. Although linear programming is satisfactory for the selection of least cost mixes of foods to meet specific nutritional requirements, it is often difficult to ensure a good balance of nutrients. Nutritionists are becoming more aware of the dangers of overdoses of some nutrients and of the need for a balanced intake of all nutrients.
In this chapter, we demonstrate the use of weighted goal programming in diet planning by using an example. It then presents the results of a problem involving selection of food nutrients and suggestion for the improvement in nutritional balance which was not achieved.

3.2 GENERIC WEIGHTED GOAL PROGRAMMING MODEL

The weighted goal programme variant allows for direct trade-offs between all unwanted deviational variables by placing them in a weighted, normalized single achievement function. Weighted goal programming is sometimes termed non-preemptive goal programming in the literature. If we assume linearity of the achievement function then we can represent the linear weighted goal programme by the following formulation:

Minimize: \[ a = \sum_{q=1}^{Q} \left( u_q n_q - v_q p_q \right) \] (1)

Subject to

\[ f_q(x) + n_q - p_q = b_q, \quad q = 1, 2, \ldots, Q \] (2)

\[ \bar{x} \in F \] (3)

where

\[ n_q, p_q \geq 0, \quad q = 1, 2, \ldots, Q \] (4)

and

\[ n_q \times \bar{x}_q = 0 \] (5)
with the variable definitions identical to those introduced for the lexicographic goal programming variant, except that the preference weights \( u_q \) and \( v_q \) are no longer indexed by priority level.

### 3.3 AN ILLUSTRATIVE EXAMPLE OF WGP MODEL

A dietician is required to propose a diet for a special needs patient. The values of protein, carbohydrate, saturated fat, vitamin B\(_6\), vitamin C, and calcium should ideally fall between the bounds given in the table below. The diet can be composed of an integer number of units of ten basic foodstuffs, termed FOOD 1, …, FOOD 10. The amount of nutrients in one unit of foodstuff and its cost is given in the table. Ideally no more than four units of any foodstuff should be consumed on a given day and the daily cost is below Rs.50 also the patient desires that no more than 3 units of FOODS 1 through 3 be consumed daily.

A normalized weighted goal programme places ten times as much importance on medical needs as cost considerations or patient preferences.

#### Table 3.1: Nutritional and Cost Data for Foodstuffs

<table>
<thead>
<tr>
<th>Food</th>
<th>Protein (g)</th>
<th>Carbohydrates (g)</th>
<th>Sat fat (g)</th>
<th>Vit B(_6) (mg)</th>
<th>Vit C (mg)</th>
<th>Calcium (mg)</th>
<th>Cost (Rs)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>3.3</td>
<td>5.0</td>
<td>1.0</td>
<td>0.06</td>
<td>1</td>
<td>120</td>
<td>2.5</td>
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<tr>
<td>2</td>
<td>25.5</td>
<td>0.1</td>
<td>21.7</td>
<td>0.10</td>
<td>0</td>
<td>720</td>
<td>15.0</td>
</tr>
<tr>
<td>3</td>
<td>2.5</td>
<td>0</td>
<td>0.6</td>
<td>0.02</td>
<td>0</td>
<td>11</td>
<td>3.3</td>
</tr>
<tr>
<td></td>
<td>4</td>
<td>5</td>
<td>6</td>
<td>7</td>
<td>8</td>
<td>9</td>
<td>10</td>
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</tr>
<tr>
<td>No. of units</td>
<td>11.0</td>
<td>27.3</td>
<td>3.3</td>
<td>1.2</td>
<td>1.2</td>
<td>2.6</td>
<td>0.4</td>
</tr>
<tr>
<td>of foodstuff 1</td>
<td>75.7</td>
<td>0</td>
<td>1.1</td>
<td>23.2</td>
<td>2.6</td>
<td>30.9</td>
<td>11.8</td>
</tr>
<tr>
<td>required by patient</td>
<td>0.4</td>
<td>5.2</td>
<td>0.2</td>
<td>0.1</td>
<td>0.1</td>
<td>0.3</td>
<td>0.0</td>
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<tr>
<td>foodstuff 2</td>
<td>0.22</td>
<td>0.29</td>
<td>0.11</td>
<td>0.29</td>
<td>0.05</td>
<td>0.07</td>
<td>0.06</td>
</tr>
<tr>
<td>required by patient</td>
<td>0</td>
<td>0</td>
<td>44</td>
<td>11</td>
<td>7</td>
<td>10</td>
<td>6</td>
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<td>foodstuff 3</td>
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<tr>
<td>required by patient</td>
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<td>foodstuff 4</td>
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<td>required by patient</td>
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<td>foodstuff 5</td>
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<td>required by patient</td>
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<td>foodstuff 6</td>
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<td>required by patient</td>
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<td>foodstuff 7</td>
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<td>required by patient</td>
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<tr>
<td>foodstuff 8</td>
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<td></td>
<td></td>
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<tr>
<td>required by patient</td>
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</tr>
</tbody>
</table>

### 3.3.1 Variables and Parameters

\[ x_1 = \text{No. of units of foodstuff 1 required by patient} \]

\[ x_2 = \text{No. of units of foodstuff 2 required by patient} \]

\[ x_3 = \text{No. of units of foodstuff 3 required by patient} \]

\[ x_4 = \text{No. of units of foodstuff 4 required by patient} \]

\[ x_5 = \text{No. of units of foodstuff 5 required by patient} \]

\[ x_6 = \text{No. of units of foodstuff 6 required by patient} \]

\[ x_7 = \text{No. of units of foodstuff 7 required by patient} \]

\[ x_8 = \text{No. of units of foodstuff 8 required by patient} \]
\( x_9 = \) No. of units of foodstuff 9 required by patient
\( x_{10} = \) No. of units of foodstuff 10 required by patient
\( n_1 = \) Underachievement of minimum daily requirement of Protein
\( p_1 = \) Overachievement of minimum daily requirement of Protein
\( n_2 = \) Underachievement of minimum daily requirement of Carbohydrates
\( p_2 = \) Overachievement of minimum daily requirement of Carbohydrates
\( n_3 = \) Underachievement of minimum daily requirement of Saturated fat
\( p_3 = \) Overachievement of minimum daily requirement of Saturated fat
\( n_4 = \) Underachievement of minimum daily requirement of Vitamin B_6
\( p_4 = \) Overachievement of minimum daily requirement of Vitamin B_6
\( n_5 = \) Underachievement of minimum daily requirement of Vitamin C
\( p_5 = \) Overachievement of minimum daily requirement of Vitamin C
\( n_6 = \) Underachievement of minimum daily requirement of Calcium
\( p_6 = \) Overachievement of minimum daily requirement of Calcium
\( nn_1 = \) Underachievement of maximum daily requirement of Protein
\( pp_1 = \) Overachievement of maximum daily requirement of Protein
\( nn_2 = \) Underachievement of maximum daily requirement of Carbohydrates
\( pp_2 = \) Overachievement of maximum daily requirement of Carbohydrates
\( nn_3 = \) Underachievement of maximum daily requirement of Saturated fat
\( pp_3 = \) Overachievement of maximum daily requirement of Saturated fat
\( nn_4 = \) Underachievement of maximum daily requirement of Vitamin B_6
\( pp_4 = \) Overachievement of maximum daily requirement of Vitamin B_6
nn₅ = Underachievement of maximum daily requirement of Vitamin C
pp₅ = Overachievement of maximum daily requirement of Vitamin C
nn₆ = Underachievement of maximum daily requirement of Calcium
pp₆ = Overachievement of maximum daily requirement of Calcium
nₓ = Underachievement of minimum daily requirement of Cost
pₓ = Overachievement of minimum daily requirement of Cost
nf₁ = Underachievement of medical need of foodstuff 1 to be consumed daily
pf₁ = Overachievement of medical need of foodstuff 1 to be consumed daily
nf₂ = Underachievement of medical need of foodstuff 2 to be consumed daily
pf₂ = Overachievement of medical need of foodstuff 2 to be consumed daily
nf₃ = Underachievement of medical need of foodstuff 3 to be consumed daily
pf₃ = Overachievement of medical need of foodstuff 3 to be consumed daily
nf₄ = Underachievement of medical need of foodstuff 4 to be consumed daily
pf₄ = Overachievement of medical need of foodstuff 4 to be consumed daily
nf₅ = Underachievement of medical need of foodstuff 5 to be consumed daily
pf₅ = Overachievement of medical need of foodstuff 5 to be consumed daily
nf₆ = Underachievement of medical need of foodstuff 6 to be consumed daily
pf₆ = Overachievement of medical need of foodstuff 6 to be consumed daily
nf₇ = Underachievement of medical need of foodstuff 7 to be consumed daily
pf₇ = Overachievement of medical need of foodstuff 7 to be consumed daily
nf₈ = Underachievement of medical need of foodstuff 8 to be consumed daily
pf₈ = Overachievement of medical need of foodstuff 8 to be consumed daily
nf₀ = Underachievement of medical need of foodstuff 9 to be consumed daily  
pf₀ = Overachievement of medical need of foodstuff 9 to be consumed daily  
 nf₁₀ = Underachievement of medical need of foodstuff 10 to be consumed daily  
 pf₁₀ = Overachievement of medical need of foodstuff 10 to be consumed daily  
 nf₁₁ = Underachievement of patient desire of foodstuff 1  
 pf₁₁ = Overachievement of patient desire of foodstuff 1  
 nf₂₂ = Underachievement of patient desire of foodstuff 2  
 pf₂₂ = Overachievement of patient desire of foodstuff 2  
 nf₃₃ = Underachievement of patient desire of foodstuff 3  
 pf₃₃ = Overachievement of patient desire of foodstuff 3  

3.3.2 Cost Consideration

The maximum cost that can be spent daily on these entire 10 foodstuffs as a whole is Rs.50:

\[ 2.5 x_1 + 15 x_2 + 3.3 x_3 + 1.8 x_4 + 20 x_5 + 2.5 x_6 + 1.5 x_7 + 6 x_8 + 1.5 x_9 + 1.6 x_{10} \]

3.3.3 Minimum Nutritional Requirement

The minimum daily requirement of Protein is 40.0 gm:

\[ 3.3 x_1 + 25.5 x_2 + 2.5 x_3 + 11 x_4 + 27.3 x_5 + 3.3 x_6 + 1.2 x_7 + 1.2 x_8 + 2.6 x_9 + 0.4 x_{10} \geq 40 \]

The minimum daily requirement of Carbohydrates is 100 gm:
5.0 x_1 + 0.1 x_2 + 75.7 x_4 + 1.1 x_6 + 23.2 x_7 + 2.6 x_8 + 30.9 x_9
+ 11.8 x_{10} \geq 100

The minimum daily requirement of Saturated fat is 2 gm:
\[ x_1 + 21.7 x_2 + 0.6 x_3 + 0.4 x_4 + 5.2 x_5 + 0.2 x_6 + 0.1 x_7 + 0.1 x_8 
+ 0.3 x_9 \geq 2 \]

The minimum daily requirement of Vitamin B\text sub {6} is 1 mg:
\[ 0.06 x_1 + 0.10 x_2 + 0.02 x_3 + 0.22 x_4 + 0.29 x_5 + 0.11 x_6 + 0.29 x_7 
+ 0.05 x_8 + 0.07 x_9 + 0.06 x_{10} \geq 1 \]

The minimum daily requirement of Vitamin C is 50 mg:
\[ x_1 + 44 x_6 + 11 x_7 + 7 x_8 + 10 x_9 + 6 x_{10} \geq 50 \]

The minimum daily requirement of Calcium is 800 mg:
\[ 120 x_1 + 720 x_2 + 11 x_3 + 35 x_4 + 7 x_5 + 40 x_6 + 6 x_7 + 20 x_8 + 18 x_9 
+ 4 x_{10} \geq 800 \]

### 3.3.4 Maximum Nutritional Requirement

The maximum daily requirement of Protein is 60 gm:
\[ 3.3 x_1 + 25.5 x_2 + 2.5 x_3 + 11 x_4 + 27.3 x_5 + 3.3 x_6 + 1.2 x_7 + 1.2 x_8 
+ 2.6 x_9 + 0.4 x_{10} \leq 60 \]

The maximum daily requirement of Carbohydrates is 300 gm:
\[ 5.0 x_1 + 0.1 x_2 + 75.7 x_4 + 1.1 x_6 + 23.2 x_7 + 2.6 x_8 + 30.9 x_9 + 11.8 x_{10} 
\leq 300 \]

The maximum daily requirement of Saturated fat is 15 gm:
\[ x_1 + 21.7 x_2 + 0.6 x_3 + 0.4 x_4 + 5.2 x_5 + 0.2 x_6 + 0.1 x_7 + 0.1 x_8 \\
+ 0.3 x_9 \leq 15 \]

The maximum daily requirement of Vitamin B<sub>6</sub> is 2 mg:
\[ 0.06 x_1 + 0.10 x_2 + 0.02 x_3 + 0.22 x_4 + 0.29 x_5 + 0.11 x_6 + 0.29 x_7 \\
+ 0.05 x_8 + 0.07 x_9 + 0.06 x_{10} \leq 2 \]

The maximum daily requirement of Vitamin C is 100 mg:
\[ x_1 + 44 x_6 + 11 x_7 + 7 x_8 + 10 x_9 + 6 x_{10} \leq 100 \]

The maximum daily requirement of Calcium is 1500 mg:
\[ 120 x_1 + 720 x_2 + 11 x_3 + 35 x_4 + 40 x_6 + 6 x_7 + 20 x_8 + 18 x_9 \\
+ 4x_{10} \leq 1500 \]

Medical need of not more than 4 units of any foodstuff should be consumed by the patient:
\[ x_i \leq 4 \quad (i = 1, 2, \ldots, 10) \]

Patient desires that no more than 3 units of food 1 through 3 to be consumed daily:
\[ x_i \leq 3 \quad (i = 1, 2, 3) \]

**Objective function:**
\[ 10 (n_1 + n_2 + n_3 + n_4 + n_5 + n_6 + pp_1 + pp_2 + pp_3 + pp_4 + pp_5 + pp_6 + pf_1 \\
+ pf_2 + pf_3 + pf_4 + pf_5 + pf_6 + pf_7 + pf_8 + pf_9 + pf_{10}) + p_c + (pf_{11} + pf_{22} \\
+ pf_{33}) \]
3.4 FORMULATION OF WEIGHTED GOAL PROGRAMMING MODEL

Using normalization the weighted goal programming model is formulated as:

**Minimize:** \[ a = (0.25 n_1 + 0.1 n_2 + 5 n_3 + 10 n_4 + 0.2 n_5 + 0.0125 n_6 + 0.1667 pp_1 + 0.033 pp_2 + 0.6667 pp_3 + 5 pp_4 + 0.1 pp_5 + 0.00667 pp_6 + 2.5 pf_1 + 2.5 pf_2 + 2.5 pf_3 + 2.5 pf_4 + 2.5 pf_5 + 2.5 pf_6 + 2.5 pf_7 + 2.5 pf_8 + 2.5 pf_9 + 2.5 pf_{10} + p_c (0.02) + (0.33 pf_{11} + 0.33 pf_{22}) + 0.33 pf_{33}) \]

**Subject to:**

1. \[ 2.5 x_1 + 15 x_2 + 3.3 x_3 + 1.8 x_4 + 20 x_5 + 2.5 x_6 + 1.5 x_7 + 6 x_8 + 1.5 x_9 + 1.6 x_{10} + n_c \quad p_c = 50 \]
2. \[ 3.3 x_1 + 25.5 x_2 + 2.5 x_3 + 11 x_4 + 27.3 x_5 + 3.3 x_6 + 1.2 x_7 + 1.2 x_8 + 2.6 x_9 + 0.4 x_{10} + n_1 - p_1 = 40 \]
3. \[ 5.0 x_1 + 0.1 x_2 + 75.7 x_4 + 1.1 x_6 + 23.2 x_7 + 2.6 x_8 + 30.9 x_9 + 11.8 x_{10} + n_2 \quad p_2 = 100 \]
4. \[ x_1 + 21.7 x_2 + 0.6 x_3 + 0.4 x_4 + 5.2 x_5 + 0.2 x_6 + 0.1 x_7 + 0.1 x_8 + 0.3 x_9 + n_3 - p_3 = 2 \]
5. \[ 0.06 x_1 + 0.10 x_2 + 0.02 x_3 + 0.22 x_4 + 0.29 x_5 + 0.11 x_6 + 0.29 x_7 + 0.05 x_8 + 0.07 x_9 + 0.06 x_{10} + n_4 \quad p_4 = 1 \]
6. \[ x_1 + 44 x_6 + 11 x_7 + 7 x_8 + 10 x_9 + 6 x_{10} + n_5 - p_5 = 50 \]
7. \[ 120 x_1 + 720 x_2 + 11 x_3 + 35 x_4 + 7 x_5 + 40 x_6 + 6 x_7 + 20 x_8 + 18 x_9 + 4 x_{10} + n_6 \quad p_6 = 800 \]
8. \[ 3.3 x_1 + 25.5 x_2 + 2.5 x_3 + 11 x_4 + 27.3 x_5 + 3.3 x_6 + 1.2 x_7 + 1.2 x_8 + 2.6 x_9 + 0.4 x_{10} + n n_1 - pp_1 = 60 \]
5.0 \( x_1 \) + 0.1 \( x_2 \) + 75.7 \( x_4 \) + 1.1 \( x_6 \) + 23.2 \( x_7 \) + 2.6 \( x_8 \) + 30.9 \( x_9 \) + 11.8 \( x_{10} \) + \( nn_2 \) \( pp_2 \) = 300
\( x_1 \) + 21.7 \( x_2 \) + 0.6 \( x_3 \) + 0.4 \( x_4 \) + 5.2 \( x_5 \) + 0.2 \( x_6 \) + 0.1 \( x_7 \) + 0.1 \( x_8 \) + 0.3 \( x_9 \) + \( nn_3 \) \( pp_3 \) = 15
0.06 \( x_1 \) + 0.10 \( x_2 \) + 0.02 \( x_3 \) + 0.22 \( x_4 \) + 0.29 \( x_5 \) + 0.11 \( x_6 \) + 0.29 \( x_7 \) + 0.05 \( x_8 \) + 0.07 \( x_9 \) + 0.06 \( x_{10} \) + \( nn_4 \) \( pp_4 \) = 2
\( x_1 \) + 44 \( x_6 \) + 11 \( x_7 \) + 7 \( x_8 \) + 10 \( x_9 \) + 6 \( x_{10} \) + \( nn_5 \) \( pp_5 \) = 100
120 \( x_1 \) + 720 \( x_2 \) + 11 \( x_3 \) + 35 \( x_4 \) + 7 \( x_5 \) + 40 \( x_6 \) + 6 \( x_7 \) + 20 \( x_8 \) + 18 \( x_9 \) + 4 \( x_{10} \) + \( nn_6 \) \( pp_6 \) = 1500
\( x_i \) + \( nf_i \) - \( pf_i \) = 4 \hspace{1cm} (i = 1, 2, \ldots, 10)
\( x_i \) + \( nf_{ii} \) - \( pf_{ii} \) = 3 \hspace{1cm} (i = 1, 2, 3)

**Non-Negative Restrictions:**

\( x_i, n_i, p_i, nn_i, pp_i, n_c, p_c, nf_i, pf_i \) \hspace{1cm} (i = 1, 2, \ldots, 10)
\( nf_{ii}, pf_{ii} \geq 0 \) \hspace{1cm} (i = 1, 2, 3)

### 3.5 RESULTS

Solving the above problem by Excel solver, we get
\( x_1 = 4, x_2 = 0, x_3 = 3, x_4 = 2, x_5 = 0, x_6 = 1, x_7 = 0, x_8 = 3, x_9 = 3, x_{10} = 0; \)
\( n_1 = 0, p_1 = 17.4, n_2 = 0, p_2 = 173, n_3 = 0, p_3 = 6, n_4 = 0, p_4 = 0.21, \)
\( n_5 = 0, p_5 = 49, n_6 = 63, p_6 = 0; \)
\( nn_1 = 3, pp_1 = 0, nn_2 = 27, pp_2 = 0, nn_3 = 7, pp_3 = 0, nn_4 = 1, pp_4 = 0, \)
\( nn_5 = 1, pp_5 = 0, nn_6 = 763, pp_6 = 0; \)
\[n_C = 1, \ p_C = 0, \ nf_1 = 0, \ pf_1 = 0, \ nf_2 = 4, \ pf_2 = 0, \ nf_3 = 1, \ pf_3 = 0, \ nf_4 = 2, \]
\[\ nf_5 = 4, \ pf_5 = 0, \ nf_6 = 3, \ pf_6 = 0, \ nf_7 = 4, \ pf_7 = 0, \]
\[\ nf_8 = 1, \ pf_8 = 0, \ nf_9 = 1, \ pf_9 = 0, \ nf_{10} = 4, \ pf_{10} = 0, \ nf_{11} = 0, \ pf_{11} = 1, \]
\[\ nf_{22} = 3, \ pf_{22} = 0, \ nf_{33} = 0, \ pf_{33} = 0; \]

The minimum unwanted deviation = 1.12

### 3.6 INTERPRETATION OF THE RESULTS

The minimum daily requirement of Proteins is overachieved by 17.4 g
The minimum daily requirement of Carbohydrates is overachieved by 173 g
The minimum daily requirement of Saturated fat is overachieved by 6 g
The minimum daily requirement of Vitamin B_6_ is overachieved by 0.21 mg
The minimum daily requirement of Vitamin C is overachieved by 49 mg
The minimum daily requirement of Calcium is underachieved by 63 mg.

The maximum daily requirement of Proteins is underachieved by 3 g
The maximum daily requirement of Carbohydrates is underachieved by 27 g
The maximum daily requirement of Saturated fat is underachieved by 7 g
The maximum daily requirement of Vitamin B_6_ is underachieved by 1 mg
The maximum daily requirement of Vitamin C is underachieved by 1 mg
The maximum daily requirement of Calcium is underachieved by 763 mg

Thus, the daily requirement of all the nutrients is being satisfied within the maximum and minimum limit.

The cost goal is underachieved from the required Rs.50 to Rs.48.5.
3.7 CONCLUSION

This chapter presents the development and testing of weighted goal programming approach for diet planning. The solution shows that all the goals have been achieved given the importance at the satisfactory level. This model may be improved by applying sensitivity analysis. Excel solver is used in solution of GP model.