CHAPTER-7
AN INTEGRATED MULTIOBJECTIVE PLANNING MODEL:
A CASE STUDY OF INDIAN STEEL PLANT INDUSTRY

7.1 OBJECTIVE
This study outlines a planning methodology that formally integrates major societal dimensions with mathematical programming in industry for a developing country. An integrated approach involving the Analytic Hierarchy Process (AHP) and Linear Goal Programming (LGP) is employed. Development objectives are classified under economic, technological, social and political factors and are prioritized using the AHP according to their degree of importance. The Priority structure is incorporated into the LGP framework to develop a multiobjective planning model. The application of the model is demonstrated using data from an export-oriented, industrial and dominant steel plant industry sector in a developing country.

7.2 DATA OF THE PROBLEM
This study was carried out by using data from an export orientated and dominant steel plant industry sector located in Vizag, Andhra Pradesh. The industry provides about 95% of foreign exchange earnings, 16-18% of the gross domestic product (GDP) and employs about 15% of the wage earners. The contribution of the steel plant industry sector to government revenue has declined over the past ten years due largely to rising production costs, falling steel prices and constraints on steel output. Annual production of steel in A.P. reached its peak of 7,47,500 metric tons in 1999, accounting for 12% of world production and representing the third largest source of steel in the world. Since then, steel output in A.P. has been on a steady decline owing to falling ore grades, misallocation of scarce resources, inefficient productive capacity, shortage of foreign exchange revenue and lack of skilled labor. Annual output of steel bottomed to a level of 4,63,354 metric tons in 2003, some 38% below the 1999. The required information is given in Table-7.1 & 7.2.
Table-7.1

Summary of Data Related to Target Levels

<table>
<thead>
<tr>
<th>Objective</th>
<th>Target level</th>
</tr>
</thead>
<tbody>
<tr>
<td>Annual incremental production</td>
<td>5%</td>
</tr>
<tr>
<td>Ore grade</td>
<td>2.5%</td>
</tr>
<tr>
<td>Export market demand</td>
<td></td>
</tr>
<tr>
<td>Upper limit</td>
<td>6,50,000 tons/ year</td>
</tr>
<tr>
<td>Lower limit</td>
<td>5,00,000 tons/ year</td>
</tr>
<tr>
<td>Employment generation</td>
<td>55,000 employees</td>
</tr>
<tr>
<td>Capital investment</td>
<td>Rs 200/ ton</td>
</tr>
<tr>
<td>Income re-distribution</td>
<td>Rs 100/ ton</td>
</tr>
<tr>
<td>Mineral export tax</td>
<td>Rs 200/ ton</td>
</tr>
<tr>
<td>Imported energy use</td>
<td>Rs 30/ ton</td>
</tr>
</tbody>
</table>

**TABLE-7.2**

<table>
<thead>
<tr>
<th>Under ground plants ($X_{ij}$)$^a$</th>
<th>Open pit plants ($Y_{ij}$)$^b$</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>$X_{11}$ $X_{12}$ $X_{13}$ $X_{21}$ $X_{31}$ $X_{32}$ $X_{41}$ $X_{42}$</td>
<td>$Y_{11}$ $Y_{12}$ $Y_{13}$</td>
<td></td>
</tr>
<tr>
<td>Model</td>
<td></td>
<td></td>
</tr>
<tr>
<td>79500</td>
<td>36660</td>
<td>37620</td>
</tr>
<tr>
<td>94320</td>
<td>82980</td>
<td>13680</td>
</tr>
<tr>
<td>57000</td>
<td>59100</td>
<td></td>
</tr>
<tr>
<td>92700</td>
<td>23220</td>
<td>23220</td>
</tr>
<tr>
<td>#1</td>
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<td></td>
</tr>
<tr>
<td>86125</td>
<td>39715</td>
<td>40755</td>
</tr>
<tr>
<td>102180</td>
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<td>61750</td>
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<tr>
<td>100425</td>
<td>25155</td>
<td>25155</td>
</tr>
<tr>
<td>#2</td>
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</tr>
<tr>
<td>74835</td>
<td>34509</td>
<td>31854</td>
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<td>88785</td>
<td>78111</td>
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<tr>
<td>97483</td>
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<td>21857</td>
</tr>
<tr>
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<tr>
<td>98571</td>
<td>24691</td>
<td>24691</td>
</tr>
<tr>
<td>638000</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

$^a$ Annual steel output (tons) from $i$-th plant divisions in $j$-th underground plant.

$^b$ Annual steel output (tons) from $i$-th plant divisions in $j$-th open pit plant.
7.3 MODEL FORMULATION

The goal programming model requires information on the relative ordering of goals. The relative preferences can be derived using the analytical hierarchy process (AHP). In this study, the relative preferences on development goals were elicited through an AHP survey study from development planners. The preemptive goal programming model adopted in this study requires that goals of a higher rank of preference be satisfied before those of lower ranks are considered. The general form of a preemptive goal programming can be expressed as:

Find \( X = (X_1, X_2, X_3, \ldots, X_j, X_{j+1}, \ldots, X_n) \) so as to

Minimize \( A = (A_1; A_2; \ldots; A_k; A_{k+1}; A_{k+2}; \ldots; A_k) \) for \( A_k = P_k(d^+ + d^-) \)

Subject to \( \sum_{j=1}^{n} C_{ij}X_j - d^+ + d^- = T_i \),

\[
\sum_{j=1}^{n} D_{ij}X_j \leq G_i; \quad X, d^+, d^- \geq 0
\]

where \( X_j \) = Decision variable of activity level.
\( T_i \) = Target or aspiration level of goal \( i \).
\( G_i \) = R-h-s bound on the system constraint
\( C_{ij} \) = Unit contribution of activity \( j \) to goal \( i \).
\( D_{ij} \) = Unit contribution of activity \( j \) to system constraint.
\( d \) = negative deviation variable for target \( T_i \)
\( d^+ \) = positive deviation variable for target \( T_i \)
\( A_k \) = Linear function of the deviation variables at priority level \( k \).
7.3.1 Decision Variables
The decision variables for the model are defined as follows.

\[ X_{ij} = \text{Annual steel output in tons from i-th plant division and j-th underground plant} \]
\[ (i=1,2,3,4; \ j=1,2,\ldots,8). \]

\[ Y_{ij} = \text{Annual steel output in tons from i-th plant division and j-th open pit plant} \]
\[ (i=1; \ j=1,2,3). \]

7.3.2 Goal Constraints
A. Economic Goals

(i) Annual Incremental Production: The annual incremental production goal constraint assumes a fractional increase in production over a specified period of time for the underground and open pit plant techniques. A target increase in production is set and the goal seeks to minimize the deviation from this target. Usually this target increase in production is determined by government planners based on policy issues related to the export market. This can be represented as:

\[ (1 + \alpha_u) \sum_i \sum_j X_{ij} + (1 + \alpha_o) \sum_i \sum_j Y_{ij} - d_i^+ + d_i^- = (1 + \alpha) \sum_i \sum_j (X_{ij} + Y_{ij}) \]

Where

\[ \alpha_u = \text{Fractional increase in underground plant production} \]
\[ \alpha_o = \text{Fractional increase in open pit plant production.} \]
\[ \alpha = \text{Target fractional increase in total plant production.} \]

Objective: Minimize the underachievement: \( \text{Min } d_i^- \)

(ii) Capital Investment: Industrial sectors in developing countries are capital intensive with considerable capital investment in plant and equipment. Investment in equipment and modernization is needed to maintain the industry’s capacity to meet the market demand. The capital-output ratio defined in Rupees of investment per ton of steel production is used to determine the extent of capital investment in the industry. The
capital-output ratios for the current period are established from the investment records for both the underground and open pit plant techniques. A predetermined target capital-output ratio is set for the entire industry. This goal constraint can be represented as follows.

$$\tau_u \sum_i \sum_j X_{ij} + \tau_o \sum_i \sum_j Y_{ij} - d_2^+ + d_2^- = \tau \sum_i \sum_j (X_{ij} + Y_{ij})$$

Where

$$\tau_u = \text{Capital-output ratio (Rs/ton) in underground plant.}$$

$$\tau_o = \text{Capital-output ratio (Rs/ton) in open pit plant.}$$

$$\tau = \text{Target capital-output ratio (Rs/ton) for the entire industry.}$$

Objective: Minimize the underachievement: Min $d_2^-$

(iii) Export Market Demand: The export market demand constraint represents the target levels on the anticipated market demand for the output production. This is determined by the trends established during the previous year’s anticipated world demand and expected growth of the industry’s market share. The production level should at least exceed a lower target to avoid lost sales in the crucial and competitive export market, but not exceed the most optimistic export market forecast. The target goals for the lower and upper levels are defined below:

$$\sum_i \sum_j (X_{ij} + Y_{ij}) - d_3^+ + d_3^- = D_l, \quad \sum_i \sum_j (X_{ij} + Y_{ij}) - d_4^+ + d_4^- = D_u$$

Where

$$D_l = \text{lower bound on projected export market demand.}$$

$$D_u = \text{upper bound on projected export market demand.}$$

Objective: Minimize the underachievement of the lower target level and overachievement of the upper target level: Min $(d_3^- + d_4^+)$
B. Technological Goals

(i) Productive Capacity Goal: The productive capacity represents the capacity of a given plant to produce steel and is therefore a function of the plant technology employed and the available plant resources (equipment, manpower, material, etc.). This capacity was established as the fraction of the total production that came from each plant in the previous year's production for each underground plant; this can be represented mathematically as:

\[ \sum_{i} \sum_{j} X_{ij} - d_{ik}^+ + d_{ik}^- = f_{ij} \sum_{i} \sum_{j} (X_{ij} + Y_{ij}), \]
\[ \sum_{i} \sum_{j} Y_{ij} - d_{2k}^+ + d_{2k}^- = h_{ij} \sum_{i} \sum_{j} (X_{ij} + Y_{ij}), \]

where

\( d_{ik}^+, d_{ik}^- \) = Deviation variables from underground plant production.

\( d_{2k}^+, d_{2k}^- \) = Deviation variables from open pit plant production.

\( f_{ij} \) = Fraction of total production from i-th division and j-th underground plant production.

\( h_{ij} \) = Represents fractions of total production from i-th division and j-th open pit plant production.

Objective: Minimize the underachievement: Min \( \left( \sum_{k=5}^{12} d_{ik}^- + \sum_{k=13}^{15} d_{2k}^- \right) \)

(ii) Ore Grade Goal: The ore grade represents the quality of steel ore the comes from each plant operation. It is economically viable to plant from those ore reserves that have higher ore grades in order to obtain lower production and preparation costs. Mathematically, this can be represented as:

\[ \sum_{i} \sum_{j} \phi_s X_{ij} + \sum_{i} \sum_{j} \phi_o Y_{ij} - d_{16}^+ + d_{16}^- = \phi \sum_{i} \sum_{j} (X_{ij} + Y_{ij}) \]

where
\[ \phi = \text{Ore grade from } j\text{-th underground plant in } i\text{-th division.} \]
\[ \phi_0 = \text{Ore grade from } j\text{-th open pit plant in } i\text{-th division.} \]
\[ \phi = \text{Target ore grade determined by industry planners.} \]

**Objective:** Minimize underachievement: \( \min d_{16}^- \)

C. Social Goals

(i) **Employment Generation:** Although the steel industry is capital-intensive, it is required to provide a certain level of employment for both skilled labor. The goal seeks to continue to maintain the industry’s role as a large employer by generating additional employment. The labor-output ratio, defined as the number of people employed per ton of steel output, is used as a measure to ensure that a given level of employment is sustained. The labor-output ratio is determined for each plant division. The employment generation constraint can be expressed as follows:

\[
\sum_i \sum_j l_i (X_j + Y_j) - d_{17}^+ + d_{17}^- = L \left[ \sum_i \sum_j (X_j + Y_j) \right]
\]

where

\( l_i = \text{Labor-output ratio in number of people employed per ton for the } i\text{-th division.} \)

\( L = \text{Target labor-output ratio in number of people employed per ton for the industry ratio for the industry.} \)

**Objective:** Minimize underachievement: \( \min d_{17}^- \)

(ii) **Income Re-distribution:** The wage increase provides the average worker with a better standard of living. The income redistribution goal constraints seeks to ensure that workers receive an equitable share of the value added to the industry through the receipt of adequate wages and salaries. The income-output ratio is defined as the average wage in Rupees received per ton of steel produced. This goal can be represented as:

\[
\beta_u \sum_i \sum_j X_j + \beta_v \sum_i \sum_j Y_j - d_{18}^+ + d_{18}^- = \beta \left[ \sum_i \sum_j (X_j + Y_j) \right]
\]
where

\[ \beta_u = \text{Average income-output ratio (Rs/ton) in underground plant.} \]

\[ \beta_o = \text{Average income-output ratio (Rs/ton) in open pit plant.} \]

\[ \beta = \text{Average target income-output ratio (Rs/ton) for the entire industry.} \]

Objective: Minimize the underachievement: Min \( d_{18}^- \)

D. Political Goals

(i) Use of Import Energy Base: The increased cost for fuel has prompted the industry to seriously examine other energy sources. By minimizing the use of imported energy, the industry encourages the use of locally produced energy and promotes economics self-reliance and self-sufficiency. This goal constraint seeks to minimize the use of imported energy used to produce steel so as to enhance utilization of energy produced using local resources. The related goal constraint can be expressed as the Rupees spent in imported energy per ton of steel produced. This is written as follows:

\[ \delta_u \sum_i \sum_j X_{ij} + \delta_o \sum_i \sum_j Y_{ij} - d_{18}^+ + d_{19}^- = \delta \left[ \sum_i \sum_j (X_{ij} + Y_{ij}) \right] \]

where

\[ \delta_u = \text{Energy-output ratio (Rs/ton) in underground plant.} \]

\[ \delta_o = \text{Energy-output ratio (Rs/ton) in open pit plant.} \]

\[ \delta = \text{Target Energy-output ratio for imported energy for the industry.} \]

Objective: Minimize the underachievement: Min \( d_{19}^- \)

(ii) Mineral Export Tax: The mineral export tax is levied on the steel industry by the government and the revenue generated from such tax is used to sustain growth in other sectors in the economy. The steel industry is the dominant sector and the primary source of revenue for the country. The government depends greatly on revenue received through an export tax on steel. Through the mineral export tax levied, the government is able to provide revenue needed for diversification of the economy to the agricultural sector and other industrial sectors. The goal can be written as follows:
\[ \text{Minimize underachievement: Min } d_{20}^- \]

**E. Other Goals**

**Balanced Production:** The steel plant industry recovers one-fourth of its production by open pit plant technique. Also, more than half of the industry’s total annual production comes from division one. To ensure a balanced production, the following goal constraints are established:

\[ \sum_i \sum_j X_{ij} - d_{21}^+ + d_{21}^- = \Gamma_0 \left[ \sum_i \sum_j (X_{ij} + Y_{ij}) \right] \]

\[ \sum_i \sum_j (X_{ij} + Y_{ij}) - d_{22}^+ + d_{22}^- = \Phi \sum_i \sum_j (X_{ij} + Y_{ij}) \]

where

\[ \Gamma_0 = \text{Fraction of total production from the open pit plant.} \]

\[ \Phi = \text{Fraction of total production from division one operation.} \]

**Objective:** Minimize the underachievement: Min \((d_{21}^- + d_{22}^-)\).

**7.3.3 Objective Function**
The objective function summarizes the objective of the model and seeks to minimize the effect of the deviations from the established target or aspiration levels. It also incorporates the different development objectives in a preemptive priority structure. The priority structures and relative weighting of the development objectives are considered policy measures over which the development planners have considerable control. These priorities were based on policy recommendations outlined in the following five-year production and investment plan. Five priorities were established as follows:
P₁: Economic goals.
P₂: Technological goals.
P₃: Social goals.
P₄: Political goals.
P₅: Other goals.

The goal objective function summarizes the objectives of the model by minimizing the sum of the deviation from the stipulated target levels. The objective function is written as follows:

\[
\text{Minimize } Z = \left\{ P₁(d₁^- + d₂^- + d₃^- + d₄^-); P₂ \left[ \sum_{k=5}^{12} (d₃k^-) + \sum_{k=13}^{15} d₂ₖ^- + d₆^- \right]; P₃(d₁₇^- + d₁₈^-); P₄(d₁₉^- + d₂₀^-); P₅(d₂₁^- + d₂₂^-) \right\}
\]

These ordered set of goals are grouped into several priority levels since the achievement of an objective at any priority level is immeasurably preferred to the achievement of lower priority level objectives. This property is stated as: \( Pₖ >>> Pₖ₊₁ \), where \( Pₖ \) is of higher priority level.

### 7.4 RESULT AND DISCUSSION

The results obtained from the AHP analysis provide the priority structure that is indicative of the policy maker’s preference on the development objectives. The priority structure obtained from the AHP incorporated into the multiobjective programming formulation as model parameters. The final model is solved using QM for WINDOWS Package. The established targets are achieved for a given annual steel production is given in Table-7.3.
### TABLE-7.3
Goal Attainment Levels For Initial Model

<table>
<thead>
<tr>
<th>Goal category</th>
<th>Goal</th>
<th>Deviation value</th>
<th>Achievement</th>
</tr>
</thead>
<tbody>
<tr>
<td>Economic</td>
<td>Annual incremental production (tons)</td>
<td>0</td>
<td>Achieved</td>
</tr>
<tr>
<td></td>
<td>Export market demand (tons)</td>
<td>0</td>
<td>Achieved</td>
</tr>
<tr>
<td></td>
<td>Capital investment (Rs)</td>
<td>0</td>
<td>Achieved</td>
</tr>
<tr>
<td>Technological</td>
<td>Productive capacity ( tons)</td>
<td>0</td>
<td>Achieved</td>
</tr>
<tr>
<td></td>
<td>Ore grade (tons)</td>
<td>3842</td>
<td>Not achieved</td>
</tr>
<tr>
<td>Social</td>
<td>Employment generation (workforce)</td>
<td>9130</td>
<td>Not achieved</td>
</tr>
<tr>
<td></td>
<td>Income re-distribution (Rs)</td>
<td>10912900</td>
<td>Not achieved</td>
</tr>
<tr>
<td>Political</td>
<td>Mineral export tax (Rs)</td>
<td>6308820</td>
<td>Not achieved</td>
</tr>
<tr>
<td></td>
<td>Use of imported energy (Rs)</td>
<td>13717200</td>
<td>Not achieved</td>
</tr>
<tr>
<td>Other</td>
<td>Balanced production (tons)</td>
<td>10860</td>
<td>Not achieved</td>
</tr>
</tbody>
</table>

Under the initial model formulation, the economic goals were accorded the highest priority followed by the technological, social, political and other goals. The economic and technological goals were achieved with the exception of the ‘ore grade’ goal, where as the social, political and other goals were not the goal attainment for the initial model formulation is summarized in Table-7.3. A zero value of the deviation from the target indicates that the goal was attained to the exact target amount. For example, a value of zero for the annual incremental production indicates that a 5% increase in production from the previous year’s production was achieved for the current planning period. However, a nonzero value for the target deviation indicates the amount by which that particular goal was not achieved. For instance, the value of 9130 in Table-7.3 indicates that the target employment generation of 55,000 workforce was underachieved by 9130 workforce. These results indicate the degree to which the development objectives are to be met if a given level of annual steel production was to be maintained. The results also establish the output level for each plant subject to the goal constraints.