CHAPTER 5

THE INTEGRATED ANALYTIC HIERARCHY PROCESS - GOAL PROGRAMMING MODEL FOR CAPITAL BUDGETING

5.1 THE INTEGRATED MODEL DESCRIPTION

A medium-scale firm producing automotive components has been selected for the study. The firm is at the threshold of upgrading its production facilities. The firm faces the problem of selecting the best manufacturing system from a group of eight alternatives - 3 stand alone systems, 2 automated systems and 3 integrated systems. The model uses the following sets of criteria and the corresponding sub-criteria, as shown in Figure 5.1:

![Hierarchical Structure of the Problem](image-url)

**Figure 5.1:** Hierarchical Structure of the Problem
Financial criteria

a. **Net income**, or net sales revenue generated by the investment (evaluated over an 8-year planning horizon) (de la Mare, 1982).

b. **Growth rate in assets**, denoting the contribution of the technology to the intrinsic value of the firm, and also its potential for stable and rising earnings (Clark et al., 1978).

\[
\text{Growth Rate in Assets} = \frac{\text{Book value of investment at the end of the planning horizon}}{\text{Book value of initial assets at the beginning of the planning horizon}}
\]

c. **Financial leverage**, reflects the firm's optimal capital structure (Bussey, 1978).

\[
\text{Leverage Goal} = \frac{\text{Total equity issued} + \text{Net income generated} - \text{Dividends paid}}{\text{Total debt incurred}}
\]

d. **NPV maximization**, where NPV is the difference between the present value of cash inflows and outflows. The NPV reveals the amount by which the productive value (present value of cash inflows) exceeds or is less than the cost (present value of cash outflows) (Kulatilaka, 1984).

\[
\text{NPV} = \sum_{t=0}^{n} \frac{S_t}{(1+k)^t} - A_n
\]

where,

- \( n \) = useful life of the asset.
- \( S_t \) = cash inflow to be received in period \( t \),
- \( k \) = appropriate discount rate (or, hurdle rate), and
- \( A_n \) = present value of the after-tax cost of the project.

Production criteria

a. **Production cost**, involves cost of goods sold (factory cost, depreciation, inventory), operating expenses (selling and administrative), non-operating...
expenses (interest, miscellaneous), and taxes (Randhawa and Bedworth, 1985).

b. **Machine utilization**, indicates reduction of idle time of the system as well as greater capacity utilization with better production and process planning (Primrose and Leonard, 1984a).

c. **Quality**, representing conformance of product to design specifications and goodness of the actual output compared to the design specifications. The cost of the quality is the sum of all internal costs associated with maintaining quality control in the plant and absorbing the external costs of loss of business, warranty and liability claims associated with a defective product. Material scrap and rework indicate internal failures which can be quantified, while external failures are difficult to assess (Chen and Adam, 1991).

d. **Flexibility**, indicates functional capabilities of a manufacturing system including design, volume, routing, machine, process and operation flexibilities. It denotes the ability of the system to handle variations in part sizes and geometry, batch size and product types. It can be measured by means of reduced lot-size, reduced set-ups, quicker response to customers and a variety of other ways (Chen and Adam, 1991).

**Strategic criteria**


b. **Technology position**, reflects the firm's policy towards modernization, innovation abilities and competitive strengths (Troxler and Blank, 1989). It is an important measure that can be evaluated by a thorough analysis of the technology components such as Technoware, Inforware, Orgaware and
Humanware (Sharif, 1988). "Technology Contribution Coefficient" proposed by Sharif (1987 a,b,c,d e and f) can be a good indicator of the technology position of a firm vis-a-vis its competitors.

The integrated AHP-GP model involves the following steps:

a. The criteria have been ranked according to their relative importance to the firm given by their AHP priorities, after eliciting the requisite information from the management. The priorities are considered as penalty weights of the criteria which are to be incorporated as objectives/constraints in the GP model. This integrates AHP with GP.

b. The GP model has been formulated with the above criteria and after obtaining data pertaining to their respective aspiration levels. The results of the GP model provide the relative contribution of each alternative to different objectives of the firm.

The following sections provide a brief description of AHP and GP.

5.2 THE ANALYTIC HIERARCHY PROCESS

The Analytic Hierarchy Process (AHP) is a multi criteria decision making technique which represents a complex decision problem as a hierarchy with different levels. Each level contains different elements with a relevant common characteristic. Using AHP, a cardinal measure of the importance or priority of each element in a level is obtained by pairwise comparisons of all elements in that level. Each element in a level serves as the basis for effecting pairwise comparisons of the elements in the immediate lower level of the hierarchy. The final priorities of the elements in the lowest level (decision alternatives) are obtained using the principle of hierarchical composition. The general methodology of AHP is described in detail in Saaty (1980),
and detailed reviews of its various applications have been made by Zahedi (1986) and Vargas (1990).

AHP uses four steps to solve decision problems:

a. Structuring of the decision problem into a hierarchical model.

b. Making pairwise comparisons and obtaining the judgmental matrix.

c. Obtaining priorities under each criterion and consistency of comparisons.

d. Aggregating priorities across various levels using the principle of hierarchical composition.

Some of the critical points in the theory and application of the AHP have been discussed elaborately in Saaty (1990, 1994).

The theory was developed to solve a specific problem in contingency planning (Saaty, 1972) and a later major application was to design alternative futures for a developing country, Sudan. The ideas have gradually evolved into a number of applications like every allocation investment in technologies under uncertainty.

The Analytic Hierarchy Process (AHP) is a decision aiding method which aims at quantifying relative priorities for a given set of alternatives on a ratio scale. It provides a comprehensive structure to combine one’s intuitive rational and irrational values during the decision making process. AHP unites perception and purpose into overall synthesis. It is a theory of measurement for dealing with tangible and intangible criteria.

The theory of AHP is based on the three stages of problems solving. They are the principles of decomposition, comparative judgements and synthesis of priorities. The
methodology of AHP attempts to analyze the impacts of elements in the lowest levels on the overall objective or focus of a hierarchy.

Problems are structured with the elements in a level being independent from those in successive levels, working downward from the focus in the top level, to criteria bearing on the focus in the second level followed by subcriteria in the third level, and so on, from the more general to more particular and concrete comparative judgements used to make pairwise comparisons of the relative importance of elements in some level with respect to a shared criterion or property in the level above. The additive aggregation rule of the AHP is useful in synthesizing the weights of the alternative about the weights of the criteria.

5.2.1 Methodology

A hierarchy of the problem is structured to encompass the basic elements. The objective is to derive priorities on the elements in the last level that best reflect their relative impact on the focus of the hierarchy. To apply principle of comparative judgements, a matrix is set up to carry out pairwise comparisons of relative importance of the elements in the second level with respect to the overall focus of the first level. The matrix is set up by listing the elements to be compared to the left and on the top. Then, an element on the left is compared with an element listed on top and a determination is made which is more important to the criterion being analyzed. When an element is compared with itself, the ratio is one when compared with another element, if it is more important, an integer value is assigned. If it is less important the reciprocal value is assigned. In either case, the reciprocal ratio is entered in the transpose position of the matrix. Thus, only positive matrices are involved and only n(n-1)/2 judgements are required.
The process of comparing elements in each level is continued down the hierarchy, comparing the set of elements in each level with respect to elements in the level above which they affect in relative importance. A set of local priorities are generated from the pairwise comparison matrices.

At this point, the synthesis of priorities is carried out. Priorities are synthesized from the second level down by multiplying local priorities by the priority of their corresponding criterion in the level above, and adding them for each element listed in a level according to the criteria it affects. The second level elements are each multiplied by one, the weight of the single top level goal. This gives the composite priority of that element which is then used to weight the local priorities of elements in the level below compared by it as criterion and so on to the bottom level.

5.2.2 Procedural Steps

i. Define the problem and determine the objective.

ii. Structure the hierarchy from the top through the intermediate levels to the lowest level.

iii. Construct a set of pairwise comparison matrices for each of the lower levels. An element in the higher level is said to be a governing element for those in the lower level, since it contributes to it or affects it. The elements in the lower level are then compared to each other based on their effect on the governing element above. This yields a square matrix of judgements. The pairwise comparisons are done in terms of which an element dominates another. These judgements are then expressed as integers. If elements being compared are equal, a 1 is assigned to both positions (Table 5.1).
iv. There are $n(n-1)/2$ judgements required to develop the set of matrices in step 3 ($n =$ number of activities in the matrix).

v. Having made all the pairwise comparisons and entered the data, the consistency is determined using the given value. Using the equation $\text{Aw} = \lambda_{\text{max}}$, $w$ is solved. The consistency index (C.I) derived from the departure of the $\lambda_{\text{max}}$ from 'n' is compared with corresponding average values for random entries yielding the consistency ratio (C.R). (A = consistent matrix, $w =$ numerical weight, $\lambda_{\text{max}} =$ Large eigen value of A.

vi. Steps 3 to 5 are performed for all levels and clusters in the hierarchy.

vii. Hierarchical composition is now used to weight the eigen vectors by the weights the criteria and the sum is taken over all weighted eigen vector entries corresponding to those in the next lower level of the hierarchy.

viii. The consistency of the entire hierarchy is found by multiplying each consistency index by the priority of the corresponding criterion and adding them together. The result is then divided by the same type of expression using the random consistency index (Table 5.2) corresponding to the dimensions of each matrix weighted by the priorities as before. The consistency ratio should be about 10% or less to be acceptable. If not, the quality of the judgements should be improved by revising the manner in which questions are asked in making pairwise comparisons.

5.2.3 Calculation of Consistency Index

Let pairwise comparison matrix be denoted by $A_1$ and the principal vector be denoted $A_2$. Then $A_3 = A_1 \cdot A_2$ and $A_4 = A_3 / A_2$.

Average of the elements of $A_4$ is calculated, it is denoted by $a_4$. 

65
C.I = (a_i - N)/(N-1) = b.

C.R = b/R

Where, N = No. of elements in the observed matrix;

R = Random index

b = C.I value.

The value of C.R is computed using the table of random consistency by appropriately selecting a value corresponding to ‘N’.

Table 5.1: Scale of Relative Importance

<table>
<thead>
<tr>
<th>Intensity</th>
<th>Definition</th>
<th>Explanation</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Equal importance</td>
<td>Two activities contribute equally to the objective</td>
</tr>
<tr>
<td>2</td>
<td>Weak importance of one over another</td>
<td>Experience and judgement slightly favour one over another</td>
</tr>
<tr>
<td>5</td>
<td>Essential or strong</td>
<td>Experience and judgement strongly favour one over another</td>
</tr>
<tr>
<td>7</td>
<td>Very strong importance</td>
<td>An activity is strongly favoured and its dominance is demonstrated in practice</td>
</tr>
<tr>
<td>9</td>
<td>Absolute importance</td>
<td>The evidence favouring one activity over another is of the highest degree possible of affirmation</td>
</tr>
<tr>
<td>2,4,6,8</td>
<td>Intermediate values</td>
<td>When compromise is needed</td>
</tr>
</tbody>
</table>
Table 5.2: Table of Random Consistency

<table>
<thead>
<tr>
<th>Order of matrix</th>
<th>Random Index</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.00</td>
</tr>
<tr>
<td>2</td>
<td>0.00</td>
</tr>
<tr>
<td>3</td>
<td>0.58</td>
</tr>
<tr>
<td>4</td>
<td>0.90</td>
</tr>
<tr>
<td>5</td>
<td>1.12</td>
</tr>
<tr>
<td>6</td>
<td>1.24</td>
</tr>
<tr>
<td>7</td>
<td>1.32</td>
</tr>
<tr>
<td>8</td>
<td>1.41</td>
</tr>
<tr>
<td>9</td>
<td>1.45</td>
</tr>
<tr>
<td>10</td>
<td>1.49</td>
</tr>
<tr>
<td>11</td>
<td>1.51</td>
</tr>
<tr>
<td>12</td>
<td>1.48</td>
</tr>
<tr>
<td>13</td>
<td>1.56</td>
</tr>
<tr>
<td>14</td>
<td>1.57</td>
</tr>
<tr>
<td>15</td>
<td>1.59</td>
</tr>
</tbody>
</table>
5.2.4 Hierarchies

A hierarchy is a particular type of system, which is based on the assumption that the entities, which have been identified, can be grouped into disjoint sets. These sets contain the entities of one group influenced by the entities of only one other group. The elements in each group of the hierarchy are assumed to be independent. If there is dependence prevailing among elements, there is a necessity of study of dependence and independence separately and combine the two.

The hierarchy should be constructed carefully in such a way like that it takes into account the complexity of the system which is going to be decomposed, by choosing between faithfulness to reality and understanding of the situation from which obtain answers. The ultimate goals of the system need to be identified at the top of the hierarchy; their sub-objectives immediately below; the forces constraining the actors still below that. Next to this level, policies finally at the bottom is a level of the various possible outcomes. This is the natural form that planning and conflict hierarchies take.

A valuable observation about the hierarchical approach to problem solving is that the functional representation of a system may differ from person to person. But people usually agree on the bottom level of alternative actions to be taken and the level above it representing the characteristics of these actions.

Priority in Hierarchies

A hierarchy, which is discussed in last section, is a more or less faithful model of a real-life situation. It represents analysis of the most important elements in the situation and of their relationships. It is not sufficient in decision making process. And it requires a method to determine the potency with which various elements in
one level influence the elements on the next higher level. For this, the relative strengths of the impacts of the elements of the lowest level on the overall objectives should be computed.

To determine the strengths, or the priorities of the elements in one level relative to their importance for an element in the next level, a mathematical model in matrix form is used. The matrix contains pairwise comparisons of elements in one level with other level. And eigen vector of this matrix corresponding to the largest eigen value is found out. The eigen vector provides the priority ordering, and the eigen value is a measure of the consistency of the judgement.

**Advantages of Hierarchies**

- Hierarchical representation of a system can be used to describe how changes in priority at upper levels affect the priority of elements in lower levels.

- These give very detailed information on the structure and function of a system in the lower levels and provide an overview of the actors and their purposes in the upper levels. Constraints on the elements in a level are best represented in the next higher level to ensure that they are satisfied.

- Natural systems assembled hierarchically, i.e. through modular construction and final assembly of modules, evolve much more efficiently than those assembled as a whole.

- They are stable and flexible; stable in that small changes have small effect and flexible in that additions to a well-structured hierarchy do not disrupt the performance.
5.3 GOAL PROGRAMMING MODEL

Goal Programming (GP), with many practical applications, is the most popular of all multi objective decision making techniques (White, 1990). GP is referred to as a quantitative decision-making tool which seeks feasible solutions that achieve a certain set of desired (but adjusted) goals as closely as possible by minimizing or penalizing deviations from the goals (Lee, 1972; Ignizio, 1976).

Decision-making is the process of selecting a possible course of action from all the available alternatives. In almost all such problems the multiplicity of criteria for judging the alternatives is pervasive. That is, for many such problems, the decision maker wants to maintain more than one objective or goal in selecting the course of action while satisfying the constraints dictated by environment, processes and resources. Another characteristic of these problems is that the objectives are apparently non-commensurable [Hwang, et al, 1979].

Mathematically this problem can be represented as:

\[
\text{Max } \{ f_1(X), f_2(X), \ldots, f_k(X) \}
\]

subject to: \( g_i(X) \leq 0 \) (\( i = 1, \ldots, m \))

Where \( X \) is an n-dimensional decision variable vector. The problem consists of n decision variables, m constraints and k objectives. Any or all of the functions may be non-linear.

The common characteristics of Multi Objective Decision Making (MODM) methods are that they possess:

i. a set of quantifiable objectives
ii. a set of well defined constraints

iii. a process of obtaining some trade-off information, implicit or explicit, between and stated quantifiable objectives and also between stated or unstated non-quantifiable objectives.

Goal Programming is one of the important methods for MODM. This is categorised under "Methods for a Priori Articulation of Preference Information Given". "A Priori" means the preference information is given to the analyst before one actually solves the problem. The decision-maker provides the information during or after the actual mathematical formulation of the problem. The information may be either: (i) Cardinal information or (ii) Mixed (Cardinal and Ordinal) information. In the case of cardinal information, the decision-maker must give some judgement about specific objective preference levels or specific trade-offs, but if the information is mixed, the decision-maker must rank the objectives in the order of their importance. The most important information needed for goal programming method is the ordinal inter-objective preference information, although some times some cardinal information may also be needed. [Hwang, 1977].

Goal programming was originally proposed by Charnes & Cooper in 1961. The technique has been expanded and popularized by the more recent works of Ijiri, Lee in 1972, and Ignizio in 1976. The approach is an extension of linear programming wherein the usual "unidimensional" objective function (i.e., the deviations from several goals are minimized according to a priority ranking scheme). The priority structure specifies a hierarchy of multiple goals wherein the highest order goals are arrived for first. Only after the optimal level of priority 1 goals has been satisfied will priority 2 goals be considered, and so on. In addition, the relative importance of two
or more goals at any priority level is shown by the weights attached to each. The model is flexible enough to handle conflicting objectives, situations wherein only underachievement or over-achievement of goal is penalized, and conditions where the decision maker seems to come as closely as possible to a desired target. GP requires the assignment of ordinal priorities to the respective goals with relative weights required by any goals placed on the same priority level. [Clark, et al. 1985]

Goal Programming Formulation

The GP model has multi dimensional objective function that seeks to minimize certain selected absolute deviations from a stated set of goals, usually within an additional set of given constraints. Each of the selected deviations in the GP objective carry ordinal priority weights so that goals are attained (or approached as nearly as possible) in strict order of priority. A preferred solution is then defined as the one which minimises the deviations from the set goals. In general, the format of the GP problem can be stated as follows: [Bussey, 1985].

Find \( \mathbf{X} = (X_1, X_2, \ldots, X_n) \) so as to

\[
\text{Min } \mathcal{Z} = f(d^+, d^-) \quad (1)
\]

Subject to

\[
\mathbf{A} \mathbf{X} = \mathbf{B} + d^+ - d^- \quad (2)
\]

\[
\mathbf{C} \mathbf{X} \leq \mathbf{D} \quad (3)
\]

\[
X, d^+, d^- \geq 0 \quad (4)
\]

Where

i. \( \mathbf{X} \) is the solution vector;
ii. Equation (1) is the GP objective of the problem;

iii. Equation (2) states the original problems objectives, converted into goals by the inclusion of intentionally permissible deviations \( (d_i^+, d_i^-) \) from RHS targets \( (B_i); i = 1,2, \ldots ,m \)

iv. Equation (3) shows the absolute constraints on the problem;

v. \( F(d^+, d^-) \) is a linear, prioritized function in of the permissible deviation variables from the associated objectives, Equation (2);

vi. \( d^+ \) is a vector of non-negative variables that represent the permissible positive deviations from the associated objectives, Equation (2);

vii. \( d^- \) is a vector of non-negative variables that represent the permissible negative deviations from the associated objectives, Equation (2);

viii. \( B \) is a vector of RHS target values, of aspiration levels, associated with the objectives. Equation (2);

ix. \( C \) is a matrix of resources consumption coefficients;

x. \( A \) is a matrix of activity coefficients;

xi. \( D \) is the vector of RHS bounds on the absolute constraints.

Quite often the objective, Equation (1), takes the form:

\[
\text{MIN } Z = \{P_1[g_1(d_1^+, d_1^-)], P_2[g_2(d_2^+, d_2^-)], \ldots , P_l[g_l(d_l^+, d_l^-)]\}
\]

Where \( g_i(d_i^+, d_i^-) \) is a linear function of the deviation variables \( P \) is the ordinal priority level associated with \( g_i(d_i^+, d_i^-) \), \( i \leq m; \) i.e., the number of ordinal priorities is equal to or less than the total number of objectives.

**Preemptive Priorities**

If \( P_i \) is the preemptive priority associated with a given set of objectives, then
That is, the satisfaction of a given set of objectives is at a lower priority level. As a result, the solution procedure does not 'find' a GLOBAL optimum satisfying all constraints, as in LPP. Rather, the GP solution procedure 'finds' a feasible set of "optional" solutions to the priority 1 level sub-problem; then within this set of solutions it finds another subset of optimal solutions (if possible) to the priority 2 level sub-problem; and so forth.

**Deviational Variables**

In GP method 'intentional' deviations from the numerically valued goals are allowed to occur. Deviations can be either positive, negative, or zero-valued movements away from goals. All variables are non-negative in a GP model. This restriction can be circumvented by a simple transformation.

For example, if \( d_i > 0 \) or \( d_i = 0 \) or \( d_i < 0 \) is a deviation from a goal, the deviation may be replaced by

\[
d_i = (d_i^+ - d_i^-)
\]

where, (a) \(- \alpha < d_i < + \alpha\); (b) \( d_i^+ \geq 0 \); (c) \( d_i^- \geq 0 \); (d) \( (d_i^+)(d_i^-) = 0 \)

**Achievement Function**

The goal programming achievement function \( g_i \) \( [d_i^+, d_i^-] \) is a variable that is both under the control of the decision maker and one that can have an impact on the problem solution. All decision variables are assumed non-negative.
Decision Variable

A decision variable, \( x_i \ (i = 1,2, \ldots \ldots , n) \) is a variable that is both under the control of the decision maker and one that can have an impact on the problem solution. All decision variables are assumed non-negative.

5.4 GOAL PROGRAMMING FOR CAPITAL BUDGETING

The primary goal of financial management is the maximization of shareholders' wealth. Given the ever-present complexities, since it is not always obvious how to maximize shareholders' wealth in an optimal manner. Thus, it seems logical that progress toward this global goal will be facilitated if it is disintegrated into various sub-goals; the rational being that as the sub-goals are achieved, definite strides will be made in the direction of shareholder wealth maximization.

If capital market imperfections exist (such as capital rationing, differences in lending and borrowing rates, and so on), then the maximization of NPV may not very well lead to the maximization of shareholders' wealth. In addition, observation plus empirical studies have demonstrated that investors and managers are interested in and motivated by several objectives. Thus, only a model that incorporates multiple criteria model in that it allows the establishment of multiple objectives with diverse penalties associated with deviations from different goals (Clark et al, 1985).

Advantages of GP

A great advantage of GP is that it can handle both complementary and conflicting goals as long as a 'trade-off function' is specified that links the conflicting goals. Since management must make decisions in a world of risk and imperfect capital markets, projects beyond NPV may have to be factored into the decision process. Interactions between the value of the firm and capital investments may have to be
recognized. Also, accounting profits may be important to the extent they influence the markets for the firm’s shares and debt instruments. GP is particularly useful because it allows management perceptions and policies, and some interrelationships between the firm and prospective capital investments to be handled simultaneously. It enables management to obtain insight into the implicit costs of its goals and trade-off functions if sensitivity analysis is carried out to show the effects of changing goal and trade-off parameters.

**Difficulties of GP**

Three difficulties affect use of GP, particularly in capital budgeting. They are:

i. In capital budgeting projects indivisibility is the rule rather than the exception. This means that ordinary LP computer codes are generally not suitable and one must resort instead to integer Programming codes that are not generally available. (Ignizio 1976 as succeeded in combining the GP methodology with a DAKIN algorithm for solving the 0-1 case).

ii. Specification of goals is often based on conjecture or “hunches” about empirical questions. Thus, different managers will generally make different subjective assessments of reality, based on individual experience, perception, and bias. This means that solutions obtained will depend on whose goals are achieved in GP formulation. There is nothing necessarily wrong with this. In fact, since goals must be clearly specified, an added benefit may result when managers must articulate goals in a form amenable to programming solution. What GP can provide is an objective procedure for systematically and accurately reaching goals – goals that themselves may have been subjectively determined.
iii. Conflicting goals require that non-commensurables be compared, that exchange rates between “apples and oranges” be defined even though the trade-off functions may not be linear, but may change over a range of values. This third difficulty means that one of the strengths of goal programming, its ability to deal with conflicting goals, is also potentially one of its great weaknesses if not approached with care.

The general form of GP models is mathematically expressed as (Min and Storbeck, 1991):

\[
\text{Minimize } Z = \sum_{i=1}^{m} w_i^+ d_i^+ + w_i^- d_i^-
\]

subject to:

\[
\sum_{j=1}^{n} a_{ij} x_j - d_i^+ + d_i^- = g_i \text{ for all } i
\]

\[
x_j, d_i^+, d_i^-, w_i^+, w_i^- \geq 0 \text{ for all } i, j
\]

where,

\[
w_i^+, w_i^- \text{ = preassigned weights representing relative, pre-emptive or combined relative-pre-emptive importance of deviations.}
\]

\[
d_i^+ = \text{respective positive deviations (over-achievement) from the goals}
\]

\[
d_i^- = \text{respective negative deviations (under-achievement) from the goals}
\]

\[
a_{ij} = \text{technological coefficients}
\]

\[
x_j = \text{decision variables,}
\]

\[
g_i = \text{goals}
\]
$d_1^*$ and $d_2^*$ are given by the following equations:

$$d_1^* = \frac{1}{2} \left[ \left| \sum_{j=1}^{n} a_{ij} x_j - g_i \right| + \left( \sum_{j=1}^{n} a_{ij} x_j - g_i \right) \right]$$

$$d_2^* = \frac{1}{2} \left[ \left| \sum_{j=1}^{n} a_{ij} x_j - g_i \right| - \left( \sum_{j=1}^{n} a_{ij} x_j - g_i \right) \right]$$

There are at least two features of GP which need subjective inputs from decision makers:

* assigning numerical weights to the objectives, and
* fixing quantitative goals for the objective functions.

In addition, it is necessary to normalize the objective functions so that the deviations ($d_1^*$ and $d_2^*$) from the goals are directly comparable.

AHP has been employed by Gass (1986) to enable decision makers to specify numerical weightages for the objectives; besides there have been other attempts to employ the Delphi technique and Conjoint analysis for this purpose.

There is a need to use AHP in conjunction with GP so as to increase the applicability of both the methodologies for problems involving syncretic (i.e., both qualitative and quantitative) criteria. The following are some of the most recent works that have used integrated AHP-GP models:


b. Greenberg and Nunamaker (1994) for budgeting of public sector organizations.
c. Benjamin et al. (1992) for planning facilities at the university of Missouri-Rolla

d. Khorramshahgol et al. (1988) for project evaluation and selection.

5.5 MODEL OUTPUT: Discussions and Conclusions

The integrated AHP-GP model has been employed to select the best manufacturing system from a set of eight alternatives (AMTs) comprising stand alone, automated, and integrated systems. At the strategic level, the firm required this technology justification process to enable selection of a suitable manufacturing system. Moreover, a comparison of AMTs with existing conventional manufacturing systems is necessary in developing countries to underscore the advantages of the former in relation to the latter. This is in sharp contrast with the prevailing situation in the developed countries where the advantages of AMTs have been highlighted by researchers (Jaikumar, 1986; Tornback, 1990; Chen and Adam, 1991; Doll and Vonderembse, 1991) and demonstrated by leaders in manufacturing who have already implemented these systems in their shopfloors (Meredith, 1988; Preece, 1989). The choice of any specific configuration of a manufacturing system for installation in the firm's shopfloor would require a more detailed analysis suited to the operational level. Such an analysis clearly lies outside the present context.

The firm specified the three major criteria, viz., financial, production and strategic as discussed above along with the corresponding sub-criteria. Additionally, the usual constraint of prohibiting multiple projects (in this case, choice of more than one AMT system) has also been incorporated as a prerequisite to the application of the integrated model, and hence is accorded the highest priority in the GP formulation. As a part of the feasibility study, the firm wished to understand the implications of
adopting each of the eight AMTs to its organizational goals. The goals have been expressed as aspiration levels pertaining to each of the sub-criteria.

The need for an integrated AHP-GP model for justifying the selection of AMTs stems from the following reasons:

a. Traditional methods of capital investment justification, based on easy-to-measure economic outcomes, (viz., NPV, IRR, Payback Period, etc.) are too narrow to capture the true value of investment in advanced technology.

b. New technology often brings operational changes, viz., flexibility, improved quality, reduced inventory, reduced work-in-progress, reduced lead times, etc., which are frequently ignored in the appraisal process.

c. As technology justification involves active participation of different groups of specialists (from Production, Marketing, Design, Finance, etc.), it is absolutely necessary to have their preferences incorporated in the decision-making process. AHP serves as an efficient way of achieving this.

d. The simple ranking of alternatives by using AHP will not be adequate to completely assess the benefits of employing AMTs. A thorough analysis of the problem, by examining the levels of fulfillment of various goals (both economic and technical), is needed. GP is employed to deal with this situation.

e. The integrated AHP-GP model provides an excellent means to combine capital budgeting decisions with the choice of a technological alternative in a manufacturing firm.

Data have been collected pertaining to the criteria identified in the previous section. An 8-year planning horizon is considered. For the purpose of illustration, the market
demand (at constant unit price of Rs.1500) for the automotive component has been assumed to grow at a conservative rate of 10 percent per year. The other relevant details for each AMT are: expected sales revenue, production cost, variable and fixed costs, inventory, depreciation and residual value of the system. An estimate has been made of the residual value of the investment - the value the investment would have to the firm at the end of the planning horizon. A “going concern” approach has been used to recognize that the assets are unlikely to be sold at the end of the planning period, but will continue to be used for production. The residual value has been estimated as the present value of 4 additional years of cash flows that are equal to the average of the last 4 years, discounted at the firm’s cost of capital of 10%. The cash flow details of the AMTs are provided in Appendix. The model’s details are provided below.

AHP has been used to set priorities among the ten sub-criteria (belonging to the three major criteria) identified earlier. The firm’s managers gave subjective value judgements which were used in the pairwise comparison matrices. The computational details of AHP have been provided for the levels 1 and 2 in Table 5.3. The C.I. and C.R. denote the consistency index and consistency ratio respectively. The overall AHP priority weights have been presented in Figure 5.2 and Table 5.4.
Table 5.3: AHP Computational Details

Level 1:

<table>
<thead>
<tr>
<th>CRITERIA</th>
<th>Financial</th>
<th>Production</th>
<th>Strategic</th>
<th>PRIORITIES</th>
</tr>
</thead>
<tbody>
<tr>
<td>Financial</td>
<td>1</td>
<td>2</td>
<td>6</td>
<td>0.58</td>
</tr>
<tr>
<td>Production</td>
<td>1/2</td>
<td>1</td>
<td>5</td>
<td>0.34</td>
</tr>
<tr>
<td>Strategic</td>
<td>1/6</td>
<td>1/5</td>
<td>1</td>
<td>0.08</td>
</tr>
</tbody>
</table>

C.I. = 0.0145 ; C.R. = 0.025

Level 2:

<table>
<thead>
<tr>
<th>CRITERIA (Financial)</th>
<th>Net Income</th>
<th>Growth Rate in Assets</th>
<th>Financial Leverage</th>
<th>NPV Maximization</th>
<th>PRIORITIES</th>
</tr>
</thead>
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<tr>
<td>Net Income</td>
<td>1</td>
<td>4</td>
<td>6</td>
<td>7</td>
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<tr>
<td>Growth Rate in Assets</td>
<td>1/4</td>
<td>1</td>
<td>3</td>
<td>4</td>
<td>0.22</td>
</tr>
<tr>
<td>Financial Leverage</td>
<td>1/6</td>
<td>1/3</td>
<td>1</td>
<td>2</td>
<td>0.10</td>
</tr>
<tr>
<td>NPV Maximization</td>
<td>1/7</td>
<td>1/4</td>
<td>1/2</td>
<td>1</td>
<td>0.06</td>
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</tbody>
</table>

C.I. = 0.034 ; C.R. = 0.037
### TABLE 5.3: AHP Computational Details (continued)

#### Level 2:

<table>
<thead>
<tr>
<th>CRITERIA (Production)</th>
<th>Production Cost</th>
<th>Machine Utilization</th>
<th>Quality</th>
<th>Flexibility</th>
<th>PRIORITIES</th>
</tr>
</thead>
<tbody>
<tr>
<td>Machine Utilization</td>
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<td>1</td>
<td>1/5</td>
<td>1</td>
<td>0.17</td>
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<tr>
<td>Quality</td>
<td>5</td>
<td>5</td>
<td>1</td>
<td>6</td>
<td>0.62</td>
</tr>
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<td>Flexibility</td>
<td>2</td>
<td>1</td>
<td>1/6</td>
<td>1</td>
<td>0.14</td>
</tr>
</tbody>
</table>

C.I. = 0.068; C.R. = 0.076

#### Level 2:

<table>
<thead>
<tr>
<th>CRITERIA (Strategic)</th>
<th>Market Position</th>
<th>Technology Position</th>
<th>PRIORITIES</th>
</tr>
</thead>
<tbody>
<tr>
<td>Market Position</td>
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<td>5</td>
<td>0.83</td>
</tr>
<tr>
<td>Technology Position</td>
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<td>1</td>
<td>0.17</td>
</tr>
</tbody>
</table>

C.I. = 0.0; C.R. = 0.0

### Table 5.4: Summary of AHP priorities expressed as weightage (%)

<table>
<thead>
<tr>
<th>Priority</th>
<th>Name of the priority</th>
<th>Weightage (%)</th>
</tr>
</thead>
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<tr>
<td>P₁</td>
<td>Prohibition of multiple projects</td>
<td>100</td>
</tr>
<tr>
<td>P₂</td>
<td>Net yearly income</td>
<td>35</td>
</tr>
<tr>
<td>P₃</td>
<td>Growth rate in assets</td>
<td>13</td>
</tr>
<tr>
<td>P₄</td>
<td>Financial leverage</td>
<td>6</td>
</tr>
<tr>
<td>P₅</td>
<td>NPV maximization</td>
<td>4</td>
</tr>
<tr>
<td>P₆</td>
<td>Production cost</td>
<td>2</td>
</tr>
<tr>
<td>P₇</td>
<td>Machine utilization</td>
<td>6</td>
</tr>
<tr>
<td>P₈</td>
<td>Quality</td>
<td>21</td>
</tr>
<tr>
<td>P₉</td>
<td>Flexibility</td>
<td>5</td>
</tr>
<tr>
<td>P₁₀</td>
<td>Market position</td>
<td>7</td>
</tr>
<tr>
<td>P₁₁</td>
<td>Technology position</td>
<td>1</td>
</tr>
</tbody>
</table>
The financial criteria received the maximum priority followed by production and strategic criteria. The priority weights of the individual sub-criteria have also been indicated in Figure 5.2. These priority weights are then used as penalty weights while formulating the GP model. They have been converted into percentages before being employed as penalty weights.

The complete GP formulation has been presented subsequently. The cash flows have been computed based on the financial details collected from the firm. They have been presented for each AMT system described in Appendix. The GP model has been solved by using a FORTRAN based source code (Ignizio, 1976). The results are
presented in Table 5.5. The results favoured the induction of an FMS, i.e., the integrated system.

The utility and effectiveness of the integrated AHP-GP model for justifying the choice of AMTs have been clearly demonstrated in this case study. They include:

a. Integration of financial, production and strategic criteria which involve both quantitative and qualitative sub-criteria.

b. A comprehensive analysis of the problem, by taking into account the ratings and opinions of managers involved in the project.

c. Incorporation of multiple conflicting objectives that do not necessarily have to be commensurable.

Goal Programming Formulation

Achievement Function

Minimize \( Z = P_1 (d_1^+ + d_2^+ + d_3^+ + d_4^+ + d_5^+ + d_6^+ + d_7^+ + d_8^+) \)
+ \( P_2 (d_9^+ + d_{10}^+ + d_{11}^+ + d_{12}^+ + d_{13}^+ + d_{14}^+ + d_{15}^+ + d_{16}^+) \)
+ \( P_3 (d_{17}^+ ) + P_4 (d_{18}^+ + d_{19}^+) + P_5 (d_{20}^+ + d_{21}^+) \)
+ \( P_6 (d_{22}^+ + d_{23}^+ + d_{24}^+ + d_{25}^+ + d_{26}^+ + d_{27}^+) \)
+ \( P_7 (d_{28}^+ ) + P_8 (d_{29}^+ ) + P_9 (d_{30}^+ ) + P_{10} (d_{31}^+ ) + P_{11} (d_{32}^+ ) \)

Objectives

a. Defining range of acceptance (P1):

\[ x_i + d_k^- - d_k^+ = 1 \quad \text{for} \quad k = 1, 2, \ldots, n \]

Where,

- \( x_i \) = Decision variable,
- \( d_k \) = Deviation variables,
- \( n \) = Number of projects.

b. Net yearly income (P2):

85
where,
\( e_j = \text{Net income generated by ongoing operations in year } j, \)
\( a_i = \text{Net income generated by project } i \text{ in year } j, \)
\( t = \text{Corporate tax}, \)
\( I_j = \text{Rupee amount of interest paid on long-term debt outstanding in year } j, \)
\( N_j = \text{Net income goal for year } j, \)

\[ e_j = t_{-1,2,\ldots,\infty} \]

\( c. \) Growth rate in assets (P3):

\[ \sum_{i=1}^{n} B_i^T \alpha_i - g A_0 - d_i^+ + d_i^- = 0 \]

where,
\( B_i^T = \text{Book value in year } T \text{ of project } i, \)
\( g = \text{Desired growth rate in assets over planning horizon}, \)
\( A_0 = \text{Book value of total operating assets at time zero}, \)
\( T = \text{Planning horizon period}. \)

d. Financial leverage (P4):

\[ E_0 + \sum_{j=1}^{t} E_j + \sum_{i=1}^{n} a_i x_i - \sum_{j=1}^{t} (1-t) I_j - \sum_{j=1}^{t} V_j (E_0 + \sum_{m=1}^{m} E_m) - S(D_0 + \sum_{j=1}^{t} D_j) - d_i^+ + d_i^- = 0 \]

where,
\( E_0 = \text{Rupee amount of equity outstanding at time zero}, \)
\( E_j = \text{Rupee amount of equity acquired during year } j, \)
\( V_j = \text{Percentage of dividends per rupee of equity to be paid in year } j, \)
\( S = \text{Leverage goal to be achieved by the end of } T, \)
\( D_0 = \text{Rupee amount of long-term debt outstanding at time zero}, \)
\( D_j = \text{Rupee amount of long-term debt acquired in year } j, \)

e. NPV maximization (P5):

\[ \sum_{i=1}^{n} \sum_{j=1}^{\infty} \frac{1}{1 + c} \left[ (b_{ij} - f_{ij}) x_i + W_j \right] - d_i^+ + d_i^- = 0 \]

where,
\( c = \text{Cost of capital}, \)
\( b_{ij} = \text{Net cash inflow generated by project } i \text{ in year } j, \)
\( f_{ij} = \text{Net cash outflow of project in year } j, \)
\( W_j = \text{Horizon value}. \)
f. Production cost ($P_b$):

$$
\sum_{i=1}^{n} p_{ij} x_i - d_i^+ + d_i^- = R_j
$$

where,

- $r_{ij}$ = Production cost of project $i$ in year $j$,
- $R_j$ = Production cost goal to be achieved in year $j$,


g. Machine utilization ($P_f$):

$$
\sum_{i=1}^{n} u_i x_i - d_i^+ + d_i^- = U
$$

where,

- $u_i$ = Machine utilization in project $i$,
- $U$ = Machine utilization goal to be achieved.


h. Quality ($P_q$):

$$
\sum_{i=1}^{n} q_i x_i - d_i^+ + d_i^- = Q
$$

where,

- $q_i$ = Scrap rate expected in the case of project $i$,
- $Q$ = Goal set for scrap rate reduction.


i. Flexibility ($P_f$):

$$
\sum_{i=1}^{n} f_i x_i - d_i^+ + d_i^- = F
$$

where,

- $f_i$ = Flexibility of project $i$,
- $F$ = Flexibility goal to be achieved.


j. Market position ($P_{10}$):

$$
\sum_{i=1}^{n} l_i x_i - d_i^+ + d_i^- = L
$$
where,

\[ l_i = \text{Market share expected of project } i, \]
\[ L = \text{Market share goal to be achieved}. \]

k. Technology position (P_{11}):

\[ \sum_{i=1}^{n} t_i x_i - d_k^+ + d_k^- = T \]

where,

\[ t_i = \text{Technology position owing to } i \]
\[ T = \text{Technology position to be achieved}. \]
Table 5.5: Results of the Integrated AHP-GP Model

<table>
<thead>
<tr>
<th>Subscript (i)</th>
<th>Decision Variable (x_i)</th>
<th>Over-achievement (d^i)</th>
<th>Under-achievement (d^-i)</th>
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</thead>
<tbody>
<tr>
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