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Case Study

Application of goal programming in project selection decision – A case study from the Indian Coal mining industry

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Abstract

This paper includes the solution of a project selection decision applying goal programming technique. A case example from the Indian coal mining industry has been taken up and discussed. A framework is introduced incorporating ratings from experts for computation of goal weights and also normalisation of deviational variables. Stochasticity of demand is included in model formulation.

Keywords: Goal programming; Chance-constrained technique

1. Introduction

Project selection is a crucial decision in capital management, involves various issues, and it is an important consideration in the mining industries [11]. So far in the Indian mining industry, little attempt has been made for development of any rational framework for project selection decisions. In this research report, it is intended to formulate a project selection problem of a coal mining company, Indian Mines Limited (IML) [1].

This section gives a brief description of IML and the remaining sections deal with problem identification, model formulation, data preparation, results and discussion.

IML is the largest coal producing company in India, producing different grades of coal. Although the nationalisation of IML took place phase-wise, its final formulation as a public sector corporate body came up in the early 70's, and included 425 coal mines. Today this company contributes more than 90% of national coal production. Being a public sector industry and coal playing a vital role in the Indian economy, the need for effective and efficient management of IML is beyond doubt. However, a critical survey on its past performance does not exhibit a bright picture in terms of its financial efficiency or capital utilisation. Further, IML has accepted a challenging task of production of 375 million tonnes of coal per annum by the turn of this century (present annual production being close to 200 million tonnes). In this pursuit, it is planning to invest around two thousand crores of rupees on capital projects.

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[1] Indian Mines Limited (IML) is a fictitious name.

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Analysis of decision making situations brings out the fact that the project selection decision very often involves different influence groups, hence different objectives/goals. Although various techniques have been reported in the literature which are capable of tackling a multi-objective decision environment (a survey of the techniques is beyond the scope of this research report), the goal programming (GP) technique has been identified as the most appropriate for this research study.

The GP technique, originally developed by Charnes and Cooper [7] has since been applied in various fields such as quality control [14], capital budgeting [1,5,8,9], resource allocation [3], manpower planning [10,15,16], etc. The GP technique has already been identified as a promising model for project selection.

The unique features of this research report include:
- computation of weights of the importance of different goals on the basis of opinions from different experts;
- incorporation of probabilistic constraints; and
- detailed analysis of the model output in order to extract more meaningful information required by the decision maker(s).

2. Problem identification

The extensive literature survey on the project selection problem reveals that various goals (mostly conflicting) may be grouped under:

(i) economic and techno-economic goals:
- minimisation of capital investment,
- minimisation of operating cost,
- maximisation of net present value (NPV),
- maximisation of operating profit,
- maximisation of production, etc.;

(ii) efficiency goals:
- maximisation of productivity,
- maximisation of profitability,
- maximisation of return on investment (ROI), etc.;

(iii) non-economic and social goals:
- maximisation of technological growth,
- maximisation of contribution to socio-economic development,
- maximisation of employment opportunity,
- maximisation of social benefit,
- maximisation of goodwill,
- maximisation of good relationships with employees,
- maximisation of customer's satisfaction,
- maximisation of safety,
- minimisation of environmental hazards, etc.

In order to identify the appropriate goals for the project selection problem of IML, operating managers (both project engineers and production executives) have been consulted. According to them, some of the economic criteria (e.g. NPV, IRR, FER, etc.) are considered during feasibility analysis of project proposals. Further, some of the above goals are qualitative in nature, involving intangible factors and which pose considerable difficulties, even if surrogate criteria are identified. The following five goals have been identified as appropriate for their inclusion in the proposed goal programming model:
- capital investment goal;
- cost of production goal;
- profit goal;
- manpower goal;
- demand goal.

Analysis of past data indicates that future coal demand is random and it is included in the proposed model as a stochastic constraint. The top management of IML wants to keep production at a level where at least 80% of demand should be satisfied. The model is formulated in the next section where the demand goal has been made as a strict constraint applying chance-constrained technique and all other goals are considered as goal constraints (flexible).

3. Model formulation

The proposed model depicts a capital investment decision situation involving selection among a set of alternative mine projects at the level of a mine area. A mine area involves management of operations of a group of mines. There are two types of mine projects – reconstruction projects and new mines. The reconstruction mine project represents an investment strategy for enhancing production capacity of an existing mine. A mine may be reconstructed by modification of the existing mine system design, by restructuring organisation structure, by application of any organisational development method or by technology updation of a subsystem or the whole mine system. The feasibility report and techno-economic data of each mine project are available and the management is to rationally distribute the total capital among any combination of these two types of mine projects. The proposed goal programming model aims at selecting the most suitable subset of mine projects among a set of feasible project proposals as an accepted investment plan with simultaneous attainment of all goals as 'best' as possible. The model may be explained as below:

Goal constraints:

(i) Capital investment goal:

$$\sum_{j=1}^{k} C_j X_j - d_1^+ + d_1^- = \mathrm{TC}, \tag{1}$$

(ii) Production cost goal:

$$\sum_{j=1}^{k} \left((\mathrm{FC})_j X_j + (\mathrm{PC})_j (1 - X_j)\right) - d_2^+ + d_2^- = \mathrm{AC} \sum_{j=1}^{k} (R_j X_j + P_j), \tag{2}$$

(iii) Profit goal:

$$\sum_{j=1}^{k} \left((\mathrm{PAI})_j X_j + (\mathrm{PBI})_j (1 - X_j)\right) - d_3^+ + d_3^- = \mathrm{TP}, \tag{3}$$

(iv) Manpower goal:

$$\sum_{j=1}^{k} \left((\mathrm{FMP})_j X_j + (\mathrm{PMP})_j (1 - X_j)\right) - d_4^+ + d_4^- = M_1, \tag{4}$$

$$\sum_{j=1}^{k} \left((\mathrm{FMP})_j X_j + (\mathrm{PMP})_j (1 - X_j)\right) - d_5^+ + d_5^- = M_{\mathrm{u}}. \tag{5}$$

System constraint:

$$\sum_{j=1}^{k} (R_j X_j + P_j) \geqslant d. \tag{6}$$

In the above:

X_j: Decision variables for $j = 1, 2, \ldots, k$. $X_j = 1$ if j-th project is selected, otherwise, $X_j = 0$.

C_j: Capital investment required for j-th project.

TC: Total capital available for investment.

$(\mathrm{FC})_j$: Future annual production cost for running j-th mine project.

$(\mathrm{PC})_j$: Present annual production cost for running j-th reconstruction project. $(\mathrm{PC})_j = 0$ for new mines.

AC: Target average cost of unit production (rupees per tonne).

R_j: Additional annual production from j-th project.

P_j: Present annual production of j-th reconstruction project. $P_j = 0$ for new mines.

$(\mathrm{PAI})_j$: Annual profit after investment from j-th project.

$(\mathrm{PBI})_j$: Annual profit before investment from j-th reconstruction project. $(\mathrm{PBI})_j = 0$ for new mines.

TP: Desired total annual profit goal.

$(\mathrm{FMP})_j$: Manpower requirement in j-th project after investment.

$(\mathrm{PMP})_j$: Present manpower deployment in j-th reconstruction project. $(\mathrm{PMP})_j = 0$ for new mines.

M_1: Desired lower limit of manpower deployment.

M_{u}: Desired upper limit of manpower deployment.

d_i^+: Positive deviational variable for i-th goal, $d_i^+ \geqslant 0$.

d_i^-: Negative deviational variable for i-th goal, $d_i^- \geqslant 0$.

d: Minimum total annual production from the mine area as a rigid target. This value is estimated on the basis of the principles of chance constrained programming technique. As the management wants that the probability of demand satisfaction is not less than 0.80, the value of d may be computed as

$$d = E(D) + 0.84\sigma(D),$$

where $E(D)$ and $\sigma(D)$ are expected value and standard deviation of the past demand data and 0.84 is obtained from a standard normal distribution table.

The manpower goal is represented as a range incorporating the lower limit and upper limit values for manpower. The lower limit of manpower reflects fulfilment of social objective of a developing economy in terms of increasing employment opportunity, whereas the upper limit of manpower exhibits the current policy of government towards more mechanisation involving less manual-oriented processes.

The objective function of the goal programming model may be stated as a function of deviational variables, like

$$\text{Minimize } F(d_1^+, d_2^+, d_3^-, d_4^-, d_5^+). \tag{7}$$

4. Incorporation of decision maker's preferences

Based on the modes of incorporating decision maker's preferences, two variants of goal programming model have emerged – the pre-emptive GP model and the Archimedian GP model, the former being most extensively employed among management practitioners and scientists [7]. Pre-emptive priorities of goals imply substantially more importance of a goal of higher priority than that of the lower one. Analysis of the problem situation and an extensive discussion with management personnel discloses the fact that in our capital budgeting problem the goals cannot be ranked on the basis of preemptive priorities. As the priorities are not truly preemptive, the attempt is then made to develop the Archimedian or weighted GP model. The objective function of the goal programming model with non-preemptive weights on goals may be formulated as

$$\text{Minimize } \left(W_1 d_1^+ + W_2 d_2^+ + W_3 d_3^- + W_4(d_4^- + d_5^+)\right). \tag{8}$$

But the goals are expressed in different measurement units and hence the integration of various goal-deviations in their original form has no practical significance. A direct weighting of such a goal-programming objective seems to be like adding 'apples to oranges' or 'pints of bitter with kilos of potatoes' [4]. Various approaches are proposed to circumvent this non-commensurability among the goals [2,6,12,17]. However, an exchange of letters by Romero and Sutcliffe [13] describes how opposing views exist in treatment of this non-commensurability.

For our capital budgeting problem, we propose a simple approach of dividing each goal constraint by its right-hand-side target value. Thus the original deviational variables d_i^+ or d_i^- will be transformed to d_i^+/T_i or d_i^-/T_i, where T_i represents the desired target value of the i-th goal. It may further be noted that the decision maker is supposed to be aware of the transformation and he assigns the weights of the deviational variables keeping in view the proposed scaling method.

5. Input data preparation

A case problem is developed for selection among eight mine projects, out of which three are reconstruction projects and the remaining five are new mines. A total of one hundred and ten crores of rupees is available for capital investment and target average cost of production is expected to be three hundred and fifty rupees per tonne of coal production. The financial performance of the coal company under consideration is quite poor and it is funded by the government to cover up the losses. However, the target loss for the project-selection case study is supposed to be six crores of rupees per annum. The lower limit and upper limit goals of manpower are expected to be eight thousands and nine thousands respectively. Analysis of past demand data of coal shows expected annual demand to be two million tonnes and standard deviation to be fifty thousand tonnes only. Relevant techno-economic data for each of the projects are given in Table 1.

Table 1
Collected data from project reports of IML

Project	Investment (Rs. crore)	Production		Increased production (MT)	Cost/year		Profit/year [a]		Manpower	
		Present [b] (MT)	Future (MT)		Present (Rs. Cr)	Future (Rs. Cr)	Present (Rs. Cr)	Future (Rs. Cr)	Present	Future
1	70.87	–	0.6	0.6	–	26.55	–	−4.55	–	2196
2	10.62	0.225	0.315	0.09	11.54	12.72	−4.00	−1.89	1792	1615
3	9.47	–	0.195	0.195	–	5.01	–	−8.38	–	958
4	19.62	–	0.293	0.293	–	8.64	–	−0.87	–	728
5	11.80	0.27	0.45	0.18	16.06	22.04	−6.62	−4.03	3042	3042
6	69.48	–	0.563	0.563	–	24.17	–	+2.27	–	1643
7	13.06	0.18	0.45	0.27	7.26	10.60	−3.03	+4.88	293	417
8	12.31	–	0.24	0.24	–	7.55	–	−1.04	–	237

[a] Positive value indicates profit, whereas negative value indicates loss.
[b] In each column of the parameters, the subcolumn 'Present' indicates the performance of the existing mines and these are basically reconstruction projects. The projects with missing data in the subcolumn 'present' are representing new mines.

For determination of the most appropriate weights of the goals several executives of the coal company and also some selected mining experts have been contacted. They have been asked to rate the goals in a scale of values ranging between 0 and 100. Due to non-exact perception of importance of a particular criterion, each respondent has been requested to give three ratings – maximum rating, most probable rating and minimum rating. Composite weight of each goal may be calculated on the basis of the following approach.

Let:

$r_{lj\,\max}$ = Maximum rating of l-th goal by j-th respondent.

$r_{lj\,\text{most probable}}$ = Most probable rating of l-th goal by j-th respondent.

$r_{lj\,\min}$ = Minimum rating of l-th goal by j-th respondent.

If

r_{lj} = overall rating of l-th goal by j-th respondent, then

$$r_{lj} = \tfrac{1}{6}\left(r_{lj\,\max} + 4\ r_{lj\,\text{most probable}} + r_{lj\,\min}\right).$$

The composite weight of the l-th goal (W_l) is equal to

$$\sum_{j=1}^{n} W_{lj} \Bigg/ \left(\sum_{j=1}^{n} \sum_{l=1}^{m} W_{lj} \right)$$

Table 2
Results

Selected projects number	Weight (W_i)	Capital investment (Rs. crore)		Average cost/ton (Rs)		Total profit per year (Rs. crore)		Manpower		Production (MT/year)	
		Target	Actual	Target	Actual	Target	Actual	Target	Actual	Min. requirement	Actual
2, 4, 6, 7, 8	$W_1 = 0.298$ $W_2 = 0.252$ $W_3 = 0.241$ $W_4 = 0.209$	110	125.09	350	374.19	−6	−3.26	8000 [a]/ 9000 [b]	7682	2.042	2.131

[a] Min. value.
[b] Max. value.

where
W_{lj} = computed weight of l-th goal by j-th respondent, and

$$W_{lj} = r_{lj} / \left(\sum_{l=1}^{m} r_{lj} \right).$$

Fifty experts and executives have been identified for computation of the composite weights of the four goals. Only forty responses have been received and the following shows the composite weights.
W_1 = Weight of capital investment goal = 0.298.
W_2 = Weight of production cost goal = 0.252.
W_3 = Weight of profit goal = 0.241.
W_4 = Weight of manpower goal = 0.209.

6. Result and discussion

The GP problem (1)–(8) is solved using the weights, as computed in the above section. The result is shown in Table 2. Out of eight project proposals only five projects are selected. The most preferred solution includes investment on two reconstruction projects and three new mine projects. The result seems to be not very encouraging due to the non-achievement of the three goals. As per this investment programme only the profit goal is satisfied. The capital expenses required for this investment programme exceed the target investment by Rs. 15 crores, whereas non-achievement of production cost goal amounts to Rs. 24 crores. On the other hand the total manpower requirement for these fine projects is somewhat lower then the minimum target of 8000. However, as per this GP solution, the amount of expected loss reduced significantly and the profit is the only goal that is fully achieved by this investment programme. This is perhaps due to the inclusion of projects number 6 and 7 in the investment plan, which are the only profitable projects. But project 6 needs Rs. 69.48 crores of capital expenditure (second most capital intensive project in the list) and it is also a very expensive project in terms of annual expenditure.

An attempt has further been made to generate some alternative investment plans, so that the corporate management may identify the most acceptable and appropriate solution depending on the prevailing situation. The following five cases have been generated by fluctuating degrees of importance of the goals. The outcome of all the cases is shown in Table 3.

Case A: Goals are given the same weights, i.e. $W_1 = W_2 = W_3 = W_4 = 0.25$. There is in fact, no change in solution.

Case B: It attempts to minimize undesirable deviation from the capital investment target (i.e. $W_1 = 1$ and $W_2 = W_3 = W_4 = 0$). Four projects are included in the investment plan, out of which three are new mine projects. The total capital requirement is almost within the investment limit. The manpower goal is also achieved. But unfortunately the expected loss is quite high compared to the target loss.

Case C: An attempt is made to minimise the undesirable deviation from the goal of production cost (i.e. $W_2 = 1$ and $W_1 = W_3 = W_4 = 0$). The outcome shows selection of maximum number of project proposals. Only project 1 is not included in the investment plan, perhaps due to its high cost of production. The average unit cost target is nearly achieved and the manpower requirement is within the target limits.

Case D: This case assumes maximum desire towards achievement of profit target (i.e. $W_3 = 1$ and $W_1 = W_2 = W_4 = 0$). The resulting investment plan does not seem to be a very effective one, although the profit target is fully achieved. The other goals remain unachieved.

Case E: Here the manpower goal represents goal of maximum importance (i.e. $W_4 = 1$ and $W_1 = W_2 = W_3 = 0$). Four project proposals are included in the investment plan. Both the manpower and profit goals are fully achieved. Clearly its outcome is better than the outcome of Case D.

Each of the above cases represents a unique situation. Table 3 may be shown to the management for providing information for this decision-making situation. Management may also select the most suitable investment plan depending on some other factors of consideration.

Table 3
Results

Model	Selected projects number	Weight (W_i)	Capital Investment (Rs. crore)		Average cost/ton (Rs.)		Total profit per annum (Rs. crore)		Actual manpower [a]	Production (MT/year)	
			Target	Actual	Target	Actual	Target	Actual		Min. requirement	Actual
Case A	2, 4, 6, 7, 8	$W_1 = W_2 = W_3 = W_4 = 0.25$	110	125.09	350	374.19	−6	−3.26	7682	2.042	2.131
Case B	1, 4, 7, 8	$W_1 = 1$ $W_2 = W_3 = W_4 = 0$	110	115.86	350	389.51	−6	−12.19	8412	2.042	2.078
Case C	2, 3, 4, 5, 6, 7, 8	$W_2 = 1$ $W_1 = W_3 = W_4 = 0$	110	146.36	350	362.05	−6	−9.05	8640	2.042	2.078
Case D	1, 5, 6, 7	$W_3 = 1$ $W_1 = W_2 = W_4 = 0$	110	165.21	350	414.77	−6	−5.43	9090	2.042	2.288
Case E	1, 2, 6, 7	$W_4 = 1$ $W_1 = W_2 = W_3 = 0$	110	164.03	350	409.92	−6	−5.91	8913	2.042	2.198

[a] Minimum requirement of target manpower = 8000; maximum requirement of target manpower = 9000.

7. Concluding remarks

The investment decision problem, like other strategic decision problems, involves various factors and interest groups leading to a multiple objective decision-making frame work. Although no model, nor the results obtained thereof, can claim to be exhaustive or absolutely correct, the goal programming model provides an effective decision support tool for project selection decision.

This paper presents a methodological foundation for using the goal programming technique for solving the investment decision problem in coal mines. The case study developed in the paper includes four goals for project selection – capital investment required, average cost of production, annual profit and manpower requirement. The set of feasible project proposals includes both reconstruction and new mine projects. As the priorities of goals are not truly preemptive, a weighted goal programming model is developed applying a simple scaling method for normalisation. An approach has been demonstrated to integrate ratings from different executives and experts for computation of composite weights. In addition, various alternative case situations have been identified to provide sufficient information for selecting the most appropriate capital investment plan.

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