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Multi-objective Approach to Project Selection of Indian Coal Mines: A Case Study

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Abstract

Project selection problem is an unceasing problem, which every organization face. In fact, it plays a key role in prosperity of the company. In this paper, a multi-objective mathematical programming model has been formulated for the project selection of an Indian Coal Mining Company, with a proposed name as the Indian Coal Mines Limited (ICML). To solve the proposed model, fuzzy programming approach with linear membership function is used to find the best compromise solution among the different project proposals. A case study from Indian Coal Mines is considered with demand of coal as normal random variable with known mean and variance.

Keywords: Project Selection, Multi-objective Linear Programming, Fuzzy Programming Approach, Chance-constrained Programming, Linear Membership Function.
MSC2010: 03B52.

1 Introduction

Project selection is a challenging task for managers of both public and private sector industry. They have to decide which project proposals to be selected for funding along with the initial investment levels of projects. This project selection problem is also an important issue for both new as well as exiting mining industries. So far, in the Indian Coal Mining Industry, very little effort has been made for development of some rational framework towards the project selection decisions.

Coal will continue to be India's prime source of energy for power generation, steel-making, powering of locomotives, and production of cement, fertilizer and domestic fuel. India is the third largest coal producing country in the world but Indian Coal Mines Limited (ICML) is the largest coal producing company in India, producing different grades of coal. It has seven wholly owned subsidiary companies which operate around 500 coal mines including opencast and underground. During the last fiscal year, around 400 million tonnes of coal was produced from all the mines, out of which contribution from underground mines was only 50 million tonnes. During the coming years, ICML has its optimistic plans afoot, aiming at substantial annual growth rate in coal production to increase it to around 600 million tonnes by the end of the eleventh national five-year plan, i.e. 2011-2012 and then to around 700 million tonnes in the terminal year of twelfth national five-year plan, i.e. 2016-2017. Being a public sector industry and since coal is playing an important role in the Indian economy, this needs an impressive and effective management of ICML. However, the past performance of production levels of ICML were undoubtedly very low due to financial inefficiency, improper management, and improper capital utilization. A proper selection of new or expansion projection projects might to be beneficial towards improving the production level.

Analysis of the decision making problem shows that the project selection decision is very much influenced by multiple conflicting objectives/goals. There are various techniques available for solving multi-criteria decision making problem such as, goal programming method, fuzzy programming method, weighting method, etc. Arıkan and Güngör [1] presented a practical application of fuzzy goal programming (FGP) in a real-life project network problem with simultaneous optimization of the two objectives as minimum completion time and crashing costs. An application of goal programming method with zero-one decision variables for project selection decision-making problems has been studied by Badri et. al. [2]. Baqeri et al. [3] proposed a multi-objective model for selecting the project portfolio that maximizes efficiency, quality while minimizes the risk involved in project execution. Carlsson et. al. [6] presented a fuzzy mixed integer programming model for the R&D optimal portfolio selection problem. A meta-heuristic multi-objective algorithm for project selection problem has been proposed by Ghorbani and Rabbani [8], to obtain diverse locally non-dominated solutions which shows the superiority of the proposed algorithm in comparison with NSGA-II. Hong et al. [9] suggested a multi-objective meansemivariance model to solve the multi-objective project selection problem by considering reinvestment and synergy between projects with different investment and operation periods with uncertainty where the objectives are to maximize the expected value of uncertain net present value and to minimize its risk. Huang et al. [11] proposed a multi-objective mean-variance model and its solution algorithms for the project selection considering synergy under the uncertain environment. Keown and Taylor [12] demonstrate a goal programming model for project selection when both profit and non-profit motivated projects are in competition for scarce resources. Kim and Emery [13] presented an application of zero-one goal programming model to project selection and resource planning of Woodward Governor Company. Khalilzadeh and Salehi [14] presented an extended multi-objective project selection (PS) problem with fuzzy parameters. which attempts to simultaneously maximize total project benefits and social responsibility, while total risk and total cost are minimized. Khalili-Damghani et al. [15] proposed a new model for project selection problem in which some parameters are assumed probabilistic. Mukherjee and Bera [17] presented an application of an interactive method for multi-objective integer linear programming in project selection decision for Indian coal mining industry. Further, they [18] also applied goal programming technique to find the optimal solution of a project selection for Indian coal mining industry. Şahin Zorluoglu and Kabak [20] designed an interactive multi-objective programming approach to integrate selection and scheduling processes in the project management. Ramadan [21] presented a model of selecting the best of the research and development (R&D) projects. A SIQRM epidemic model with vaccination and relapse possibility is proposed by Odetunde and Ibrahim [24] for analysis of the effect of immunity obtained from vaccine or treatment, quarantine effect as well as waning effect of immunity on the transmission rate of Tuberculosis within a population that is subjected to proper education without restricted access. Aako et al. [25] presented a new distribution called Marshall-Olkin Inverse log-logistic distribution, which has a more tractable form and can cope well with outliers in the upper tails and also statistical properties of the distribution,such as survival function, hazard function, moments, and order statistic, were investigated along with mean, variance, and mode of the distribution.

The main contribution of the present research work is to developed a new methodology for solving the multi-objective mathematical model for selecting the project proposals of Indian coal mines using fuzzy programming technique. A case study has been taken to justify the solution procedure and find the best compromise solution among the different project proposals of ICML. Chance constrained programming problem has been used to handle the randomness present in the

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demand constrained of coal as normal random variable.

2 Linear Membership Functions

The linear membership function is widely used to convert the fuzzy linear programming problems to its crisp linear programming and is defined as follows:

The linear membership function for a maximization type objective function is given by

$$\mu_{Z_r}(X) = \begin{cases} 1, & if\ Z_r(X) \geq U_r^* \\ \frac{Z_r(X)-L_r^-}{U_r^*-L_r^-}, & if\ L_r^- < Z_r(X) < U_r^*, \\ 0, & if\ Z_r(X) \leq L_r^- \end{cases} \quad r = 1,2,3,...,R \tag{2.1}$$

Similarly, linear membership function for a minimization type objective function is given by

$$\mu_{Z_r}(X) = \begin{cases} 1, & if\ Z_r(X) \leq L_r^* \\ \frac{U_r^- - Z_r(X)}{U_r^- - L_r^*}, & if\ L_r^* < Z_r(X) < U_r^-, \\ 0, & if\ Z_r(X) \geq U_r^- \end{cases} \quad r = 1,2,3,...,R \tag{2.2}$$

where $\mu_{Z_r}(X)$ is the membership function of the r-th objective function of $Z^{(r)}(x)$. U_r^* is the best upper bound and L_r^- is the worst lower bound for the maximization type of objective function; and L_r^* is the best lower bound and U_r^- is the worst upper bound for the minimization type of objective function $\forall\ r = 1,2,...,R$.

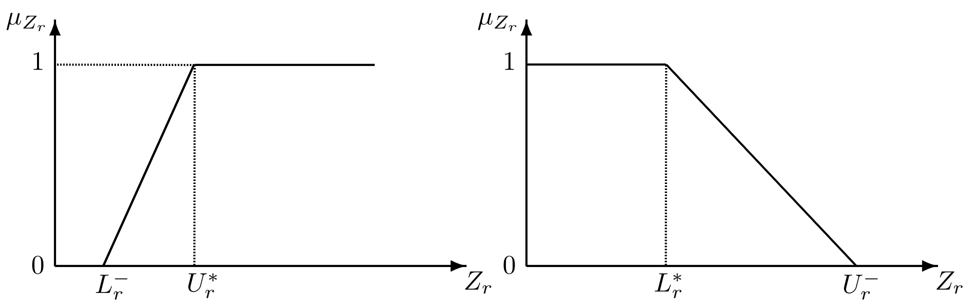

Fig. 1. Membership function of maximization and minimization type of objective functions (Z_r)

3 Mathematical Programming Model Formulation

3.1 General Multi-objective Linear Programming (MOLP) Problem:

A general model of MOLP problem is given as:

find $x = (x_1, x_2, x_3, \ldots, x_n)$, so as to

$$\max : z_r = \sum_{j=1}^{n} c_j^r x_j, \quad r = 1,2,3,\ldots,R \tag{3.1}$$

subject to

$$\sum_{j=1}^{n} a_{ij}x_j \leq b_i, i = 1,2,\ldots,m \tag{3.2}$$

$$x_j \geq 0, j = 1,2,\ldots,n \tag{3.3}$$

where $x_j, j = 1,2,\ldots,n$ are the decision variables, $a_{ij}, i = 1,2,\ldots,m, j = 1,2,\ldots,n$ are the coefficients of the technological matrix, $c_j, j = 1,2,\ldots,n$ are the coefficients associated with the objective function, and $b_i, i = 1,2,\ldots$ are the resource coefficients.

3.2 Mathematical Programming Model of Project Selection Problem:

The MOLP model of project selection describes a capital budgeting decision making problem of selecting an alternative mine project proposals at the level of mine area which includes management of operating group of mines. In the present mathematical programming model, five opencast mine project proposals are considered. Taking the feasibility report and techno-economic data of different project proposals given by the mines management group. A decision on rational distribution of capitals among different mine project proposals is taken by the mines management group.

A mathematical model of the project selection problem has been formulated including five objectives and six system constraints as decided by the mines management group as follows:

Capital Investment:

Initially some capital is invested for starting a new business. But every business has an aim of investing less capitals and getting more profit. In this objective of our model, the initial capital that are available for investment among five different opencast mine project proposals have been minimized. Mathematically, it can be written as:

$$\min : z_1 = \sum_{j=1}^{5} CP_j x_j \tag{3.4}$$

where x_j = the decision variable associated with the j-th mine project, and is defined as x_j= 1 if j-th mine project is selected, and = 0 otherwise(i.e. x_j are binary variables).

CP_j = the initial capital available for investment in the j-th mine project proposal.

Profitability:

Profitability is the main aim of every business because an investor always thinks about getting as much profit as possible from his business. Therefore, the objective of maximizing the annual profit in the mathematical programming model for selecting suitable project proposals have been considered. Mathematically, it can be written as:

$$\max : z_2 = \sum_{j=1}^{5} AP_j x_j \tag{3.5}$$

where AP_j = the annual profit obtained from the j-th mine project proposal.

Cost of Production:

Whenever a cost coming into business, it should be always minimized for getting more profit. In this mathematical programming model, the objective of minimizing the annual production cost (in crore of rupees) for selecting suitable project proposals have been considered. Mathematically, it can be written this objective function as:

$$\min : z_3 = \sum_{j=1}^{5} APC_j x_j \tag{3.6}$$

where APC_j = the annual production cost for working j-th mine project proposal.

Mine Life:

This is the fourth objective of our model in which we want to maximize the mine life i.e. the life of the mine project, so that almost all the natural resources could be dug out from mine face area for individual use. Mathematically, it can be written as:

$$\max : z_4 = \sum_{j=1}^{5} MPL_j x_j \tag{3.7}$$

where MPL_j = the mine life associated with the j-th mine project.

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Internal Rate of Return (IRR):

he internal rate of return (IRR) is a rate of return used in capital budgeting to measure and compare the profitability of investments. This is the fifth objective of our model in which we want to maximize the IRR from all the selected mine project proposals, so that it also maximizes the rate of return of whole mining industry. Mathematically, we can write this objective function as:

$$\max : z_5 = \sum_{j=1}^{5} IRR_j x_j \tag{3.8}$$

where IRR_j = the internal rate of return associated with the j-th mine project.

Employment of Manpower Constraint:

Manpower is very important for functioning of an industry. In this constraint we restrict the number of manpower employed as lower limit M_l and upper limit M_u in such a manner that the profit and production process of the mining industry is not affected. Mathematically, this constraint can be written as:

$$\sum_{j=1}^{5} ME_j x_j \leq M_u \tag{3.9}$$

and

$$\sum_{j=1}^{5} ME_j x_j \geq M_l \tag{3.10}$$

where ME_j= the manpower employed for working j-th mine project.
M_u = the desired upper limit of manpower employment.
M_l = the desired lower limit of manpower employment.

Demand of Coal Constraint:

In this constraint of our mathematical programming model, we consider the demand of coal as a normal random variable with known mean and variance. The past demand data of coal shows that the future coal demand is random in nature due to seasonal effects. This constraint is considered as a probabilistic constraint in our model and it can be transformed to deterministic by using chance-constraint technique [7]. The management of ICML wants that the probability of demand of coal satisfaction should be at least 85%. Mathematically, this constraint can be written as:

$$\Pr\left(\sum_{j=1}^{5} P_j x_j \geq D\right) \geq \alpha \tag{3.11}$$

where Pr represent the probability of the constraint
P_j = the annual production in million tonnes from j-th mine project
D = the minimum total annual production from the mine face area.
α = the specified probability level assign by the mine manager.

Equipment Availability Constraint:

In this constraint of our mathematical programming model, we restrict the equipments according to requirement for working of the mine projects properly. Mathematically, it can be written as:

$$\sum_{j=1}^{5} EA_j x_j \leq TEA \tag{3.12}$$

where EA_j = the equipment available for working j-th mine project
TEA = the total number of equipment available for the mine project proposals

Water Demand Constraint:

Water is a basic and important need for human life. Without water life can not exit. So taking this aspects into account, we consider this constraint for requirement of water in mining industry for smooth working of the mine projects. Actually in the mining industry water is needed for industrial work as well as for meeting the residential requirements. Mathematically, it can be written as:

$$\sum_{j=1}^{5} WD_j x_j \leq TWD \tag{3.13}$$

where WD_j = water demand for working j-th mine project proposal
TWD = total water demand for the mine project proposal

Energy Consumption Constraint:

Energy consumption is the consumption of energy or power. Energy means electric energy is required for smoothly working an industry. Consumption of energy is possible when we use it in a proper way. In this constraint we restrict the consumption of energy i.e. to use it in a systematic manner without energy loss in any way. Mathematically, it can be written as:

$$\sum_{j=1}^{5} EC_j x_j \leq TEC \tag{3.14}$$

where EC_j = energy consumed for j-th mine project
TEC = total energy consumed for the mine project proposals

Coal Reserve Constraint:

Mining industry exits whenever there is some reserve of natural resources like coal or ore found under the earth. In this constraint we consider coal reserve associated with each project proposal and restrict according to managerial decision . Mathematically, it can be written as:

$$\sum_{j=1}^{5} CR_j x_j \leq TCR \tag{3.15}$$

where CR_j = coal reserve for j-th mine project proposal
TCR = total coal reserve for the mine project proposals

Now combining the equations from (3.4)-(3.15), we state the proposed MOLP problem of project selection of ICML as follows:

$$\min : z_1 = \sum_{j=1}^{n} CP_j x_j \tag{3.16}$$

$$\max : z_2 = \sum_{j=1}^{n} AP_j x_j \tag{3.17}$$

$$\min : z_3 = \sum_{j=1}^{5} APC_j x_j \tag{3.18}$$

$$\max : z_4 = \sum_{j=1}^{5} MPL_j x_j \tag{3.19}$$

$$\max : z_5 = \sum_{j=1}^{5} IRR_j x_j \tag{3.20}$$

Subject to

$$\sum_{j=1}^{5} ME_j x_j \leq M_u \tag{3.21}$$

$$\sum_{j=1}^{5} ME_j x_j \geq M_l \tag{3.22}$$

$$\Pr\left(\sum_{j=1}^{5} P_j x_j \geq D\right) \geq 0.85 \tag{3.23}$$

$$\sum_{j=1}^{5} EA_j x_j \leq TEA \tag{3.24}$$

$$\sum_{j=1}^{5} WD_j x_j \leq TWD \tag{3.25}$$

$$\sum_{j=1}^{5} EC_j x_j \leq TEC \tag{3.26}$$

$$\sum_{j=1}^{5} CR_j x_j \leq TCR \tag{3.27}$$

$$x_j = 0/1, j = 1, 2, \ldots, 5 \tag{3.28}$$

3.3 Data for the Project Selection Mathematical Programming Model

A case study has been proposed for project selection among five open cast mine project proposals. Relevant techno-economic data for each of the project proposals are given in Table 1. Instead of the techno-economic data, some managerial decisions are required for the feasibility of the developed model. So, following are some managerial decisions taken by mines management committee for constraints of the mathematical model of project selection problem:

- The number of manpower employed should be at least 2750 (i.e. lower limit of manpower M_l) and at most 4680 (i.e. upper limit of manpower M_u) for working the mining industry.
- The number of equipments required for working the industry properly should be at most 188
- The demand of water for residential and industry purposes should be at most 3398 KL
- The average energy (i.e. electric energy) consumption for both residential and industry purposes should be at most 30.81 KWH
- The total reserve of coal should be at most 128.52 million tonnes
- Analysis of past demand data of coal shows that the expected annual demand to be 4 million tonnes and standard deviation to be 1.2 million tonnes only.

Following notations are used in Table-1:
PN: Project Number;
PR: Production;
PL: Project Life;
MP: Manpower;
CI: Capital Investment (Rs. Crore);
PT: Profit (Rs. Crore);

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CP: Cost of Production per Year(Rs. Crore);
EA: Equipment Availability;
IRR: Internal Rate of Return (%)
TR: Total Reserve (MT)
AEC: Average Energy Consumption (KWH)
WD: Water Demand (KL)
MT: Million Tonne;
Cr: Crore

4 Fuzzy Programming Approach

Now a days, fuzzy set theory has been applied successfully in several multi-criteria decision making problems. In multi-criteria decision making problems the objective functions are represented by fuzzy sets and the decision set is defined as the intersection of all the fuzzy sets associated with the constraints. Bellman and Zadeh [4] first introduced the concept of fuzzy set theory. Later on Zimmermann [23] used fuzzy set theory concept with suitable choice of membership function and derived a fuzzy linear program, which is identical to present day maximin problem. He shows that the solutions obtained by fuzzy linear programming technique are always efficient. The decision rule is to select the solution having the highest membership value of the decision set. Our proposed mathematical programming model of the project selection problem is a multi-objective linear programming problem. So fuzzy programming technique is applied to find solution of the proposed model. Several literatures [5, 10, 16, 19, 22] have been found in this direction.

4.1 Solution Procedure

Following are the important steps of fuzzy programming technique as:

Step 1: In order to solve the given multi-objective linear programming (MOLP) problem, first solve the problem taking only one objective function $Z_r(X), r = 1, 2, \ldots, 5$ at a time and ignoring the others using standard linear/non-linear programming technique. Let $X^{(1)}, X^{(2)}, \ldots, X^{(5)}$ be the ideal solutions for the respective objective functions. Repeat the process 5 times for 5 different objective functions.

Step 2: Using the ideal solutions obtained from Step 1, find the corresponding value of the objective functions and form a pay-off matrix Table as:

Table 2: Pay-off Matrix

	$Z_1(X)$	$Z_2(X)$	$\ldots$	$Z_5(X)$
$X^{(1)}$	Z_{11}	Z_{12}	$\ldots$	Z_{15}
$X^{(2)}$	Z_{21}	Z_{22}	$\ldots$	Z_{25}
$\vdots$	$\vdots$	$\vdots$	$\vdots$	$\vdots$
$X^{(5)}$	Z_{51}	Z_{52}	$\ldots$	Z_{55}

Step 3: From pay-off matrix determine the bounds for r-th objective function $Z_r(X), r = 1, 2, \ldots, 5$. If an objective function is of maximization type find the best upper bound $U_r^*, r = 1, 2, \ldots, 5$ and worst lower bound $L_r^-, r = 1, 2, \ldots, 5$. If a objective function is of minimization type find the best lower bound $L_r^*, r = 1, 2, \ldots, 5$ and worst upper bound U_r^-, $r = 1, 2, \ldots, 5$ (From Step 2). Using the bounds of objective functions define linear membership functions as described in Section 2.

Step 4: Using the linear membership functions and max-min operator, formulate the crisp linear or non-linear programming problem and solved by using standard linear/non-linear programming technique. The obtained solution is the best compromise solution to the given problem.

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Table 1: Collected data from project reports of ICML

PN	CI(Cr)	PT(Cr)	PL(Yr)	PR(MT)	MP	CP(Cr)	IRR (%)	EA	TR(MT)	AEC(KWH)	WD(KL)
1	86.4685	2.9867	25	1	728	9.145	23.49	33	22.741	5.06	370
2	418.2939	−3.1908	20	3.83	2422	14.2878	33.28	47	65.64	5.45	1740
3	88.3892	−3.2401	22	0.65	1012	12.9951	17.36	41	13.16	6.8	930
4	44.6644	1.2892	18	0.45	239	4.6411	14.85	35	7.05	7.7	130
5	47.8793	0.784	17	0.4	270	11.7365	21.74	28	16.64	5.6	2200

5 Result Analysis

Using data Table 1, we formulate the multi-objective linear programming model for project selection of ICML. The best compromise solution is obtained by using fuzzy programming technique as described in Section 4 and shown in the Table 2 as:

Table-2: Solution by Fuzzy Programming Technique

Selected Project Number	Degree of Membership Value(λ)
1, 2, 4, 5	0.4358974

From the solution Table 2 , it has been seen that out of five project proposals only suitable four are selected. From the selected project proposals, we get the following results:

- Minimum 599.3061Cr rupees of capitals are required for investment programme
- Maximum profit will be 1.8791Cr rupees
- Cost of production of coal per ton will be 39.8104 Cr rupees
- Maximum life of the project will be 80 years
- Maximum IRR will be 39.8104%
- The number of manpower employed will be 3659
- Minimum production of coal per year will be 5.68 MT
- The number of equipment available will be 143
- Demand of water will be 2460 KL
- Consumption of energy will be 23.81 KWH
- Total coal reserve will be 112.071 MT

6 Conclusions

In this paper, a case study of selecting suitable project proposals of ICML is proposed. In this multi-criteria decision making problem, we considered five desirable objectives along with six applicable constraints. A well known approach namely, fuzzy programming is used to solve the mathematical programming model of project selection. Out of five project proposals only four efficient projects are selected. The obtained solution is the "best compromise" solution along with degree of acceptance of solution level is 0.4358974. Future research direction may include the development of a decision making problem of project selection incorporating the fuzziness or randomness in the data of the problem which adds some flexibility to the problem of project selection.

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