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Optimizing Efficiency of Coal Mines using Constant Return to Scale (CRS) Model

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ABSTRACT

Coal accounts for 50% of total commercial energy supplied in India. The rising demand for coal and the inability of the domestic coal production to meet the demand is a challenging task to improve the productivity and reducing cost through technological upgradation. SCCL is a public sector mining organization is the largest producer of coal in India after coal India Limited (CIL) with manpower of 77,000 and catering the energy needs of southern part of India. The company is now operating 42 Underground (UG) mines and 15 Open Cast (OC) mines. Productivity improvement and cost control have become key objectives of SCCL coal mines in recent years. As a result many research works have carried out on productivity improvement in coal mines.

Keywords : Data Envelopment Analysis , CRS , Benchmark.

1.INTRODUCTION

Selected various coal mines in SCCL and calculated relative efficiency of mines by using Data Envelopment Analysis (DEA) which helps to rank them based on their efficiency score.The efficiency score has been calculated based on two approaches of DEA Viz., Constant Return to Scale (CRS) model.For every inefficient coal mine, DEA identifies a set of corresponding efficient coal mines that can be utilized as benchmarks for improvement of performance and productivity. DEA developed based on two scale of assumptions viz., **Constant Return to Scale (CRS**) output model.

Methodology

Data envelopment analysis (DEA) is a linear programming based technique for measuring the relative performance of organizational units where the presence of multiple inputs and outputs makes comparisons difficult. DEA developed based on two scale of assumptions viz., Constant Return to Scale (CRS) model and the DEA model which allows relative efficiency measures to be determined is developed.

A common measure for relative efficiency is,

$$\text{Efficiency} = \frac{\textbf{Weighted sum of outputs}}{\textbf{Weight sum of inputs}}$$

The Constant Returns to Scale Model (CRS)

The following discussion of DEA begins with a description of the input-orientated CRS model was the first to be widely applied. The original constraint is manipulated in order to convert the fractional program to a linear program. These two steps result in the following:

The interpretation of **ur** and **vi** is that they are weights applied to outputs yrj and inputs xij

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and the are chosen to maximize the efficiency score h_0 h_0 for DMU_0. The constraint forces the efficiency score to be no greater than 1 for any DMU. In order to convert the fractional program to a linear program. These two steps result in the following:

$$\max h_0 = \sum_r u_r y_{rj_0}$$

$$\sum_r u_r y_{rj} - \sum_i v_i x_{ij} \le 0$$

$$\text{subject to } \sum_i v_i x_{ij_0} = 1$$

$$u_r, v_i \ge 0$$

CRS Output-oriented Model

Alternately, one could have started with the output side and considered instead the ratio of virtual input to output. This would reorient the objective from max to min.

$$\min q = \sum_{i=1}^{m} v_i x_{io}$$
$$\text{subject to}$$
$$\sum_{i=1}^{m} v_i x_{ij} - \sum_{r=1}^{s} \mu_r y_{rj} \ge 0$$
$$\sum_{r=1}^{s} \mu_r y_{ro} = 1$$
$$\mu_r, v_i \ge \varepsilon, \quad \forall r, i$$

$$\max \phi + \varepsilon\left(\sum_{i=1}^{m} s_i^- + \sum_{r=1}^{s} s_r^+\right)$$
$$\text{subject to}$$
$$\sum_{j=1}^{n} x_{ij}\lambda_j + s_i^- = x_{io} \quad i = 1,2,\ldots,m;$$
$$\sum_{j=1}^{n} y_{rj}\lambda_j - s_r^+ = \phi y_{ro} \quad r = 1,2,\ldots,s;$$
$$\lambda_j \ge 0 \qquad j = 1,2,\ldots,n.$$

Data Collection and Preparation for the Model

we have chosen **four input variables** namely, Wage Cost (In Lakhs rupees per year), Store Cost (In Lakhs rupees per year),OBR Cost (In Lakhs rupees per year), Other cost (In Lakhs rupees per year) and **one output variable** namely Production (in Lakh Tonnes per year).

Table I: Input and Output Variables used in the analysis

Input/output variable	Open-Cast mines
Wage Cost (Input)	It includes all the wages paid to the employees
Store Cost (Input)	Cost of Explosives, spares and other maintenance items used
Other cost (Input)	Cost of Capital equipment, Depreciation.
OBR cost (Input)	Cost of over burden removal from above coal seams
Production (output)	Saleable Coal

2. ANALYSIS OF OC MINES

OC mines with output – oriented CRS model

Using CRS algorithm for every single DMU a linear program with one objective function and 16 side conditions was designed. These 16 linear programs were solved using TORA package and DEAP.

Table II: Efficiency Scores, Shadow values and Peer Groups of OC mines after solving Output – oriented CRS model

DMU	Efficiency	Shadow Values	Peer Groups
OCM1	55.10%	1.0472, 0.1562, 12.0735	4,6,7
OCM2	100%	1.0000	2
OCM3	100%	1.0000	3
OCM4	100%	1.0000	4
OCM5	67.80%	1.8195, 1.0240, 4.4250	3,4,7
OCM6	100%	1.0000	6
OCM7	100%	1.0000	7
OCM8	71.40%	0.9187, 0.1812, 5.1385	2,6,7
OCM9	85.70%	0.5024, 0.0140, 2.6086	2,6,7
OCM10	83.40%	0.0508, 1.9817, 0.4145	2,7,11
OCM11	100%	1.0000	11
OCM12	96.40%	0.1589, 4.5520, 1.4152	2,7,11
OCM13	68.20%	1.6040, 1.2875, 8.9947	3,4,7
OCM14	64.30%	1.7000, 0.1935, 2.9741	3,4,7
OCM15	39.70%	1.8219, 2.4135, 3.3739	3,4,7

Six Mines namely OCM2, OCM3, OCM4, OCM6, OCM7 and OCM 11 got 100% efficiency, so these mines are called the benchmarking or referring mines.

Table III: Ranking and Peer count of OC Mines after solving Output – oriented CRS model

DMU	Efficiency	Peer Group	Ranking	Peer Count
OCM1	55.10%	4,6,7	13	0
OCM2	100%	2	3	5
OCM3	100%	3	3	5
OCM4	100%	4	2	6
OCM5	67.80%	3,4,7	11	0
OCM6	100%	6	4	4
OCM7	100%	7	1	10
OCM8	71.40%	2,6,7	9	0
OCM9	85.70%	2,6,7	7	0
OCM10	83.40%	2,7,11	8	0
OCM11	100%	11	5	3
OCM12	96.40%	2,7,11	6	0
OCM13	68.20%	3,4,7	10	0
OCM14	64.30%	3,4,7	12	0
OCM15	39.70%	3,4,7	14	0

The above table 4.10 shows relative efficiency of OC Mines calculated by comparing with other uniform DMUs with same Input and Output variables. . The shadow values related to the constraints limiting the efficiency of each unit to be no greater than 1.

Table IV: Improvements in Inputs and Output of OC Mines after solving Output – oriented CRS model

	Wage Cost	Store Cost	OBR Cost	Other Cost	Production
DMU	**Actual to Target**	**Actual to Target**	**Actual to Target**	**Actual to Target**	**Actual to Target**
OCM1	1.4159 to 1.4159	1.3481 to 0.871	1.626 to 1.626	1.5881 to 1.5881	1.498 to 2.7194
OCM2	0.4178 to 0.4178	0.275 to 0.275	1.1271 to 1.1271	0.6606 to 0.6606	1.0283 to 1.0283
OCM3	0.8347 to 0.8347	0.3747 to 0.3747	0.2395 to 0.2395	0.2439 to 0.2439	0.4547 to 0.4547
OCM4	0.2877 to 0.2877	0.0429 to 0.0429	0.0886 to 0.0886	1.4318 to 1.4318	0.9398 to 0.9398
OCM5	2.2116 to 2.2116	2.7843 to 1.0089	1.0544 to 1.0544	1.9245 to 1.9245	1.6182 to 2.3861
OCM6	0.1794 to 0.1794	0.3421 to 0.3421	0.5946 to 0.5946	0.3132 to 0.3132	0.69 to 0.69
OCM7	0.09 to 0.09	0.064 to 0.064	0.1193 to 0.1193	0.0033 to 0.0033	0.1348 to 0.1348
OCM8	0.8788 to 0.8788	0.6435 to 0.6435	2.305 to 1.7562	0.6806 to 0.6806	1.2584 to 1.7624
OCM9	0.4472 to 0.4472	0.3099 to 0.3099	1.5266 to 0.8858	0.3449 to 0.3449	0.7523 to 0.8779
OCM10	0.314 to 0.314	0.1812 to 0.1812	0.5095 to 0.4961	0.1531 to 0.1531	0.4167 to 0.4995
OCM11	0.2761 to 0.2761	0.0975 to 0.0975	0.4884 to 0.4884	0.2727 to 0.2727	0.4347 to 0.4347
OCM12	0.8668 to 0.8668	0.473 to 0.473	1.9179 to 1.4133	0.5059 to 0.5059	1.3427 to 1.3922
OCM13	2.5188 to 2.5188	3.8545 to 1.2319	1.5713 to 1.5713	2.2644 to 2.2644	2.1494 to 3.1519
OCM14	1.7423 to 1.7423	1.7183 to 0.8356	0.7791 to 0.7791	0.7015 to 0.7015	0.872 to 1.3557
OCM15	2.5188 to 2.5188	2.4909 to 1.0022	1.0527 to 1.0527	3.9112 to 3.9112	1.4102 to 3.5515

The following fig I shows clearly the difference between Actual Production and Target Production.

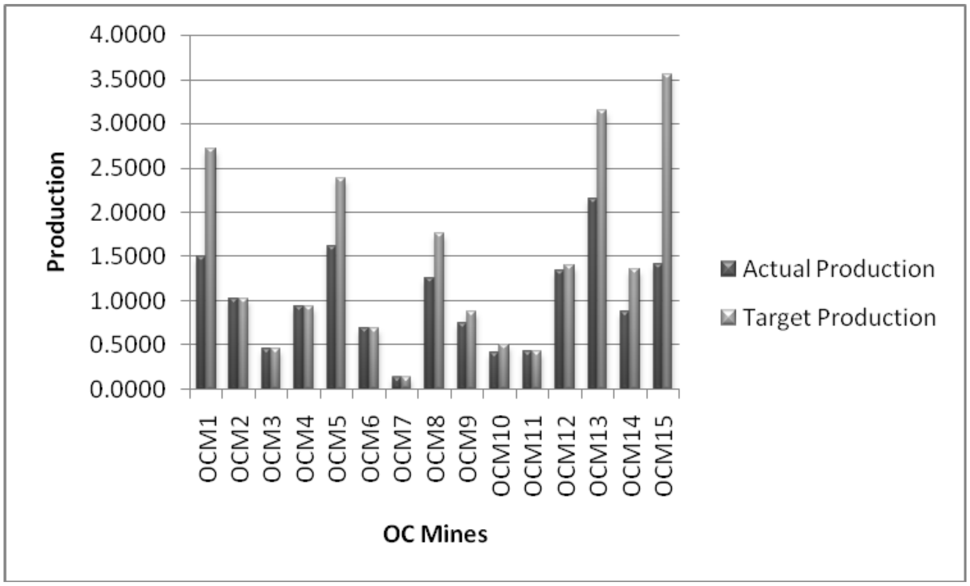

Fig-I: Actual Production Vs Target Production for Output – oriented CRS model

3. CONCLUSION

One could alternatively ask the question ": "By how much more output can potentially be produced without altering the input quantities used?" This is an output-orientated measure as opposed to the input-oriented measure. six units OCM2, OCM3, OCM4, OCM6, OCM7 and OCM 11 got 100% efficiency acts as a peer groups for other nine inefficient mines. But two OC mines are OCM7 and OCM4 appeared maximum number of times (10 and 6) as a peer groups. So, these two mines built the efficient frontier for improvement of other mines and acts as a benchmarking for other units which are given the 1st and 2nd ranks by DEA. OCM2, OCM3, OCM6 and OCM 11 assigned less ranking then OCM7 and OCM4 even though got 100% efficiency due to these units appeared less peer count.

However, there is a scope for improvement of Open cast mines because mean efficiency score for all DMUs shows 0.8213 (82.13%).There is lot of scope for further improvement in the output production without changing all input variables by adjusting slack variable in one Input of each Coal mine. Table IV shows in both the input and output-oriented cases lot of improvement in output can be achieved by decreasing the input based on the analysis given by the DEA CRS method. After Benchmarking it is found that there is sufficient scope for improvement in coal mines .The fruits of process benchmarking could bring in substantial savings by way of overall cost reduction and cycle time which improves the Productivity of Coal mines.

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