Optimization of Coal Mines using Data Envelopment Analysis

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ABSTRACT

Productivity improvement and cost control have become key objectives of SCCL coal mines in recent years. Data Envelopment Analysis (DEA) and Bench marking etc are very popular tools in productive improvement which can aggregate the input and output components in such situations for obtaining an overall performance measure to improve productivity. 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. Discussed and analyzed the improvement areas of in-efficient coal mines.

I. INTRODUCTION

Singareni Collieries Company Limited (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.

This paper provides to evaluate the performance of the Coal mines to establish the bench marking of Open Cast (OC) mines using Input-oriented CRS model. Identified the best mines in each category is used as bench mark for improvement productivity of corresponding inefficient coal mines. Virtual efficient inputs or output and target production of mines are calculated for improvement by reducing slacks and reducing inputs.

Methodology

Data Envelopment Analysis (DEA): DEA is a multi-factor productivity analysis model for measuring the relative efficiency of a homogenous set of coal mines (DMU's). 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.

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.

CRS Input- oriented Model

In all variations of the DEA models, the DMU(s) with the best inherent efficiency in converting inputs **X1, X2,…,Xn** into outputs **Y1, Y2,…,Ym** is identified, and then all other DMUs are ranked relative to that most efficient DMU. For DMU 0, the basic CRS Input Oriented model (so-called CCR after Charnes, Cooper, and Rhodes) is calculated as follows:

$$\max h_0 = \frac{\sum_r u_r y_{rj_0}}{\sum_i v_i x_{ij_0}}$$

$$\text{subject to} \quad \frac{\sum_r u_r y_{rj}}{\sum_i v_i x_{ij}} \le 1 \quad \text{for each unit j}$$

$$u_r, v_i \ge 0$$

The interpretation of **ur** and **vi** is that they are weights applied to outputs yrj and inputs xij and the are chosen to maximize the efficiency score 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:

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

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

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

$$u_r, v_i \ge 0$$

Data Collection and Preparation for the Model

For the empirical application we worked with data on a survey of 15 Open Cast (OC) mines of SCCL.For our analysis, 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

II. ANALYSIS OF OC MINES

OC mines with Input – 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 VI : Normalized Data for Open-Cast mines

Normalized data of OC mines					
Mines(DMU)	Wage Cost	Store Cost	OBR Cost	Other Cost	Production
OCM1	1.4159	1.3481	1.6260	1.5881	1.4980
OCM2	0.4178	0.2750	1.1271	0.6606	1.0283
OCM3	0.8347	0.3747	0.2395	0.2439	0.4547
OCM4	0.2877	0.0429	0.0886	1.4318	0.9398
OCM5	2.2116	2.7843	1.0544	1.9245	1.6182
OCM6	0.1794	0.3421	0.5946	0.3132	0.6900
OCM7	0.0900	0.0640	0.1193	0.0033	0.1348
OCM8	0.8788	0.6435	2.3050	0.6806	1.2584
OCM9	0.4472	0.3099	1.5266	0.3449	0.7523
OCM10	0.3140	0.1812	0.5095	0.1531	0.4167
OCM11	0.2761	0.0975	0.4884	0.2727	0.4347
OCM12	0.8668	0.4730	1.9179	0.5059	1.3427
OCM13	2.5188	3.8545	1.5713	2.2644	2.1494
OCM14	1.7423	1.7183	0.7791	0.7015	0.8720
OCM15	2.5188	2.4909	1.0527	3.9112	1.4102

DEA Linear Programming Formulation for OC Mines

Max 1.4980 u_1

Subject to

$1.4159 v_1 + 1.3481 v_2 + 1.6260 v_3 + 1.5881 v_4 = 1$

$1.4980 u_1 - 1.4159 v_1 - 1.3481 v_2 - 1.6260 v_3 - 1.5881 v_4 <= 0$

$1.0283 u_1 - 0.4178 v_1 - 0.2750 v_2 - 1.1271 v_3 - 0.6606 v_4 <= 0$

$0.4547 u_1 - 0.8347 v_1 - 0.3747 v_2 - 0.2395 v_3 - 0.2439 v_4 <= 0$

$0.9398 u_1 - 0.2877 v_1 - 0.0429 v_2 - 0.0886 v_3 - 1.4318 v_4 <= 0$

$1.6182 u_1 - 2.2116 v_1 - 2.7843 v_2 - 1.0544 v_3 - 1.9245 v_4 <= 0$

$0.6900 u_1 - 0.1794 v_1 - 0.3421 v_2 - 0.5946 v_3 - 0.3132 v_4 <= 0$

$0.1348 u_1 - 0.0900 v_1 - 0.0640 v_2 - 0.1193 v_3 - 0.0033 v_4 <= 0$

$1.2584 u_1 - 0.8788 v_1 - 0.6435 v_2 - 2.3050 v_3 - 0.6806 v_4 <= 0$

$0.7523 u_1 - 0.4472 v_1 - 0.3099 v_2 - 1.5266 v_3 - 0.3449 v_4 <= 0$

$0.4169 u_1 - 0.3140 v_1 - 0.1812 v_2 - 0.5095 v_3 - 0.1531 v_4 <= 0$

$0.4347 u_1 - 0.2761 v_1 - 0.0975 v_2 - 0.4884 v_3 - 0.2727 v_4 <= 0$

$1.3427 u_1 - 0.8668 v_1 - 0.4730 v_2 - 1.9179 v_3 - 0.5059 v_4 <= 0$

$2.1494 u_1 - 2.5188 v_1 - 3.8545 v_2 - 1.5713 v_3 - 2.2644 v_4 <= 0$

$0.8720 u_1 - 2.5188 v_1 - 2.4909 v_2 - 1.0527 v_3 - 3.9112 v_4 <= 0$

$u_1, v_1, v_2, v_3, v_4 \geq 0$

Ranking of OC mines based on their efficiency scores and also mentioned the peer count means how many times efficient mines referred as a Bench mark for other in-efficient mines? This will helps to takes bench marking as a reference for further improvement of low performing coal mines.

Table VII: Efficiency Scores, Peer weights and peer groups for OC mines after solving Input – oriented CRS model

OPEN CAST MINES			
Mines (DMU)	**Efficiency Score**	**Shadow Values**	**Benchmark or Peer groups**
OCM1	54.96%	0.5792	4
OCM2	100.00%	1.0000	2
OCM3	100.00%	1.0000	3
OCM4	100.00%	1.0000	4
OCM5	67.73%	1.2315, 0.6959, 3.0016	3, 4, 7
OCM6	100.00%	1.0000	6
OCM7	100.00%	1.0000	7
OCM8	71.25%	0.6592, 0.1316, 3.6353	2, 6, 7
OCM9	85.51%	0.4325, 0.0133, 2.2152	2, 6, 7
OCM10	83.19%	0.0455, 1.6392, 0.3429	2, 7, 11
OCM11	100.00%	1.0000	11

OCM12	92.19%	0.1628, 4.3572, 1.3535	2, 7, 11
OCM13	68.06%	1.0897, 0.8812, 6.1311	3, 4, 7
OCM14	64.22%	1.0914, 0.1257, 1.9125	3, 4, 7
OCM15	39.68%	0.7226, 0.9589, 1.3411	3, 4, 7

Table VIII: Ranking and peer count of OC mines after solving Input – oriented CRS model

OPEN CAST MINES					
Mines (DMU)	**Efficiency Score**	**Peer weights**	**Peer group**	**Ranking by DEA**	**Peer count**
OCM1	54.96%	0.5792	4	12	0
OCM2	100.00%	1.0000	2	3	5
OCM3	100.00%	1.0000	3	3	5
OCM4	100.00%	1.0000	4	2	6
OCM5	67.73%	1.2315, 0.6959, 3.0016	3, 4, 7	10	0
OCM6	100.00%	1.0000	6	4	3
OCM7	100.00%	1.0000	7	1	9
OCM8	71.25%	0.6592, 0.1316, 3.6353	2, 6, 7	8	0
OCM9	85.51%	0.4325, 0.0133, 2.2152	2, 6, 7	6	0
OCM10	83.19%	0.0455, 1.6392, 0.3429	2, 7, 11	7	0
OCM11	100.00%	1.0000	11	4	3
OCM12	92.19%	0.1628, 4.3572, 1.3535	2, 7, 11	5	0
OCM13	68.06%	1.0897, 0.8812, 6.1311	3, 4, 7	9	0
OCM14	64.22%	1.0914, 0.1257, 1.9125	3, 4, 7	11	0
OCM15	39.68%	0.7226, 0.9589, 1.3411	3, 4, 7	12	0

Fig: OC Mines Vs Efficiency Score for Input – oriented CRS model (OC Mines)

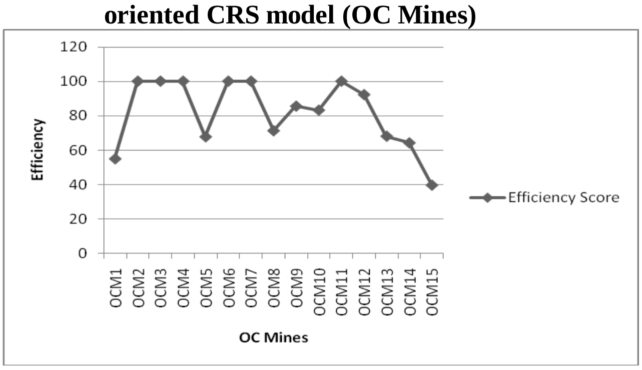
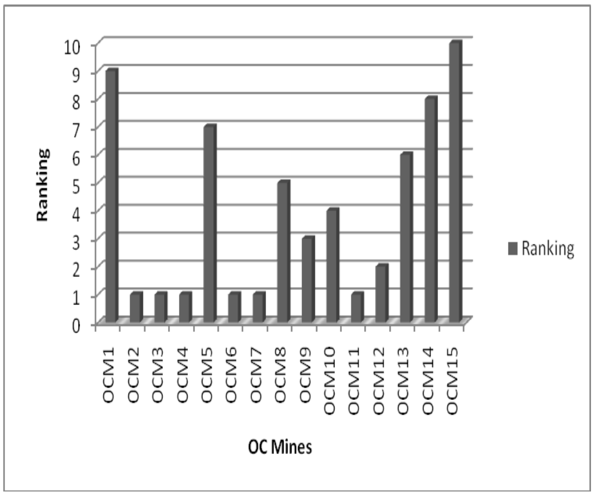


Fig: Ranking of Opencast Mines for Input – oriented CRS model (OC Mines)



Virtual Efficient Inputs of OC Mines

Every DMU beneath this efficient frontier is inefficient among the efficient mines. The usage of combinations of efficient DMUs is called virtual producers corresponding to the inefficient ones. The "shadow values" and "peer groups" are helpful in constructing the virtual producers. For example mine OCM5 has got efficiency score less than 1. OCM3, OCM4 and OCM7 are in the peer group of OCM5 and their corresponding shadow values are 1.2315, 0.6959 and 3.0016 respectively. Its virtual producer is a linear combination of inputs or outputs of efficient mines of OCM3, OCM4 and OCM7 (peer group which have a relative efficiency 1 with respect to OCM5). This efficient wage cost for OCM5 is 1.2315*0.8347+0.6959+0.2877+3.0016*0.0900.Similarly, the efficient store cost is 1.2315*0.3747+0.6959*0.0429+3.0016*0.0640.Similarly, the efficient OBR cost is 1.2315*0.2395+0.6959*0.0886+3.0016*0.1193 and other cost is 1.2315*0.2439+0.6959*1.4318+3.0016*0.0033.

These virtual producers provide a direction to improve the efficiency. In input orientation measure indicates how much the existing input to be reduced to produce a given level of output.

Table XI: Virtual Efficient Inputs Calculated for OC Mines after solving Input – oriented CRS model

Open Cast Mines								
Mines (DMU)	**Actual Input**				**Virtual Efficient Input**			
	Wage cost	**Store Cost**	**OBR Cost**	**Other cost**	**Wage cost**	**Store cost**	**OBR Cost**	**Other cost**
OCM1	1.4159	1.3481	1.6260	1.5881	0.1666	0.0248	0.0513	0.0829
OCM2	0.4178	0.2750	1.1271	0.6606	0.4178	0.2750	1.1271	0.6606
OCM3	0.8347	0.3747	0.2395	0.2439	0.8347	0.3747	0.2395	0.2439
OCM4	0.2877	0.0429	0.0886	1.4318	0.2877	0.0429	0.0886	1.4318
OCM5	2.2116	2.7843	1.0544	1.9245	1.4952	0.6833	0.7146	1.3066
OCM6	0.1794	0.3421	0.5946	0.3132	0.1794	0.3421	0.5946	0.3132
OCM7	0.0900	0.0640	0.1193	0.0033	0.0900	0.0640	0.1193	0.0033
OCM8	0.8788	0.6435	2.3050	0.6806	0.6261	0.4589	1.2549	0.4886
OCM9	0.4472	0.3099	1.5266	0.3449	0.3824	0.2652	0.7596	0.2971
OCM10	0.3140	0.1812	0.5095	0.1531	0.2612	0.1508	0.4143	0.1289
OCM11	0.2761	0.0975	0.4884	0.2727	0.2761	0.0975	0.4884	0.2727
OCM12	0.8668	0.4730	1.9179	0.5059	0.8338	0.4555	1.3643	0.4910
OCM13	2.5188	3.8545	1.5713	2.2644	1.7148	0.8385	1.0704	1.5477
OCM14	1.7423	1.7183	0.7791	0.7015	1.1192	0.5367	0.5006	0.4524
OCM15	2.5188	2.4909	1.0527	3.9112	0.9997	0.3977	0.4180	1.5536

III. CONCLUSIONS

DEA efficiency ranking finds that 6 DMUs out of 15 DMUs have emerged as benchmarking units for the other 9 DMUs. The benchmarking units are listed as OCM2, OCM3, OCM4, OCM6, OCM7 and OCM11 as shown in table VIII (OC Mines). The efficiency score for these DMUs approaches unity while that of DEA-inefficient DMUs is less than unity. For example, OCM5 having efficiency score of 67.73% can refer OCM3, OCM4 and OCM7. OCM5 can assign a weightage of 1.2315 to OCM3, 0.6959 to OCM4 and 3.0016 to OCM7 to become a benchmark unit.

One DMU (e.g. OCM7) have become the peer unit nine times while OCM4 becomes the referring institute for six times, respectively. OCM2 and OCM3 becomes the referring institute for five times whereas OCM6 and OCM11 for three times respectively. Six mines ranked as 1 have become efficient units. However, there is a scope for improvement of Open cast mines because mean efficiency score for all DMUs shows 0.8178 (81.78%).

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.

IV. REFERENCES

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