CHAPTER 6

CONCLUSIONS AND SCOPE FOR FUTURE WORK

This chapter presents the conclusions of the present research work. The significant contributions of the research were highlighted and the scope for future work is discussed.

6.1 Summary

The purpose of this study is to collect data relating to the group of different costs have been divided into 4 major costs like wage cost, store cost, OBR cost and other cost (inputs) and productivity (output) in a group of coal mines (UG and OC), analyze data and evaluate the performance of Coal Mines using the Data Envelopment Analysis (DEA) models. The analysis carried out by using TORA and DEAP software's.

The analysis has been carried out in 4 Modules:

In the first module, evaluated efficiencies and benchmarking of 42 UG Mines & 15 OC Mines using Input-oriented Constant Return to Scale (CRS) Model and also evaluated performance of OC Mines using Output-oriented CRS Model. Comparison is made between Input-oriented CRS and Output-oriented CRS Models of OC Mines (See Chapter 4).

In the second module evaluated benchmarking and ranking of 15 OC Mines using Input-oriented Variable Return to Scale (VRS) and Output-oriented VRS Models and comparison is made between Input-oriented VRS and Output-oriented VRS Models of OC Mines (Refer Chapter 5).

In the third module comparison is made between Input-oriented CRS and Input-oriented VRS Models of OC Mines (Refer Chapter 5) and also comparison is made between Output-oriented CRS and Output-oriented VRS Models of OC Mines (Refer Chapter 5).
In the **fourth module** evaluated efficiencies and analyzed using advanced models of DEA are 1. Increasing Returns Scale (IRS) Model, 2. Decreasing Returns Scale (IRS) Model, 3. Cross Efficiency (CE) Method 4. Scale Efficiency (SE) Model 5. Super Efficiency Model and 6. Additive Model (See Chapter 5).

The objectives of this research work have been achieved to the maximum extent possible. Suitable suggestions and recommendations are made at each chapter and wherever felt necessary under the discussions on results.

### 6.2 Conclusions

In this thesis, a methodology based on Data Envelopment Analysis (DEA) is discussed to evaluate efficiencies, benchmarking and rank the Coal mines (UG and OC mines) with reference to the Singareni Collieries Company Limited (SCCL) using their Inputs (costs) and Output (productivity). This methodology facilitates to identify the benchmarking or peer group coal mines (efficiency = 1) which can be referred by inefficient coal mines (efficiency < 1) to become efficient mines. Two approaches of DEA viz. CRS and VRS are considered to obtain efficiency of DMUs.

The conclusions drawn from the aforesaid discussion of results after thorough analysis and scrutiny are summarized in the paragraphs to follow.

1. **Performance evaluation of 42 UG Mines using Input-oriented CRS Model**

   DEA efficiency ranking finds that 8 DMUs out of 42 DMUs have emerged as benchmarking units for the other 34 DMUs. The benchmarking units are listed as UGM2, UGM6, UGM20, UGM21, UGM22, UGM28, UGM30 and UGM37 as shown in table 4.5. The efficiency score for these DMUs approaches unity while that of DEA-inefficient DMUs is less than unity. Two DMUs (e.g. UGM30 and UGM37) have become the peer units twenty two times while UGM21 and UGM22 becomes the referring institute for sixteen and
eleven times, respectively. Eight mines ranked as 1 have become efficient units. However, there is a scope for improvement of Underground mines because mean efficiency score for all DMUs shows 0.7607 (76.07%).

2. Performance evaluation of 15 OC Mines using Input-oriented CRS Model
The DEA analysis shows that 6 OC Mines out of 15 Mines have efficiency score approaches unity while that of 9 DEA-inefficient DMUs is less than unity. The benchmarking units are listed as OCM2, OCM3, OCM4, OCM6, OCM7 and OCM11 as shown in table 4.8 got 100% efficiency which can acts as reference units for other inefficient coal mines. 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%).

The maximum Production around 90% of the Coal produced from Open Cast Mines only due to that only Open Cast Mines (15 mines) considered for further analysis of DEA models in order to cover maximum number of models. Six units OCM2, OCM3, OCM4, OCM6, OCM7 and OCM11 got 100% efficiency acts as a peer groups for other nine inefficient mines (table 4.13). 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. However, there is a scope for
improvement of Open cast mines because mean efficiency score for all DMUs shows 0.8213 (82.13%).

4. Comparison between Input-oriented and Output-oriented CRS Models

Six Mines OCM2, OCM3, OCM4, OCM6, OCM7 and OCM 11 got 100% efficiency acts as a peer groups in both Input-oriented and output-oriented models (table 4.16). The efficiency scores of inefficient mines almost equal with little difference but peer groups assigned in both the cases also equal except in OCM1. Observing Peer counts of OCM6 and OCM7 are 3, 9 and 4, 10 respectively have the slight difference in both the model while remaining mines are same. Five mines are OCM2, OCM3, OCM4, OCM6 and OCM7 assigned same rank in both the cases. In Input-oriented model the mean efficiency score for all DMUs shows 0.8178 (81.78%) whereas in Output-oriented model is 0.8213 (82.13%). That shows almost equal with little difference but mainly Output-oriented model helpful for fixing of the targets for productivity improvement of OC Mines in future.

5. Analysis of OC Mines using Input-oriented VRS model

DEA VRS efficiency analysis finds that 8 DMUs out of 15 DMUs have emerged as benchmarking units for the other 7 DMUs. The benchmarking units are listed as OCM2, OCM3, OCM4, OCM6, OCM7, OCM11, OCM12 and OCM13 (table 5.4). The inefficient units can refer the peer groups given with the corresponding weightage (table 5.1) for improvement in productivity. One DMU (e.g. OCM4) have become the peer unit six times. OCM4 ranked as 1 due to maximum number of peer count (6) among the efficient mines and OCM6, OCM12 and OCM13 are ranked as 2 are called as dominant peers which are the Benchmarking for the other mines for improving productivity. However, there is a scope for improvement of Open cast
mines because mean efficiency score for all DMUs shows 0.9392 (93.92%).

6. Analysis of OC Mines using Output-oriented VRS mode
Eight units OCM2, OCM3, OCM4, OCM6, OCM7, OCM11, OCM12 and OCM13 got 100% efficiency acts as a peer groups for other 7 inefficient mines (table 5.9). Four OC mines are OCM12, OCM13 and OCM4, OCM6 appeared maximum number of times 6 and 5 respectively as a peer groups. So, these 4 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, OCM7 and OCM11 assigned less ranking 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 0.9619 (96.19%).

7. Comparison between Input-oriented and Output-oriented VRS models
Eight Mines OCM2, OCM3, OCM4, OCM6, OCM7, OCM11, OCM12 and OCM13 got 100% efficiency acts as a peer groups in both Input-oriented and Output-oriented VRS models. The efficiency scores and peer groups of inefficient mines almost equal except in case of OCM8 and OCM15. (table5.12). Observing Peer counts of OCM2, OCM4, OCM12 and OCM13 are having slight difference between both models. Four mines OCM2, OCM6, OCM14 and OCM15 assigned same rank in both the cases. In Input-oriented model the mean efficiency score for all DMUs shows 0.9392 (93.92%) whereas in Output-oriented model is 0.9619 (96.19%). That shows Output-oriented model having greater mean efficiency than Input-oriented model.
8. **Comparison between Input-oriented CRS and Input-oriented VRS**

In CRS model 6 units and in VRS model 8 units are becomes benchmarking units. Two mines OCM12 and OCM13 are inefficient mines in CRS model becomes as efficient mines in VRS model (table 5.13). The efficiency scores in VRS model greater than the CRS model, which shows a lot of improvement taken place to adopt the VRS model for analysis. Peer groups and peer count are different in both the cases except in few cases. Ranking assigned by DEA also different in both the cases except OCM7 has given 1 rank in CRS but 4 in VRS model whereas OCM4 has given 1 rank in VRS but 2 in VRS model.

The overall VRS model shows more performance than CRS model. The mean efficiency score for all DMUs shows 0.8178 (81.78%) in CRS model and mean efficiency score for all DMUs shows 0.9392 (93.92%) in VRS model.

9. **Comparison between Output-oriented CRS and Output-oriented VRS**

The efficiency scores in Output-oriented VRS model drastically increased than CRS model (table 5.14). These results are same as Input-oriented comparison between both the models mentioned in **conclusion 8**. OCM7 assigned 1 rank in CRS model where as 3 ranks in VRS model and OCM13 assigned 1 rank in VRS model where as 10 in CRS model.

10. **Correlation between CRS and VRS models**

High degree of correlation \((r_s = 0.7465)\) between the ranks assigned by input-oriented CRS and input-oriented VRS models has been observed (from section 5.4). Similarly, the correlation between rankings of output-oriented CRS and output-oriented VRS models is 0.5929, which indicates a very weak relationship between the rankings.
of the two models. However an average degree of correlation is found between the ranks assigned by input, output oriented ranking using CRS and VRS model 0.6697.

11. Significance Evaluation using Paired Two Sample T-test for Means

In order to verify the significance difference between Technical Efficiency (TE) scores are calculated using the two models viz., CRS and VRS (from section 5.5). The results show that P value (in case input- oriented is 0.002 and in case of output-orientation is 0.0080) allowing us to reject null hypotheses with an $\alpha$ (probability of type 1 error) value as low as 0.01. That means there is a significance difference between the efficiency scores obtained through CRS and VRS models with input and output orientations.

12. Performance evaluation of 15 OC Mines using Advanced DEA models

Cross efficiency score of a DMU represents how well the unit is performing with respect to the optimal weights of another DMU. Table 5.19 helps to compare with all the units performance easily. There is lot of improvements in efficiency scores as well as in target production in Decreasing returns model than the Increasing Returns model (table 5.15 & 5.17). If super-efficiency is interpreted as input saving or output surplus achieved by a specific efficient DMU, infeasibility does not necessary mean the highest super-efficiency. From table 5.21 two mines OCM7 efficiency is 1500.97% and OCM efficiency is 964.02% achieved highest super-efficiency. In Additive model, we combine both input-oriented and output-oriented models in a single model.

The objective function of OCM2, OCM3, OCM4, OCM6, OCM7 and OCM11 efficient mines is 0 whereas other than 0 for in-efficient mines (table 5.22). These advanced models are helpful to improve productivity of mines by reducing inputs in different ways.


The usage of combinations of efficient DMUs is called virtual producers corresponding to the inefficient ones. The “shadow values”
and "peer group" are helpful in constructing the virtual producers. 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 and in output orientation measure indicates how much the existing output to be increased to improve the efficiency or productivity. The adjustments of slack variables assigned to inefficient coal mines for further improvement in the efficiency of coal mines.

The how much amount of inputs to reduced or output to be increased from actual values to target values of inefficient mines to become as efficient mines are analyzed and calculated. The results are clearly shown in tables 4.6, 4.9, 4.14, 5.5, 5.10, 5.16 and 5.18 and figs 4.3, 4.4, 4.5, 4.6, 4.9, 4.10, 4.11, 4.12, 4.15, 5.3, 5.4, 5.5, 5.6, 5.9, 5.11 and 5.13. There is a scope for improving the productivity from 10% to 100% to implement the DEA methodologies.

6.3 Research contribution

This performance analysis enables us to identify the benchmark, guide us to build the strategies and help us to set the targets for future. These advantages are of critical importance in this competitive globalized era. Traditional performance indicators for mining industry considers only labour component. Though it is meaningful indicators for mining industry (Since it is labour intensive), but it cannot give the idea about the overall performance. In doing so, a Coal Mines sets average performance of the group as its benchmark which is undesirable. DEA can overcome some of the major limitations of the existing technique as it sets best in the group as the benchmarking unit and suggest the slacks for each of the quality dimension for improvement. Since slacks are quantified, it helps the managers to try out methods, procedures and
techniques to achieve the optimal level of productivity. The applications of the methodology in mining sector are limited.

In this research considered 42 UG Mines and 15 OC Mines of Singareni Collieries Company Limited (SCCL) which is largest producer of coal in India after Coal India Limited (CIL). We have gathered the relevant data/information through exhaustive surveys, field visits, records and discussions with the experts in the diversified areas of the organization. In the first stage we have broadly classified the mines into two categories i.e. UG and OC mines with 4 inputs and 1 output. The relative efficiency calculated for a Coal Mines using DEA models which helps to rank them based on their efficiency score. The efficiency score, peer groups, shadow values, slacks, peer count and rankings have been calculated based on two scale of assumptions viz., Constant Return to Scale (CRS) and Variable Return to Scale (VRS) using both Input-oriented and output-oriented models. Finally, a comparison is made between the CRS and VRS Models. The results were discussed in 6.2 Summary.

We have been fixed as the ratio of weighted sum of perceptions to the weighted sum of expectations assuming that perception of o coal mines touches the expectation. The general Input-oriented and Output-oriented CRS model is used to obtain efficiency score. After that observed variation in inputs may not lead to the same level of variation in the output in all situations like CRS model. In order to overcome this problem an extension of CRS model, which is VRS model used for analysis and results compared with CRS model. The Correlation is calculated using the Spearman’s rank correlation coefficient between CRS and VRS models.

We have been evaluated performance of OC Mines using some advanced models like Increasing Returns to Scale (IRS), Decreasing Returns to Scale (DRS), Cross Efficiency (CE), Scale Efficiency (SE), Super Efficiency and Additive Models. This helps to improve the efficiency and productivity of mines in broadly in various methods. This provides the flexibility to managers
The inefficient coal mines can pursue continuous improvement strategies by adjusting the slack and target values. To address these issues, the objectives of this thesis focuses on finding out benchmarking coal mines, ranking of coal mines of SCCL based on their efficiency scores, and discuss improvement areas for inefficient Coal Mines. 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. These analyzed strategies have been proposed to SCCL for implementation.

6.4 Scope for Future Research

In this study, only the various cost items that are relevant for improving the productivity of coal mines have been considered. Other pertinent factors like production equipment like shovels, dumpers, reliability, safety, maintenance, labour productivity, incentives, unions, man efficiency, environmental conditions, quality of coal, lead time and planning etc. also affect the overall performance of the mines.

The basic DEA models always assume that inputs and outputs can be altered by the DMUs. In realistic situation there are often exogenous variables that cannot be altered. For example the distribution of competitors may influence efficiency scores without being alterable by the DMUs are called nondiscretionary variables. During the last ten years a lot of extensions to these four models have been developed that allow further fine tuning to the basic models.

Apart from the mentioned models (in 6.2) in this thesis there is significant scope for doing research in the areas of stochastic DEA, sensitivity analysis in DEA, window analysis in DEA, malmquist index, target
setting in DEA, more effective ways of weight restrictions in DEA is being carried. Some of the interesting extensions in this area can include the improvement of discriminatory power of non-constant returns to scale models, better methods for benchmarking, developing the robustness of cross-efficiency models, etc. Multi-output forms of stochastic production frontiers have been developed but remain highly complex.

It is strongly believed that the suggestions and recommendations made at the end of analysis of each model in chapter 4, chapter 5 and chapter 6 (summary, conclusions and research contribution) can identify enhance the productivity by reducing the various input costs of coal mines. The expected improvement in production also achieved by the implementation of the results obtained from various DEA models in this thesis.