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[1]A Data Envelopment Analysis Approach for Benchmarking of Safety Performance

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Abstract. The main purpose of the present study is to develop apposite construct to benchmark the safety performance in Indian industries. Data envelopment analysis (DEA), being a robust tool, has been employed to evaluate the performance of industries. DEA, basically, takes into account the input and output components of a decision making unit (DMU), to calculate technical efficiency (TE). TE is treated as an indicator for safety performance of DMUs and comparison has been made among them. Thirty Indian organizations under three industrial categories such as construction, refractory and steel are chosen for comparison purpose. It has been observed that safety performance of construction industries is consistently low as compared to other categories of industries. TE has been calculated using a models called constant return to scale (CRS) of DEA. Mean efficiency of thirty samples is found as 0.898 using CRS model.

Keyword: Safety performance; Benchmarking; Data envelopment analysis (DEA); Decision making unit (DMU); Constant return to scale (CRS)

1. Introduction

The problem of occupational safety, earlier exclusively the state's concern, has now become the shared responsibility of the owners of enterprises, government, and non-government organizations. Now, safety is treated as a vital element to develop or retain the goodwill in the market place. El-Mashaleh et al. (2009) have used DEA for benchmarking the safety performance in construction industries. Abbaspour et al. (2009) have applied DEA to assess the efficiency of environmental performance concerning health and safety of twelve oil and gas contractors. Lei and Ri-jia (2008) have made an efficiency assessment of coal mine safety using DEA and recommended the use of funds and management resources to improve efficiency. Fuller (1997) has attempted to benchmark health and safety management in intra- and inter-company of a large food manufacturer. Odeck (2006) have identified best practices for traffic safety with application of DEA. Zhou et al. (2008) have proposed energy and environmental (E&E) modelling to minimize environmental pollution using DEA. Tyteca (1996) has applied DEA to analyze environmental performance of various firms with respect to certain environmental characteristics. Feroz et al. (2001) have used DEA to test the economic consequences of the occupational health and safety administration caused due to cotton dust in fabric industries. In this work, an

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attempt has been made to analyse safety performance in three different industrial categories such as construction, refractory, and steel in India using data envelopment analysis. It address directly management's need for consistent benchmarking, target setting and designing focused on-site work environment in an attempt to identify and transfer best-practices. The construction sector is largely characterized by unorganized workforce and hardly follows standard regulations laid down by the government agencies whereas refractory and steel sectors have mixed organized and unorganized workforce. Both refractory and construction firms are usually small in size in terms of manpower and investment.

2. Methodology

2.1 Data envelopment analysis

The proposed methodology uses DEA for benchmarking of safety performance of Indian industrial organizations. DEA is linear programming based tool for measuring the relative efficiency of each unit in a set of comparable organizational units using theoretical optimal performance for each organization. In DEA, the organization under study is called a decision making unit. A DMU is regarded as the entity responsible for converting inputs (i.e. resource, money etc.) into outputs (i.e. sales, profits etc.). In this study, a DMU refers to one from three types of industries (construction, refractory, and steel industry). Usually, the investigated DMUs are characterized by a vector of multiple inputs converting to multiple outputs making it difficult to directly compare them.

In order to aggregate information about input and output quantities, DEA makes use of fractional programming problem (FPP) and corresponding Linear programming problem (LPP) together with their duals to measure the relative performance of DMUs (Charnes et al., 1978; Charnes et al., 1994; Cooper et al., 2000). The Charnes, Copper and Rhodes (CRR) model is a FPP model which measures the efficiency of DMUs by calculating the ratio of weighted sum of its outputs to the weighted sum of its inputs. The fractional programme is run for each DMU to subject to the condition that no DMU can have relative efficiency score greater than unity for that set of weights. Thus, the DEA model calculates a unique set of factor weights for each DMU. The set of weights has the characteristics that it maximizes the efficiency of the DMU is calculated.

The basic DEA model for 'n' DMUs with 'm' inputs and 's' outputs proposed by CCR, the relative efficiency score of P^{th} DMU is given by

$$MaxZ_p = \frac{\sum_{k=1}^{s} v_k y_{kp}}{\sum_{j=1}^{m} u_j x_{jp}} \quad (1)$$

$$s.t. \quad \frac{\sum_{k=1}^{s} v_k y_{ki}}{\sum_{j=1}^{m} u_j x_{ji}} \leq 1 \forall i \text{ and } v_k, u_j \geq 0 \forall k, j$$

where $k = 1$ to s (no. of outputs); $j = 1$ to m (no. of inputs); $i = 1$ to n (no. of DMUs); y_{ki} = amount of output k produced by DMU_i ; x_{ji} = amount of input j utilized by DMU_i ; v_k = weight given to output k and u_j = weight given to input j.

The fractional programme shown in equation (1) can be reduced to LPP as follows:

$$Max\ Z_p = \sum_{k=1}^{s} v_k y_{kp} \quad (2)$$

$$s.t. \quad \sum_{j=1}^{m} u_j x_{jp} = 1 \text{ and } \sum_{k=1}^{s} v_k y_{ki} - \sum_{j=1}^{m} u_j x_{ji} \leq 0 \forall i \text{ where } v_k, u_j \geq 0 \forall k, j$$

The model is called CCR output oriented maximization DEA model. The efficiency score of 'n' DMUs is obtained by running the above LPP 'n' times.

2.2 Input and output selection of DMUs

In order to identify DMUs, thirty Indian industrial organizations from three sectors where DMUs 1 to 10 represent construction, 11 to 20 belong to refractory and 21 to 30 refer steel industries of eastern region have been considered. The ranking of DMUs is made based on total score summed over perceptual score and factual score obtained from each DMU. The benchmarking of safety score considers four input and five output parameters. All the items are relevant for evaluating safety performance not only in Indian context but are quite generic to be adopted anywhere. The responses under each item are collected through field visits to thirty organizations. The input items selected in such a manner that expenses on various items may likely to improve the safety performance by the industries. Each item is expressed as a percentage of total revenues of the annual budget averaged over last five years. These expenses include expenses in health care (I_1), expenses in safety training (I_2), expenses in up-gradation of process related tools, instruments, machines, materials leading to safe and healthy environment (I_3), and expenses on safety equipment and tools (I_4).

The safety performance is measured by number of different categories of accidents occurring in a year. The occurrence of accidents is a random phenomenon and many a time difficult to assign any reasons. However, safety performance can be improved through commitment from management, change in work practices, investment on safety tools, change in equipment and machinery, improving attitude and safety perception of employees, and training. It is assumed that more than one type of accidents is unlikely to occur at the same time. As far as output is concerned, number of different types of accidents occurring per year in a DMU averaged over last five years is recoded. The different types of accident include accident that do not cause any disability and do not involve any lost work days (O_1), accident that do not cause any disability but involve lost work days (O_2), accident that cause temporary disability (O_3), accident that cause permanent partial disability (O_4) and accident that cause permanent full disability or fatality (O_5). The reciprocal of each output item is used in DEA because accidents are unfavorable for a DMU.

3. Results and discussion

The main objective of the present study is to develop a valid model for assessing safety performance of DMUs in different categories of Indian Industries using a model constant return to scale (CRS). A DMU is regarded as a benchmark unit when its objective function (technical efficiency) becomes unity. The general input oriented maximization CCR-DEA model is used to obtain efficiency score. Data Envelopment Analysis Programme (DEAP version 2.1) has been used to solve the model. The results thus obtained are summarized in Table I (CRS model). The first column of the table represents the selected DMUs arranged in a sequential manner. The second column specifies the efficiency score of the corresponding DMUs. Based on the efficiency score, the DMUs are ranked as shown in the third column. The fourth column shows the peers or the benchmarking units for the corresponding DMU.

The fifth column indicates the weight of each of the peers or the benchmarking unit. The last column shows the peer count of the DMUs. Ranking based on relative efficiency scores indicate that seven DMUs out of 30 DMUs have emerged as benchmarking units for the other 23 DMUs. The efficient or benchmarking units are listed as DMU_{12}, DMU_{16}, DMU_{17}, DMU_{22}, DMU_{25}, DMU_{29}, and DMU_{30} as shown in Table I. The efficiency score for these DMUs approach unity while that of DEA-inefficient DMUs show relative efficiency less than unity. The inefficient units can refer the DMUs listed in column 4 with corresponding peer weight given in column 5 for the improvement in safety performance. For example, DMU_1 having efficiency score of 0.877 can refer DMU_{16}, DMU_{12} and DMU_{25}. DMU_1 can assign a weightage of 0.341 to DMU_{16}, 0.277 to DMU_{12} and 0.382 to DMU_{25} to become a benchmark unit.

It is evident from column 4 that there are thirteen DMUs (DMU_1, DMU_2, DMU_4, DMU_9, DMU_{10}, DMU_{11}, DMU_{13}, DMU_{18}, DMU_{19}, DMU_{20}, DMU_{21}, DMU_{23}, and DMU_{24}) consult three benchmarking organizations. The Seven DMUs (DMU_3, DMU_6, DMU_7, DMU_8, DMU_{14}, DMU_{15}, and DMU_{28}) which can refer four different DEA-efficient units with varying degree of weightages. The Two DMUs (DMU_{26} and DMU_{27}) which can refer five different DEA efficient units with the corresponding weightages whereas it is interesting to note that DMU_6 is the only DMU that has six reference units (DMU_{17}, DMU_{12}, DMU_{29}, DMU_{22}, DMU_{16}, and DMU_{25}). It is further observed that DMU_{12}, DMU_{16}, DMU_{17}, DMU_{22}, DMU_{25}, and DMU_{29} have become peer units nineteen, twenty-three, nine, four, eighteen, and ten times respectively. It is to be noted that DMU_{16} is ranked as best first because it has efficiency score of one and more number of referring DMUs as far as safety performance is concerned whereas DMU_3 is ranked last one having efficiency score 0.694 denoted as most inefficient unit. It is important to note that not a single DMU from construction category has become efficient one. The overall efficiency score of thirty DMUs is found to be 0.898 meaning that there exists a large scope for improvement of safety performance in Indian industries. When mean efficiency scores of three industrial categories are compared, it reveals that construction sector (mean efficiency = 0.856) perform worst in regard to safety performance and refractory sector (mean efficiency = 0.921) is best in that respect. However, safety performance of steel sector (mean efficiency = 0.916) lies in between them. The difference in mean efficiency score of steel and refractory units is marginal. Therefore, steel units can approach refractory sector with least resistance whereas construction sector must work hard to improve their safety performance through a broad based policy.

When the averages of inputs and outputs between efficient (DMU_{16}) and inefficient (DMU_3) DMUs, are compared, it is observed that efficient DMU spends less than their inefficient counterpart on safety. Still the efficient DMU records less number of accidents compared to inefficient DMU. It means that inefficient DMU is not effectively converting its committed resources into lower number of accidents. Therefore, the inefficient DMU needs to examine its safety expenses properly and find cost minimization opportunity without impacting safety performance of the organization.

4. Conclusions

This paper attempts to provide a framework for assessing safety performance of three industrial sectors based on DEA approach. The methodology helps to identity benchmarking units in same or other sectors so that the best practices of peers can be implemented to become efficient one. It also quantifies how much efficiency score needs to be improved to reach at referring unit's score.

The genesis of the work is based on fact that safety performance can be improved through adequate allocation of annual budget of the firm in different safety activities. Therefore, the percentage of annual budget on various safety activities is considered as inputs to DEA model. The numbers of accidents of different nature occurring in a unit are treated as outputs of the model and signify the safety performance of a firm. DEA approach helps to identify the benchmarking organizations which can be referred by inefficient units to become efficient one. One approach of DEA known as CRS is considered to obtain efficiency of DMUs. Seven units out of thirty are found to be efficient in CRS model. Seven DMUs (DMU_{12}, DMU_{16}, DMU_{17}, DMU_{22}, DMU_{25}, DMU_{29}, and DMU_{30}) have become efficient units in CRS model based on their efficiency scores.

The efficiency scores obtained by CRS models are compared using one-sample t-test. It has been demonstrated that statistical significant difference exists on ranking of units in both models. Therefore, managers must be cautious regarding use of scale assumption. A thorough understanding of behavior of input and output variables is needed while assuming scale. Seven units have resulted as efficient in DEA-CRS model. They are three (DMU_{12}, DMU_{16} and DMU_{17}) from refractory and four (DMU_{22}, DMU_{25}, DMU_{29} and $DMU_{30)}$ from steel industries. It is to be noted that not a single unit from construction sector is eligible to be efficient one.

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DMUs	Efficiency	Ranking by DEA	Peers	Peer weights	Peer count
DMU_{15}	0.857	16	16	0.003	0
			17	0.674	
			12	0.027	
			25	0.281	
DMU_{16}	1.000	1	16	1.000	23
DMU_{17}	1.000	1	17	1.000	9
DMU_{18}	0.910	6	12	0.339	0
			25	0.255	
			16	0.406	
DMU_{19}	0.980	2	29	0.718	0
			16	0.032	
			25	0.132	
DMU_{20}	0.867	14	16	0.378	0
			12	0.265	
			25	0.357	
DMU_{21}	0.883	11	12	0.297	0
			25	0.296	
			16	0.410	
DMU_{22}	1.000	1	22	1.000	4
DMU_{23}	0.896	8	16	0.266	0
			25	0.432	
			12	0.301	
DMU_{24}	0.894	9	12	0.004	0
			22	0.469	
			16	0.293	
DMU_{25}	1.000	1	25	1.000	18
DMU_{26}	0.810	22	25	0.217	0
			29	0.406	
			16	0.260	
			22	0.172	
			12	0.062	
DMU_{27}	0.757	23	29	0.145	0
			16	0.092	
			25	0.749	
			17	0.002	
			12	0.140	
DMU_{28}	0.924	4	12	0.180	0
			17	0.064	
			16	0.377	
			29	0.218	
DMU_{29}	1.000	1	29	1.000	10
DMU_{30}	1.000	1	30	1.000	0

Overall mean efficiency (DMU_1 to DMU_{30}) = 0.898 Mean efficiency (DMU_1 to DMU_{10}) = 0.856
Mean efficiency (DMU_{11} to DMU_{20}) = 0.921 Mean efficiency (DMU_{21} to DMU_{30}) = 0.916

TABLE I. Results of DEA (CRS model)

DMUs	Efficiency	Ranking by DEA	Peers	Peer weights	Peer count
DMU_1	0.877	12	16	0.341	0
			12	0.277	
			25	0.382	
DMU_2	0.876	13	25	0.117	0
			16	0.103	
			17	0.871	
DMU_3	0.694	24	25	0.092	0
			16	0.239	
			22	0.444	
			29	0.007	
DMU_4	0.861	15	12	0.247	0
			25	0.443	
			16	0.310	
MU_5	0.918	5	17	0.073	0
			12	0.321	
			29	0.326	
			22	0.086	
			16	0.176	
			25	0.135	
DMU_6	0.840	19	17	0.059	0
			12	0.153	
			25	0.477	
			16	0.311	
DMU_7	0.834	20	16	0.178	0
			29	0.098	
			25	0.729	
			12	0.082	
DMU_8	0.940	3	17	0.197	0
			29	0.106	
			12	0.158	
			16	0.382	
DMU_9	0.893	10	12	0.307	0
			25	0.320	
			16	0.373	
DMU_{10}	0.832	21	16	0.028	0
			25	0.221	
			17	0.738	
DMU_{11}	0.844	18	12	0.462	0
			29	0.004	
			16	0.537	

DMU_{12}	1.000	1	12	1.000	19
DMU_{13}	0.847	17	16	0.707	0
			29	0.387	
			12	0.099	
DMU_{14}	0.907	7	25	0.459	0
			12	0.311	
			17	0.003	
			16	0.227	