Journal of Offshore Structure and Technology
ISSN: 2349-8986 (online)
Volume 1, Issue 3
www.stmjournals.com

Use of Data Envelopment Analysis to Measure the Technical Efficiencies of Oil Refineries in India

Kartikey Pandey, Suchismita Satapathy*
Department of Mechanical Engineering, KIITs University, Bhubaneswar, Orissa, India

Abstract
This paper is an attempt to implement the Data Envelopment Analysis (DEA) approach to measure the relative efficiency of a sample of oil refineries in India over a period of two years, 2012, 2013. We demonstrate that DEA is an effective tool for the Ministry of Petroleum (MOP) for monitoring and controlling the performance of oil refineries, which are growing as an important sector in India. We followed a case study methodology where data about the inputs and outputs of refineries are gathered and analyzed to compute the relative efficiency of the refineries. Based on the results obtained, 91.66 of the refineries were efficient in 2011, and the same percentage was efficient in 2012. The overall efficiency of the refineries studied was about 98 and 98.9%, respectively. Later, inefficient refineries were investigated closely to identify the areas in which the use of resources manifest decreasing returns to scale. We concluded the paper with some recommendations on the applicability of the DEA for oil refinery efficiency evaluation. Due to the absence of research work, in this discipline, in the oil sector in India, this study will add to our knowledge on how oil refineries in India may apply DEA to measure their efficiency, and how they might use the results to overcome efficiency problems. Although the results of the present paper are limited to the oil refineries studied; the DEA approach could trigger the attention of policy makers in the MOP to apply DEA to improve the efficiency of other DMUs. In addition, other manufacturing and service sectors in India could also benefit from this approach.

Keywords: *Data envelopment analysis, technical efficiency, oil refineries, oil refinery performance*

****Author for Correspondence*** E-mail: suchismitasatapathy9@gmail.com

INTRODUCTION

In 2012, India was the world's 4th largest oil consumer, and had the nineteenth largest proven oil reserves but only a small portion of India's known fields are in the development process. The country may be one of the few places in the world where great reserves (proven and unknown) have slightly been exploited. The energy sector in India is heavily dependent upon oil. Revenues from crude oil accounted for over 1/3 of the GDP in 2009. Indian refineries are somewhat eroded infrastructure, and run at utilization rates of 50% or more. Regardless of several attempts to improve the refineries in recent years, the sector has not been able to meet domestic demand of about 3,292,000 b/d because of sabotage, deferred maintenance, and unreliable electric power supplies, refinery operations are insufficient for domestic needs [1]. The refineries produce, mainly, heavy fuel oil and some other needed refined products. Therefore, at this time, analyzing the performance of national oil refineries is important for many reasons. Firstly, oil refineries are national and dominate the proven oil reserves. Secondly, oil refineries are expected to supply, at least, the domestic needs for different fuel types. Thirdly, the oil sector dominates the economy and is considered the major source of economic development and GDP.

In fact oil refineries seek to create value by virtue of their national mission, and the shareholder is the government which tries to maximize the social welfare. Oil refineries can create value by various links in the oil industry value chain. This chain starts from the oil fields and moves through: production, processing, transportation, and market. The oil fields are the gift of nature; however, the production stage is the important link that is related to field recovery factors and production costs. The production link of the refinery is a function of its technical efficiencies.

So far, we are not aware of any previous research on measuring the efficiency and productivity of oil refineries in India via the DEA approach. Therefore, much work is needed to measure the relative efficiency of oil refineries to identify areas of inefficiencies. This shall help in improving the use oil refinery resources, and reduce the dependence on fuel types imported from abroad to satisfy domestic needs.

The present study is important for three reasons:

i. It increases our knowledge and understanding about measuring the technical efficiency of oil refineries.
ii. In India, it coincides with and supports the MOP's efforts to improve the performance of oil refineries.
iii. It is the first study of this type in this domain. The results of this study are expected to provide policy makers at the MOP with some helpful insights in developing national strategies directed towards improving the efficiency of national oil refineries in India.

OIL INDUSTRY IN INDIA: A CONCISE BACKGROUND

India is the fifth largest energy consumer in the world. The Indian Oil and Gas industry plays an important role in the Indian economy with major refineries and gas companies in the country.

The Indian Oil and Gas sector is primarily controlled by state owned Oil and Natural Gas Corporation (ONGC) which accounts for approx. 60% of India’s crude oil output. The industry consumption was around 3.57 mn barrels per day (b/d) in 2012 compared to around 3.27 mn b/d in 2011 and is expected to reach 4.20 mn b/d by 2017. The refinery industry has approximately 21 refineries with total oil refinery capacity being around 3.6 mn b/d which is expected to reach 4.29 mn b/d by 2016. The significance of the Indian Oil and Gas Sector can be gauged from the following facts:

- It is the largest contributor to the national exchequer in 2011-12 with taxes amounting to US $27 billion.
- Oil and Gas constituted 47% of primary energy source in 2010.
- India is sixth largest crude oil consumer in the world with consumption at 138.3 MMT in 2010.
- Petroleum, Oil Lubricants (PoL) imports is 28% (Source: PwC Analysis) of the total imports of India and PoL exports is 8% of total exports.
- All five Indian companies appearing on the Fortune 500 list operate in the Oil and Gas sector.
- India is Ninth largest crude oil importer in the world.
- India ranks sixth in refining capacity in the world with capacity at 2.5 million barrels of oil per day which is 3% of the world’s refining capacity.
- Reliance Industries Ltd (RIL) in India is the largest refinery in the world.

DEMAND AND SUPPLY OVERVIEW OF CRUDE OIL AND NATURAL GAS

India met 75% of its crude oil demand through imports. The domestic production of crude oil has been in the range of 32-34 MMT over the past few years. About 60% of its crude imports are from the Middle East.

SEGMENTAL OVERVIEWS

Upstream Segment

India has 26 sedimentary basins with an area of 3.14 million square km and prognosticated reserves of 28 billion tons of oil equivalent of gas. The country is relatively unexplored with only 18% of area extensively explored (Source: DGH). Only 25% of the prognosticated reserves have been established till date.

Post 2000, India witnessed some world class discoveries. RIL struck gas in the offshore Krishna Godavari (KG) Basin on the East coast of India with estimated reserves of 14 tcf in 2002 (world’s biggest gas discovery of 2002) and Cairn Energy Plc. discovered oil onshore in Rajasthan (Western region of India) in 2004 with estimated production capability of 100,000 barrels per day (4.9 MMTPA).

Other major players of this segment are RIL, British Gas, Cairn Energy and Niko Resources. Under the five periodic rounds of awards of upstream blocks under New Exploration Licensing Policy (NELP), launched in 1999, private and foreign companies along with the NOCs committed about US $5 billion for exploration in more than 100 Production Sharing Contracts (PSCs). The periodic rounds of awards are continuing and the exploration investments are projected to rise considerably.

Refining and Marketing Segment
In the last five years, the downstream sector has witnessed additions in the refining capacities and the trend is expected to continue with some new major capacities also getting off the ground. It is expected that by 2007, the refining capacity of the country would increase from 127.4 MMTPA (Million metric tons per annum) to 141.7 MMT (Source: Midterm year Review of Tenth Five Year Plan). India is net exporter of petroleum products. The production of petroleum products for 2004-05 was 118.23 MMT with consumption being 111.56 MMT (Source: Midterm year Review of Tenth Five Year Plan). Prior to 2002, the Government of India (GoI) administered pricing of transport and domestic fuels under the Administered Pricing Mechanism(APM). The APM regime was dismantled in 2002 as a step towards free market pricing. Currently, the Government attempts to distribute equitably the severe burden of oil price hike amongst various stakeholders, i.e., oil marketing companies, Government and consumers. The Government periodically reviews movements in global crude oil and product prices and advises the Government owned oil marketing companies (OMCs) on retail price determination. In March 2002, the Government granted transport fuel marketing rights to private and foreign players and thereby allowed retail stations to be opened up by other than existing PSU OMCs. The new entrants were NRL, MRPL, ONGC, Assar Oil, RIL and Shell, of which the former five have commenced retail operations.

DEA: A THEORETICAL BACKGROUND

Data Envelopment Analysis (DEA) is an approach to measure the relative efficiency of Decision Making Units (DMU's) [2]. DMU's could be organizations, divisions, or units that use similar inputs and produce similar outputs. DEA is defined as a linear programming technique which identifies the best practice among a sample of units, and measures efficiency based on the difference between best practice and the observed units [3]. Best practice could be identified at the organizational, national, and international levels. In essence, DEA attempts to measure the technical efficiency (TE). The latter is expressed as the potential to increase quantities of outputs from given quantities of inputs. This approach was first proposed by Charnes *et al.* (1978) [4], and later extended by Banker, Charnes, and Cooper (1984) [5].

The work of Charnes *et al.* is actually based on Farrell's input and output method to measure efficiency. Farrell's work entitled "The Measurement of Productive Efficiency" was introduced in 1957 in the Journal of Royal Statistical Society [6]. Farrell's TE considers multiple inputs and outputs simultaneously to measure the efficiency of organizations using one input to produce one output, or uses one input to produce two outputs, or uses two inputs to produce one output. Farrell's technique plots an efficiency frontier or a group of best performers. The efficiency frontier is the curve plotting the minimum amount of an input (or combination of inputs) required to produce a given quantity of output (or combination of outputs). The best performers are plotted on the efficient frontier to indicate that they use their resources more efficiently, than others, to create outputs.

Table 1: *Data for Single Input-Output.*

Stores	A	B	C	D	E	F	G	H
Workers	2	3	3	4	5	5	6	8
Sales	1	3	2	3	4	2	3	5
Sales/Workers	0.5	1	0.67	075	0.8	0.4	0.5	0.625

Source: *Ghosh, 2008*

To explain some of the concepts brought by Farrell, we consider Table 1 which represents the sales (output) of eight stores generated by workers or salespersons (input). The last row of Table 1 is the ratio of sales/workers which is referred to as efficiency and is computed by the following equation:

Efficiency = output(s)/input(s) (1)

It appears that store B, a DMU, is the most efficient one, while store F is the least efficient DMU. By plotting the data provided by Table 1, we obtain Figure 1.

From this figure, the line OO' which passes through B represents the efficiency frontier. All the points below OO' are said to be inefficient. Hence, OO' contains or "envelopes" the rest of the points on Figure 1.

Using the least squares method [7], it is possible to derive the regression line for the data presented by Table 1:

$y = 0.67x$ (2)

Where y is sales, and x is the number of workers. By plotting this line on Figure 1, we obtain Figure 2.

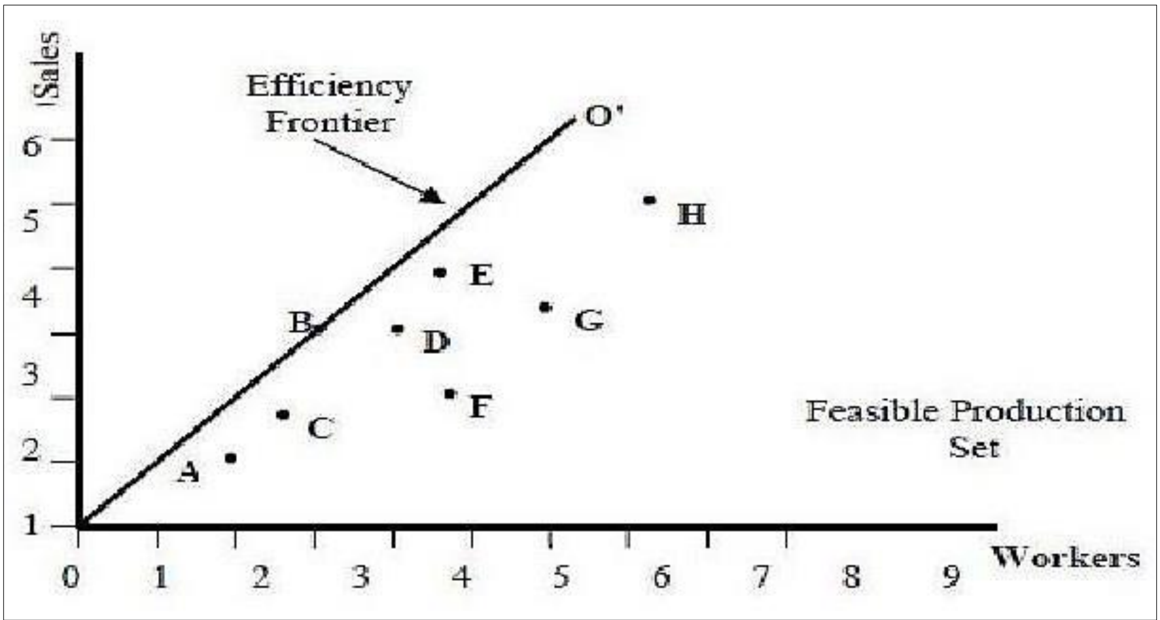

Fig. 1: *Efficiency Frontier and Feasible Production Set.*

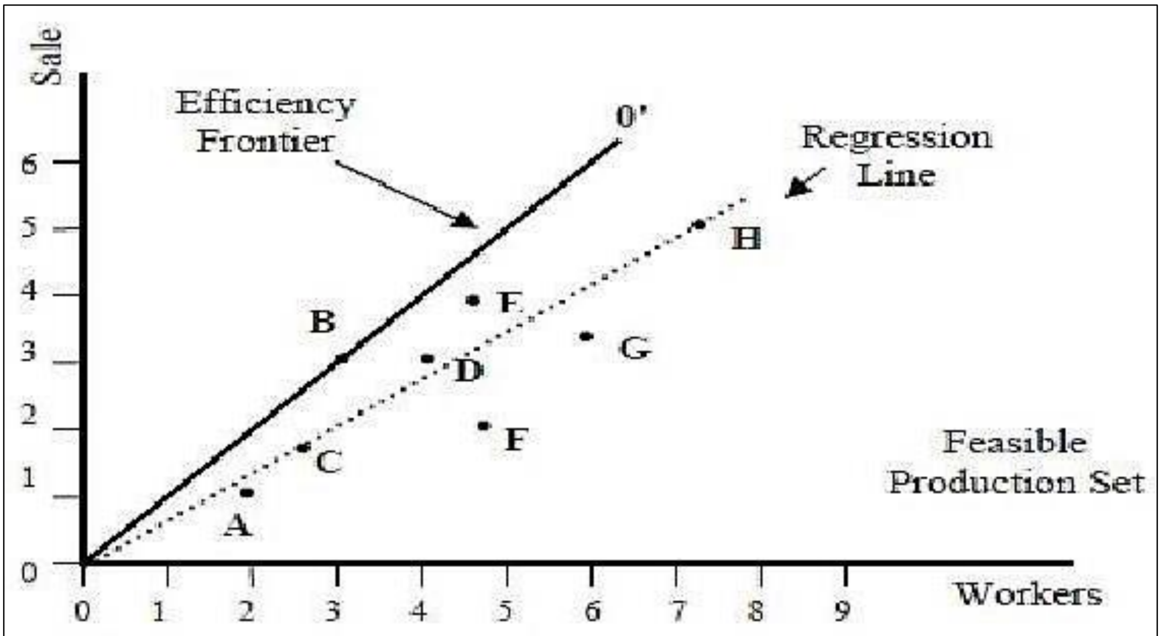

Fig. 2: *Regression Line and Efficiency Frontier.*

From the last figure, we notice that the regression line passes in the middle of the data. The points below the regression line refer to inferior performance, while those above the regression line are considered to have excellent performance. It is evident from Figure 2 that the regression analysis does not identify the best practice or the benchmark for performance. This explains why organizations prefer DEA over regression analysis in measuring performance [8]. Farrell, also, proposed the Input-Oriented Measure of TE manifested in Figure 3. Here, a company uses two inputsX1, X2 to produce one output Q. If the company produces along QQ′, then it is technically efficient. However, if the company uses a level of input that corresponds to D to produce one unit of Q, then the company is said to be inefficient. The level of inefficiency is measured by the distance CD. This distance represents the amount by which the inputs must be reduced to achieve technical efficiency without reducing inputs. Meanwhile, CD/OD represents the ratio by which the inputs must be reduced to reach technical efficiency. In other words TE = 1–CD/OD, thus that is somewhere between 0 and 1. Assuming the X1 X2 prices are fixed, then the distributed efficiency is represented byte ratio of OB/OC, and the distance BC is the amount by which the costs of inputs must be reduced to produce at p′.

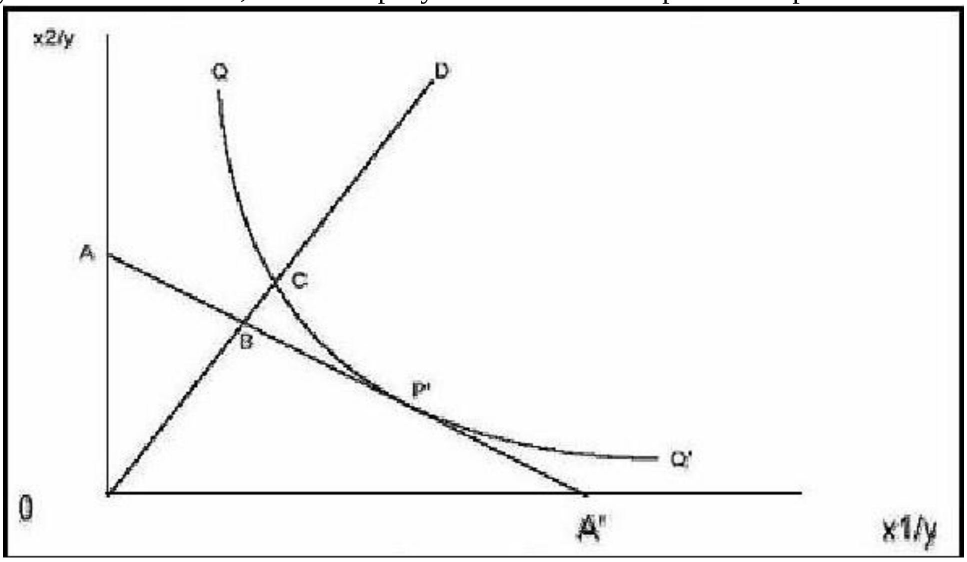

Fig. 3: *Input-oriented Technical Efficiency*.

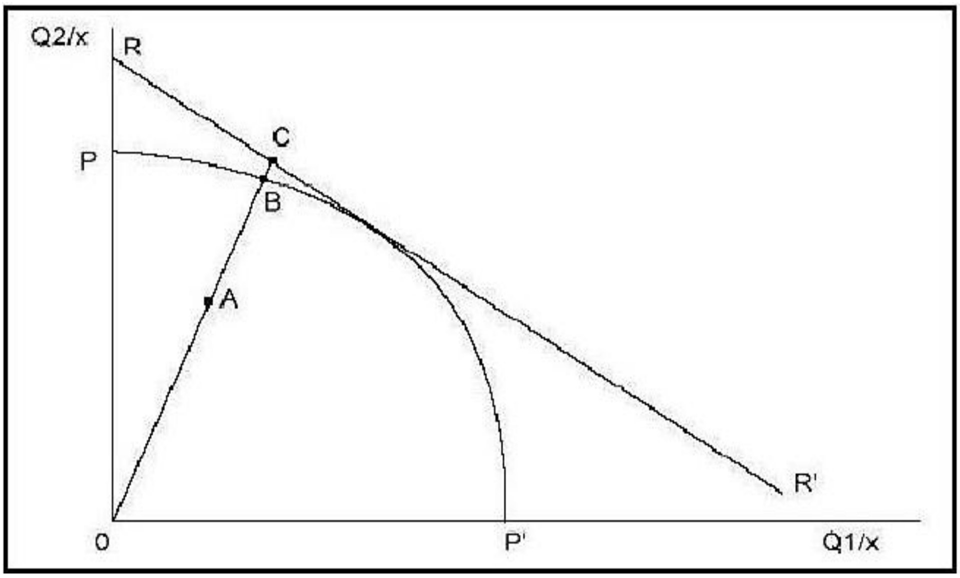

Fig. 4: *Output-oriented Technical Efficiency. (Source: Ghosh, 2008, 52 p).*

Furthermore, Figure 4 provides a schematic representation of Farrell's Output-Oriented Measure of Technical Efficiency where a company uses one input X1 to produce two outputs Q1, Q2. In this figure, pp' represents the production frontiers. All the points that lie on pp' (such as B) are technically efficient, while all the points that fall below pp' are technically inefficient, such as A. The distance AB is the measure of technical inefficiency, or the amount by which outputs may be increased without increasing inputs. The ratio OB/OC is the measure of distributed efficiency, or the ratio by which returns may be increased without affecting the inputs. From the above discussion it's evident that the Farrell's method is limited by the number of inputs/outputs.

To overcome the limitation of the Farrell's work, Charnes, Cooper, and Rhode [4] introduced their CCR DEA model that can handle multiple inputs and multiple outputs to measure TE. In the presence of multiple input and output factors, technical efficiency are defined as follows:

$$Technical\ Efficiency = \frac{weighted\ sum\ of\ outputs}{weighteed\ sum\ of\ inputs}$$

Assuming that there are *n* DMUs, each one has *m* inputs and *s* outputs, and then technical efficiency of the *p's* DMU is given by the following model proposed by Charnes *et al.* (1978) [4]:

$$\max \quad \frac{\sum_{k=1}^{s} vk\ ykp}{\sum_{j=1}^{m} uj\ xji}$$

$$st. \quad \frac{\sum_{k=1}^{s} vk\ ykp}{\sum_{j=`1}^{m} uj\ yji} \le 1 \quad \forall i$$

$$vk, uj \ge 0\ \forall k, j$$

Where, $k = 1$ to s, $j = 1$ to m, $i = 1$ to n, yki = amount of output k produced by DMU i, xji = amount of input j used by DMU i, vk = weight assigned to output k, uj = weight assigned to input j. Because of the difficulty of solving fractional linear programs, Charnes *et al.* converted the above model into a more simplified model which is expressed below [9].

$$\max \sum_{k=1}^{s} vk\ ykp$$

$$st. \quad \sum_{j=1}^{m} uj\ xjp = 1$$

$$\sum_{k=1}^{s} vk\ yki - \sum_{j=1}^{m} uj\ xji \quad \le 0 \quad \forall\ i$$

$$vk, uj\ \ge 0 \quad \forall\ k, j$$

The previous model is executed *n* times to identify the relative efficiency scores of all DMUs involved in the evaluation. Inputs and outputs that maximize the efficiency of each DMU are selected for each DMU. The DMU is considered efficient if it obtains a score of 1, otherwise the DMU is inefficient [10]. In order to identify benchmarks for the inefficient DMUs, DEA provides a set corresponding efficient units that may be used as benchmarks to improve the inefficient DMUs. The solution of the following dual form of the above linear model provides the possible benchmarks for the inefficient units.

$$\min \theta$$

$$st \sum_{i=1}^{n} \lambda i\ xij \ - \ \theta xjp \ \le 0 \quad \forall j$$

$$\sum_{i=1}^{n} \lambda i yki - ykp \ \ge 0 \qquad \forall k$$

$$\lambda i\ \ge 0 \quad \forall i$$

$Where$

$\theta = Efficiency\ Scores$

$\lambda s = Dual\ Variables$

Model (4) and its dual form are known to be DEA models with constant returns to scale (CSR). CSR indicates that doubling the inputs of a DMU will result in doubling the outputs, too [3]. In other words, there are no economies or diseconomies of scale, and that the size of the organization is not considered appropriate for measuring efficiency. To overcome this limitation of the DEA CCR model, Banker, Charnes, and Cooper extended the Remodel to handle problems with variable returns to scale (VRS). The new model, BCC, referred to by the initials of the authors, is capable of dealing with problems that exhibit decreasing, constant, and increasing returns to scale [5]. According to Ghosh (2008), DEA has the following characteristics [8]:

i. It is a nonparametric optimization method that determines production frontiers.
ii. It is a linear programming method that constructs frontiers to calculate efficiency relative to peers, and then decides which peer can be set as benchmark for other DMUs.
iii. It is a generalization of the Farrell's single-input single-output technical efficiency to multiple-input multiple-output through constructing a virtual single output to virtual single input ratio.
iv. DEA considers multiple factors and does not necessitate parametric assumptions of traditional multivariate methods.
v. Inputs and outputs may assume different units.

Furthermore, the following are some limitations of the DEA [10, 11]:

i. Since DEA is a deterministic model (and descriptive in nature) it therefore provides results that are sensitive to input measurements errors.
ii. DEA attempts to measure the efficiency of a particular sample relative to best practice. Hence, it is not useful to compare the scores between two different studies.
iii. DEA results are sensitive to output and input specification, and the size of the sample. Large sample size tends to produce lower average efficiency scores. While including few DMUs relative to the number of inputs and outputs will tend to inflate the efficiency scores.
iv. Since DEA is a nonparametric approach, therefore statistical tests are not applicable.

Despite these limitations, DEA has received an increasing importance during the last two decades, and it has been used as a tool for evaluating and improving the performance of different organizations (manufacturing and service). According to Charnes *et al.* (1994) [12], DEA is extensively applied in performance evaluation and benchmarking in hospitals, bank branches, libraries, production plants, etc. In addition, Tavaresx (2002) developed a DEA database which included 3,203 references, 2,152 authors and 1,242 keywords. The references are distributed over seven publication types.

LITERATURE REVIEW

In a world of global competition, success is dependent on the proper use of inputs to generate outputs. Financial and operational problems could result from failure to optimize the efficient use of resources. Hence, researchers exerted great efforts to develop approaches that help businesses to improve the use of resources. The DEA was one of the most popular approaches proposed to improve the efficient use of resources. Since its introduction by Charnes, Cooper, and Rhode, the DEA approach has attracted the attention of academicians and practitioners all over the world. It has also seen a wide variety of applications to evaluate the performance of various types of DMUs engaged in different activities in different environmental contexts, and in different countries [13]. The DEA applications were evident in service and manufacturing sectors.

Odeck and Alkadi (2001) attempted to evaluate the performance of Norwegian bus companies subsidized by the government [14]. The authors used the DEA approach to measure efficiency in this sector. Several issues were addressed in this context, such as: efficiency rankings, distribution and scale properties in the bus industry, potentials for efficiency improvements in the sector, the impact of ownership, etc. The findings of this study show that the average bus company exhibits increasing return to scale in production of its services.

The implications of DEA results are discussed and concluding remarks offered. Banker *et al.* (2002) attempted to measure the productivity of Acer to determine whether the introduction of information technology at the firm in 1998 had some impact on the company's performance. Based on different efficiency ratings, the authors concluded that the introduction of information technology resulted in productivity increases in 1997-1999 [15]. The findings of the study assisted the applicability of the DEA approach to measure the productivity of the firm at different points in time. Mahadevan (2002) sought to explain the productivity growth performance in the manufacturing sector in Malaysia using a panel of data of 28 industries from 1981-1996 [16].

The author applied the DEA approach to compute and to decompose the Malmquist index of total factor productivity (TFP) growth into technical change, change in technical efficiency and change in scale efficiency. The rationale behind this decomposition was to identify the sources that were crucial for policy formulation. The study revealed that the annual TFP growth of the Malaysian manufacturing sector was low at 0.8% and this was due to small gains in both technical change and technical efficiency, with industries operating close to optimum scale. Wang (2006) believes that no one performance measurement tool can provide a composite picture about the performance of a firm, therefore he proposed the use of DEA and the Balanced Scorecard (BSC) approaches to determine whether these two approaches are appropriate to Acer firm with information about the firm's performance between 2001-2003 [17].

The author reports that the two approaches provided illuminating information about Acer's performance, and that other firms could benefit from both approaches. Oliveira *etal.* (2007) mention that the last two decades were characterized by high oil prices, thus many countries in the world were vulnerable to this phenomenon [18]. On the other side, the production of oil and gas sponsored the industrialization of many countries worldwide including South America countries. The authors analyzed the performance of some South America countries using the DEA to measure the efficiency regarding the usage and dependency on production, consumption, and proved resources of oil and gas.

The authors claim that their study could be extended to evaluate other countries around the world. Zhou *et al.* (2008) argues that DEA has gained an immense popularity in the energy and environmental sectors in recent years [19]. Thus, the authors presented a literature survey on the application of DEA to the energy and environmental studies. The most popular DEA techniques were introduced first, and then followed by a classification of 100 publications in this field.

The authors concluded that DEA is gaining more popularity in the energy and environmental studies, and that there is a lack in literature review in this field. They also believe that the classification of DEA studies reached in their study is useful to researchers entering this exciting field. Motivated by the rise of energy prices in the transportation sector, Malhotra *et al.* (2008) applied the DEA approach to analyze the performance of seven North American Class I freight railroads. The authors analyzed the financial ratios of a firm as opposed to its peers [20].

The DEA brought out the firms that were operating more efficiently compared to other firms in the industry. The study pointed out the areas where poor performing firms need to improve. Mekaroonreung and Johnson (2009) used DEA as a method for evaluating the technical efficiency of 113 U.S. oil refineries in 2006 and 2007 [21]. The authors implemented several measures based on the DEA approach; these measures were compared to study the impact of disposability assumptions. The authors demonstrated that oil companies can improve efficiencies regardless of the assumption of disposability of bad outputs. Sepehrdoust (2011) applied the DEA to evaluate the housing industry performance in many states, in Iran, based on the data collected from the Statistical Center of Iran from 2006-2009 [22]. The author reported that only 37% of the states studied operated efficiently and the average efficiency score obtained by all states was around 94%.

The author proposed some measures that could be applied by the government to stimulate the efficiency of the housing sector in Iran. Ines and Martinez (2011) used the DEA to measure energy efficiency development in the non-energy-intensive sectors (NEISs) in Germany and Colombia through a production-bases theoretical framework using data from 1998-2005 [23]. The authors compared energy efficiency performances at two levels of aggregation and then applied different alternative models. The results indicated considerable variations in energy efficiency performance in the NEISs of the two countries studied. Ajalli *etal.* (2011) investigated the problem of separability in DEA where the number of DMUs is lower compared to the number of input and output [24]. The authors evaluated 23 provincial gas companies considering the higher output rates of each provincial gas company. To achieve the objectives of the study, an integrative model was developed using the Anderson-Peterson Method along with DEA. The results contributed to the increased power of evaluation, separability, and adequate ranking of the companies studied.

The above review is no way exhaustive about the widespread use of DEA, however, it demonstrates the applicability of this approach to a multiplicity of sectors. The benefits obtained from this approach shall continue to trigger interests among researcher to pursue more developments and applications of the DEA.

RESEARCH PROBLEM AND OBJECTIVES

The literature review provides DEA applications in different business sectors and in different countries. However, we did not encounter any study that measures and documents the performance of oil refineries in India. Currently, the Economic Division of the Ministry of Petroleum evaluates the refinery company performance based on the performance of the following units within each company: Legal, Managerial, Contractual, Auditing, and Financial.

The evaluation is done using a form that contains several questions which are supposed to be answered by the functional directors at the end of the year. By reviewing the annual evaluation reports of the refineries, we observed that neither the criteria nor the weights used to measure the refinery's performance are uniform. Hence, it is not possible know precisely which refineries are using their resources more efficiently than the others, nor does the present method assists the MOP to analyze the inefficiency problems within each refinery. The research problem lies in the absence of a formal approach to measure the technical efficiency of oil refineries at the MOP. The authors believe that this work is worthwhile, and shall shed the light on this area.

The findings of this paper provide a clear indication of the refineries which are using their resources efficiently. This information can be applied by the MOP to augment decision making with information regarding best practices for the oil refineries. The present study is significant at this time because it coincides with the reconstruction efforts of the MOP to enhance the oil industry in India.

The present research attempts to achieve the following objectives:

i. Developing and applying a DEA model to measure the TE of a sample of oil refineries (DMUs) in India.
ii. Comparing the TE of the studied refineries to identify the refinery (ies) that could be used as a benchmark.
iii. Identifying and explaining the reasons that impede the refineries from reaching efficiency frontiers.
iv. Computing the quantities by which inputs should be reduced so that inefficient refineries can attain the efficient production frontiers of the oil industry in India.

RESEARCH METHODOLOGY

In this work a case study approach was followed to compute and analyze the technical efficiency of the refineries studied. The case study approach was also used by Oliveira *et al.*, Ajalli *et al.*, Mekaroonreung and Johnson and Ines and Martinez to measure the TE in the energy industry. The sample of the refineries studied consists of 12 refineries. To measure the TE of the sample studied, the authors followed the following steps [18, 21, 23, 24]:

- Sample Selection: twelve refineries were selected for this study.
- Data Collection: for the purposes of this study, four inputs {crude oil Throughput (TMT), workforce (workers), electricity (Kw/h) and land (hectares) }, and four outputs {naphtha (TMT) , Superior Kerosene Oil (TMT), High Speed Diesel

(TMT) and Aviation Turbine Fuel (TMT)} were identified and fed into the DEA model. Tables 2 and 3 present the input/output data for all the refineries involved in this study during 2011, 2012 respectively.

- Model Selection: the DEA VRS with Variable returns to scale model developed by Charnes and Cooper (1978) and presented by (4) is used to measure the TE of the refineries [3].

Several software packages are available to solve the DEA model such as DEA windows, Frontier Analyst, DE Frontier, DEAP V2.1 etc. In this study, we used DEAP V2.1 to perform the calculations.

DEA APPLICATION

Using the DEA VRS model with variable returns to scale and the input- output data presented in Tables 2 and 3, a DEA model was developed to calculate the TE for each refinery during 2012 and 2013.

The algorithm for writing the program in DEAP V2.1 is as follows:

eg1-dta stores the data to be computed.

eg1-ins stores the algorithm or the instructions to be performed on the data expressed in Eg1-dta.

The algorithm for this problem is as follows:

$eg1-dta.txt \quad DATA FILE\ NAME$

$eg1-out.txt \quad OUTPUT\ FILE\ NAME$

$12 \quad NUMBER OF\ FIRMS$

$1 \quad NUMBER OF\ TIME\ PERIODS$

$4 \quad NUMBER OF\ OUTPUTS$

$4 \quad NUMBER OF\ INPUTS$

$0 \quad 0 = INPUT\ AND$

$1 = OUTPUT\ ORIENTATED$

$1 \quad 0 = CRS\ AND 1 = VRS$

$0 \quad 0 = DEA(MULTI-STAGE),$

$1 = COST-DEA,$

$2 = MALMQUIST-DEA,$

$3 = DEA(1-STAGE),$

$4 = DEA(2-STAGE)$

This algorithm is run in Deap.exe and the command eg1-ins.txt is written in the command window.

Table 2: *Inputs and Outputs for 2012.*

Refinery	**Output**				**Input**			
	LPG (TMT)	**Naphtha (TMT)**	**Aviation Turbine Fuel (TMT)**	**High Speed Diesel (TMT)**	**Crude Throughput (TMT)**	**Workforce (Workers)**	**Electricity KW/h**	**Land (Hectares)**
IOC, Koyali	489	785	393	6020	13155	4321	77199296	855
IOC, Haldia	218	545	345	2694	7490	304	7086	1110
IOC, Mathura	305	636	597	3156	8561	575	5451	323
BPCL, Mumbai	452	1586	742	5354	13077	256	2300	600
BPCL, Kochi	471	675	423	4600	10105	2899	105346000	2000
HPCL, Mumbai	435	409	537	2211	7748	2995	69830000	1350
HPCL, Vishakhapatnam	383	251	66	3116	8028	241	2250	80
RPL, Jamnagar	753	5662	2118	10448	32613	3981	3600000	423
RPL,SEZ	938	1631	1243	16604	35892	4000	221592	128
EOL, Vadinar	821	837	10	9020	19769	290	4590	8000
MRPL, Mangalore	281	1482	1458	5573	14415	571	888	4000
NRL, Numaligarh	48	108	61	1648	2478	4638	400	600

Table 3: *Inputs and Outputs for 2013.*

Refinery	Output				Input			
	LPG (TMT)	Naphtha (TMT)	Aviation Turbine Fuel (TMT)	High Speed Diesel (TMT)	Crude Throughput (TMT)	Workforce (Workers)	Electricity KW/h	Land (Hectares)
IOC, Koyali	410	712	391	5911	12197	4301	77192123	855
IOC, Haldia	195	515	301	2056	7067	291	7032	1110
IOC, Mathura	297	623	523	3700	8913	509	5443	323
BPCL, Mumbai	452	1623	792	5110	12957	223	2365	600
BPCL, Kochi	503	679	401	4673	10121	2741	1053234	2000
HPCL, Mumbai	450	423	521	2210	7714	2981	69830000	1350
HPCL, Vishakhapatnam	375	257	58	3118	8012	197	2212	80
RPL, Jamnagar	741	6321	2298	10423	32641	3932	3600432	423
RPL,SEZ	938	1681	1275	16612	35212	4512	221231	128
EOL, Vadinar	800	890	4	9001	19123	221	4521	8000
MRPL, Mangalore	197	1431	1459	5572	14134	531	823	4000
NRL, Numaligarh	19	99	50	1638	2432	4321	434	600

RESULTS

Table 4: *Refineries According to their TE.*

DMU	2011	2012
IOC, Koyali	1	1
IOC, Haldia	.763	.862
IOC, Mathura	1	1
BPCL, Mumbai	1	1
BPCL, Kochi	1	1
HPCL, Mumbai	1	1
HPCL, Vishakhapatnam	1	1
RPL, Jamnagar	1	1
RPL,SEZ	1	1
EOL, Vadinar	1	1
MRPL, Mangalore	1	1
NRL, Numaligarh	1	1

Detailed Report 2011 Sample Deap Output

Results from DEAP Version 2.1
Instruction file = EG1-ins.txt
Data file = eg1-dta.txt
Input orientated DEA
Scale assumption: VRS

Slacks calculated using multi-stage method

Efficiency Summary

Firm	Crste	Vrste	Scale
1	1.000	1.000	1.000 -
2	0.763	1.000	0.763 irs
3	1.000	1.000	1.000 -
4	1.000	1.000	1.000 -
5	1.000	1.000	1.000 -
6	1.000	1.000	1.000 -
7	1.000	1.000	1.000 -
8	1.000	1.000	1.000 -
9	1.000	1.000	1.000 -
10	1.000	1.000	1.000 -
11	1.000	1.000	1.000 -
12	1.000	1.000	1.000 -
Mean	**0.980**	**1.000**	**0.980**

Note: *crste = technical efficiency from CRS DEA*
vrste = technical efficiency from VRS DEA
scale = scale efficiency = crste/vrste
Note also that all subsequent tables refer to VRS results

Summary of Output Slacks

Firm Output	1	2	3	4
1	0.000	0.000	0.000	0.000
2	0.000	0.000	0.000	0.000
3	0.000	0.000	0.000	0.000
4	0.000	0.000	0.000	0.000
5	0.000	0.000	0.000	0.000
6	0.000	0.000	0.000	0.000
7	0.000	0.000	0.000	0.000
8	0.000	0.000	0.000	0.000
9	0.000	0.000	0.000	0.000
10	0.000	0.000	0.000	0.000
11	0.000	0.000	0.000	0.000
12	0.000	0.000	0.000	0.000
Mean	**0.000**	**0.000**	**0.000**	**0.000**

Summary of Input Slacks

Firm Input	1	2	3	4
1	0.000	0.000	0.000	0.000
2	0.000	0.000	0.000	0.000
3	0.000	0.000	0.000	0.000
4	0.000	0.000	0.000	0.000
5	0.000	0.000	0.000	0.000
6	0.000	0.000	0.000	0.000
7	0.000	0.000	0.000	0.000
8	0.000	0.000	0.000	0.000
9	0.000	0.000	0.000	0.000
10	0.000	0.000	0.000	0.000
11	0.000	0.000	0.000	0.000
12	0.000	0.000	0.000	0.000
Mean	**0.000**	**0.000**	**0.000**	**0.000**

Summary of Peers

Firm	Peers:
1	1
2	2
3	3
4	4
5	5
6	6
7	7
8	8
9	9
10	10
11	11
12	12

Summary of Peer Weights
(in same order as above)

Firm	Peer Weights:
1	1.000
2	1.000
3	1.000
4	1.000
5	1.000
6	1.000
7	1.000
8	1.000
9	1.000
10	1.000
11	1.000
12	1.000

PEER COUNT SUMMARY
(i.e., no. times each firm is a peer for another)

Firm	Peer Count:
1	0
2	0
3	0
4	0
5	0
6	0
7	0
8	0
9	0
10	0
11	0
12	0

Summary of Output Targets

Firm Output	1	2	3	4
1	410.000	712.000	391.000	5911.000
2	195.000	515.000	301.000	2056.000
3	297.000	623.000	523.000	3700.000
4	452.000	1623.000	792.000	5110.000
5	503.000	679.000	401.000	4673.000
6	450.000	423.000	521.000	2210.000
7	375.000	257.000	58.000	3118.000
8	741.000	6321.000	2298.000	10423.000
9	938.000	1681.000	1275.000	16612.000
10	800.000	890.000	4.000	9001.000
11	197.000	1431.000	1459.000	5572.000
12	19.000	99.000	50.000	1638.000

Summary of Input Targets

Firm Input	1	2	3	4
1	12197.000	4301.000	77192123.000	855.000
2	7067.000	291.000	7032.000	1110.000
3	8913.000	509.000	5443.000	323.000
4	12957.000	223.000	2365.000	600.000
5	10121.000	2741.000	1053234.000	2000.000
6	7714.000	2981.000	69830000.000	1350.000
7	8012.000	197.000	2212.000	80.000
8	32641.000	3932.000	3600432.000	423.000
9	35212.000	4512.000	221231.000	128.000
10	19123.000	221.000	4521.000	8000.000
11	14134.000	531.000	823.000	4000.000
12	2432.000	4321.000	434.000	600.000

FIRM BY FIRM RESULTS

Results for Firm: 1
Technical efficiency = 1.000
Scale efficiency = 1.000 (crs)

Projection Summary:

Variable	Original Value	Radial Movement	Slack Movement	Projected Value
output 1	410.000	0.000	0.000	410.000
output 2	712.000	0.000	0.000	712.000
output 3	391.000	0.000	0.000	391.000
output 4	5911.000	0.000	0.000	5911.000
input 1	12197.000	0.000	0.000	12197.000
input 2	4301.000	0.000	0.000	4301.000
input 3	77192123.000	0.000	0.000	77192123.000
input 4	855.000	0.000	0.000	855.000

Listing of Peers:
peer lambda weight
1 1.000

Results for Firm: 2
Technical efficiency = 1.000
Scale efficiency = 0.763 (irs)

Projection Summary:

Variable	Original Value	Radial Movement	Slack Movement	Projected Value
output 1	195.000	0.000	0.000	195.000
output 2	515.000	0.000	0.000	515.000
output 3	301.000	0.000	0.000	301.000
output 4	2056.000	0.000	0.000	2056.000
input 1	7067.000	0.000	0.000	7067.000
input 2	291.000	0.000	0.000	291.000
input 3	7032.000	0.000	0.000	7032.000
input 4	1110.000	0.000	0.000	1110.000

Listing of Peers:
peer lambda weight
2 1.000

Results for Firm: 3
Technical efficiency = 1.000
Scale efficiency = 1.000 (crs)

Projection Summary:

Variable	Original Value	Radial Movement	Slack Movement	Projected Value
output 1	297.000	0.000	0.000	297.000
output 2	623.000	0.000	0.000	623.000
output 3	523.000	0.000	0.000	523.000
output 4	3700.000	0.000	0.000	3700.000
input 1	8913.000	0.000	0.000	8913.000
input 2	509.000	0.000	0.000	509.000
input 3	5443.000	0.000	0.000	5443.000
input 4	323.000	0.000	0.000	323.000

Listing of Peers:
peer lambda weight
3 1.000

Results for Firm: 4
Technical efficiency = 1.000
Scale efficiency = 1.000 (crs)

Projection Summary:

Variable	Original Value	Radial Movement	Slack Movement	Projected Value
output 1	452.000	0.000	0.000	452.000
output 2	1623.000	0.000	0.000	1623.000
output 3	792.000	0.000	0.000	792.000
output 4	5110.000	0.000	0.000	5110.000
input 1	12957.000	0.000	0.000	12957.000
input 2	223.000	0.000	0.000	223.000
input 3	2365.000	0.000	0.000	2365.000
input 4	600.000	0.000	0.000	600.000

Listing of Peers:
peer lambda weight
4 1.000

Results for Firm: 5
Technical efficiency = 1.000
Scale efficiency = 1.000 (crs)

Projection Summary:

Variable	Original Value	Radial Movement	Slack Movement	Projected Value
output 1	503.000	0.000	0.000	503.000
output 2	679.000	0.000	0.000	679.000
output 3	401.000	0.000	0.000	401.000
output 4	4673.000	0.000	0.000	4673.000
input 1	10121.000	0.000	0.000	10121.000
input 2	2741.000	0.000	0.000	2741.000
input 3	1053234.000	0.000	0.000	1053234.000
input 4	2000.000	0.000	0.000	2000.000

Listing of Peers:
peer lambda weight
5 1.000

Results for Firm: 6
Technical efficiency = 1.000
Scale efficiency = 1.000 (crs)

Projection Summary:

Variable	Original Value	Radial Movement	Slack Movement	Projected Value
output 1	450.000	0.000	0.000	450.000
output 2	423.000	0.000	0.000	423.000
output 3	521.000	0.000	0.000	521.000
output 4	2210.000	0.000	0.000	2210.000
input 1	7714.000	0.000	0.000	7714.000
input 2	2981.000	0.000	0.000	2981.000
input 3	69830000.000	0.000	0.000	69830000.000
input 4	1350.000	0.000	0.000	1350.000

Listing of Peers:
peer lambda weight
6 1.000

Results for Firm: 7
Technical efficiency = 1.000
Scale efficiency = 1.000 (crs)

Projection Summary:

Variable	Original Value	Radial Movement	Slack Movement	Projected Value
output 1	375.000	0.000	0.000	375.000
output 2	257.000	0.000	0.000	257.000
output 3	58.000	0.000	0.000	58.000
output 4	3118.000	0.000	0.000	3118.000
input 1	8012.000	0.000	0.000	8012.000
input 2	197.000	0.000	0.000	197.000
input 3	2212.000	0.000	0.000	2212.000
input 4	80.000	0.000	0.000	80.000

Listing of Peers:
peer lambda weight
7 1.000

Results for Firm: 8
Technical efficiency = 1.000
Scale efficiency = 1.000 (crs)

Projection Summary:

Variable	Original Value	Radial Movement	Slack Movement	Projected Value
output 1	741.000	0.000	0.000	741.000
output 2	6321.000	0.000	0.000	6321.000
output 3	2298.000	0.000	0.000	2298.000
output 4	10423.000	0.000	0.000	10423.000
input 1	32641.000	0.000	0.000	32641.000
input 2	3932.000	0.000	0.000	3932.000
input 3	3600432.000	0.000	0.000	3600432.000
input 4	423.000	0.000	0.000	423.000

Listing of Peers:
peer lambda weight
8 1.000

Results for Firm: 9
Technical efficiency = 1.000
Scale efficiency = 1.000 (crs)

Projection Summary:

Variable	Original Value	Radial Movement	Slack Movement	Projected Value
output 1	938.000	0.000	0.000	938.000
output 2	1681.000	0.000	0.000	1681.000
output 3	1275.000	0.000	0.000	1275.000
output 4	16612.000	0.000	0.000	16612.000
input 1	35212.000	0.000	0.000	35212.000
input 2	4512.000	0.000	0.000	4512.000
input 3	221231.000	0.000	0.000	221231.000
input 4	128.000	0.000	0.000	128.000

Listing of Peers:
peer lambda weight
9 1.000

Results for Firm: 10
Technical efficiency = 1.000
Scale efficiency = 1.000 (crs)

Projection Summary:

Variable	Original Value	Radial Movement	Slack Movement	Projected Value
output 1	800.000	0.000	0.000	800.000
output 2	890.000	0.000	0.000	890.000
output 3	4.000	0.000	0.000	4.000
output 4	9001.000	0.000	0.000	9001.000
input 1	19123.000	0.000	0.000	19123.000
input 2	221.000	0.000	0.000	221.000
input 3	4521.000	0.000	0.000	4521.000
input 4	8000.000	0.000	0.000	8000.000

Listing of Peers:
peer lambda weight
10 1.000

Results for Firm: 11
Technical efficiency = 1.000
Scale efficiency = 1.000 (crs)

Projection Summary:

Variable	Original Value	Radial Movement	Slack Movement	Projected Value
output 1	197.000	0.000	0.000	197.000
output 2	1431.000	0.000	0.000	1431.000
output 3	1459.000	0.000	0.000	1459.000
output 4	5572.000	0.000	0.000	5572.000
input 1	14134.000	0.000	0.000	14134.000
input 2	531.000	0.000	0.000	531.000
input 3	823.000	0.000	0.000	823.000
input 4	4000.000	0.000	0.000	4000.000

Listing of Peers:
peer lambda weight
11 1.000

Results for Firm: 12
Technical efficiency = 1.000
Scale efficiency = 1.000 (crs)

Projection Summary:

Variable	Original Value	Radial Movement	Slack Movement	Projected Value
output 1	19.000	0.000	0.000	19.000
output 2	99.000	0.000	0.000	99.000
output 3	50.000	0.000	0.000	50.000
output 4	1638.000	0.000	0.000	1638.000
input 1	2432.000	0.000	0.000	2432.000
input 2	4321.000	0.000	0.000	4321.000
input 3	434.000	0.000	0.000	434.000
input 4	600.000	0.000	0.000	600.000

Listing of Peers:
peer lambda weight
12 1.000

Table 4 lists the refineries according to their TE calculated by the DEA models. It appears that 11 out of 12 (91.66%) refineries attained TE in 2011, and same refineries were technically efficient in 2012. Eleven DMUs (refineries) were technically efficient in both years such as DMU 1,3,4,5,6,7.8.9.10.11.12. DMU 2 suffered in efficiency in 2012 compared to 2011. The average TE of all the refineries in 2011 was 98%, while in 2012 the average TE was 98.9%, these results coincide with the estimates reported by Jaffe (2007). The annual average improvement achieved in 2010 was about 0.9%. The least TE in 2011and 2012 was achieved by DMU2. To identify the causes of inefficient operations, the authors conducted several interviews with directors at the MOP [25].

The following are the most frequent causes that were delineated:

- Frequent electric power interruptions.
- Insurgency attacks, sabotages and looting of crude oil.
- Suboptimal utilization of the land available for refineries.
- Excessive workforce due to the return of fired employees before 2003.
- Hydrogen and propane shortages.
- Shortages of fuel required to operate the refineries.
- Maintenance activities are not performed as planned.
- Shortage of trained personnel.
- Shortage of capacity to store finished products.
- Underutilization of workforce.
- Use of inadequate spare parts.
- Shortage of heavy equipment (bulldozers, cranes, etc.) to facilitate the refinery's operations.

Unless these problems are resolved and resources are restructured, the inefficient refineries shall remain inefficient in the future.

CONCLUSION

Performance measurement tools can help organizations to evaluate the allocations of their resources in order to determine the way those resources may be managed and allocated to value-adding activities. Hence, DEA can also assist in identifying areas where resources are misallocated.

In this study we demonstrated that the DEA is a powerful non-parametric approach for measuring the TE of the refineries studied, and it can provide a summary measure of the relative performance of each refinery. It is clear that the DEA approach offers illuminating information to the MOP which can benefit from such information regarding decision making for the oil refineries. Based on the results obtained, 91.66% of the refineries were efficient in 2011, while same percentage in 2012. The overall efficiency of the refineries studied was about 82% and 98% in 2011 and 2012 respectively. It is interesting to note that the oil industry in India is not effectively under the pressures (at least now) of environmental regulations.

The present study revealed that there is a waste or underutilization of resources at the inefficient refineries. Those inefficient refineries manifest decreasing returns to scale and need to reorganize their structure of inputs in order to reach efficiency production frontiers. Although this study is not a large scale, it provides policy makers at the MOP with an insight about the relative performance of the oil refineries, and in deriving strategies to reconstruct their inputs to eliminate waste and optimize outputs.

REFERENCES

1. Kumins L. Iraq Oil: Reserves, Production, and Potential Revenues. CRS Report for Congress, RS21626, 2005.
2. Taylor B. *Introduction to Management Science* (7th ed.). Prentice-Hall. New Jersey, USA, 2002.
3. Steering Committee for the Review of Commonwealth (SCRC)/State Service Provision. (1997). *Data Envelopment Analysis: A technique for measuring the efficiency of government service delivery*. AGPS, Canberra.
4. Charnes A, Cooper W W, Rhodes E. Measuring the Efficiency of Decision Making Units. *Eur J of Operations Res*. 1978; 12(6): 429–44p. http://dx.doi.org/10.1016/0377-2217(78)90138-8
5. Banker RD, Charnes A, Cooper WW. Some Models for Estimating Technical and Scale Inefficiencies in Data Envelopment Analysis. *Management Science*. 1984; 30(9): 1078–92p. http://dx.doi.org/10.1287/mnsc.30.9.1078
6. Tone K, Seiford L, Cooper W. *Data Envelopment Analysis -A Comprehensive Text with Models, Applications, References and DEA-Solver Software*. Norwell, MA:Kluwer Academic Publishers. 2000.
7. Clark C, Schkade L. *Statistical Analysis for Administrative Decisions* (2nd ed.). Southwestern Publishing Company. Dallas, Texas, 1978.
8. Ghosh N. Data Envelopment Analysis: A New Horizon in Measuring Technical Efficiency and Benchmarking. *TIG Res J*. 2008; 1(1): 49–56p.
9. Tavaresx G. Data Envelopment Analysis: Models and Extensions. *Decision Line*. 2000; 31(3): 8–11p.
10. Cooper WW, Seiford LM, Tone K. *Introduction to Data Envelopment Analysis and Its Uses*. Springer, NY, USA, 2006.
11. Kuosmanen T, Post GT, Scholtes S. Testing for Productive Efficiency in Case of Errors-in-Variables. *J of Econometrics*. 2007; 136*:* 131–62p.
12. Charnes A, Cooper WW, Lewin AY, Seiford LM. *Data envelopment analysis: Theory, methodology, and applications*. Boston: Kluwer, 1994.
13. Cooper W, Seiford L, Zhu J. *DATA ENVELOPMENT ANALYSIS: History, Models and Interpretations*. Kluwer Academic Publishers, Boston, 2004.
14. Odeck J, Alkadi A. Evaluating Efficiency in the Norwegian Bus Industry Using Data Envelopment Analysis. *Transportation*. 2001; 28(3): 211-232p. http://dx.doi.org/10.1023/A:1010333518966
15. Banker RD, Chang HH, Kao YC. Impact of information technology on public accounting firm productivity. *J of Information Syst*. 2002; 16(2): 209–22p.
16. Mahadevan R. A DEA Approach to Understanding the Productivity Growth of Malaysia's Manufacturing Industry. *ASIA Pacific J of Manage*. 2002; 19(4): 587-600p. http://dx.doi.org/10.1023/A:1020577811369
17. Wang J. Corporate Performance Efficiency Investigated by Data Envelopment Analysis and BalancedScorecard. *The J of Am Acad of Business*, *Cambridge*. 2006; 9(2): 312–8p.
18. Oliveira L, Cristina T, Carlos J. Data Envelopment Analysis Applied to Evaluate the Usage of Oil and Natural Gas: South America Case. 6th International Conference on Operations Research for Development, Fotalenza, CE, 2007.
19. Zhou P, Ang B, Poh L. A survey of data envelopment analysis in energy and

environmental studies. *Eur J of Operations Res.* 2008; 189: 1–18p. http://dx.doi.org/10.1016/j.ejor.2007.04.042

20. Malhotra R, Malhotra D, Lermack H. Using DEA to Analyze the Performance of North American Class I Freight Railroads. *Appl of Manage Sci*. 2008; 13: 113–31p.
21. Mekaroonreung M, Johnson A. Estimating Efficiency of U.S. Oil Refineries under Varying Assumptions Regarding Disposability of Bad Outputs. *Int J of Energy Sector Manage*. 2009; 4(3): 356–98p. http://dx.doi.org/10.1108/17506221011073842
22. Sepehrdoust H. Efficiency Measurement of Housing Sector; Using DEA Model. *International Conference on Economics and Finance Research. IPEDR.4 (2011).* IACSIT Press, Singapore, 2011.
23. Ines C, Martinez P. Energy Efficiency Development in German and Colombia non-energy-intensive sectors: a non-parametric analysis. *Energy Efficiency*. 2011; 4(1): 115–31p. http://dx.doi.org/10.1007/s12053-010-9078-2
24. Ajalli M, Bayat N, Mirmahalleh S, Ramazani M. Analysis of the Technical Efficiency of the Provincial Gas Companies in Iran Making use of the Synthetic Model of Data Envelopment Analysis and Anderson-Peterson Method (DEA-AP). *Eur J of Social Sci*. 2011; 25(2): 156–60p. http://dx.doi.org/10.1016/j.seps. 2007.07.002
25. Jaffe A. *Iraq's Oil Sector: Past, Present and Future.* James A. Baker III Institute for Public Policy and the Japan Petroleum Energy Center. Rice University, 2007.

AUTHOR BIOGRAPHY

K. Pandey is a Research Scholar in the Department of Mechanical Engineering, KIITs University for last two years. His area of research is data envelopment analysis, TQM, service quality management. His area of interest includes total quality management, statistical process control, and service quality management. He has published more than two research papers in various international and national conferences and journals.

S. Satapathy is an Associate Professor in the Department of Mechanical Engineering, KIIT University, India. She has more than 11 years of experience in teaching and research. Her current area of research includes quality engineering, service quality management, statistical process control, quality engineering and multi-criteria decision-making. She has published more than 20 research articles in referred journals. She is currently dealing with few sponsored research projects.