Application of Data Envelopment Analysis to Measure the Technical Efficiency of Oil Refineries: A Case Study

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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 Iraq over a period of two years, 2009-2010. 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 Iraq. The authors 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, 50% of the refineries were efficient in 2009, while 58% of them were efficient in 2010, and the overall efficiency of the refineries studied was about 82% and 87% 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 Iraq, this study shall augment our knowledge on how oil refineries in Iraq 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 Iraq could, also, benefit from this approach.

Keywords: Data envelopment analysis, Technical efficiency, Oil refineries, Oil refinery performance, Iraq

1. Introduction

In 2009, Iraq was the world's 12th oil producing country, and the fourth largest proven oil reserves after Saudi Arabia, Canada, and Iran. Only a small portion of Iraq'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 Iraq is heavily dependent upon oil. Revenues from crude oil accounted for over 2/3 of the GDP in 2009. Iraqi 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 600 000 bbl/d. Iraq reportedly has nearly 600 000 b/d of refining capacity at several facilities. But because of looting, sabotage, deferred maintenance, and unreliable electric power supplies, refinery operations are insufficient for domestic needs (Kumins, 2005). The refineries produce, mainly, heavy fuel oil and some other needed refined products. Therefore, Iraq relies on imports for about 30% of its gasoline and 17% of its LPG (MOP, 2009). To alleviate this problem, Iraq adopted a strategic plan for 2008-2017 to increase the refining capacity to 1.5 million bpd (US Commercial Services, 2012). 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 especially in the developing countries such as Iraq (Stevens, 2008) (Hartley & Medlock, 2007).

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, the authors are not aware of any previous research on measuring the efficiency and productivity of oil refineries in Iraq 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: it increases our knowledge and understanding about measuring the technical efficiency of oil refineries in Iraq, it coincides with and supports the MOP's efforts to improve the performance of oil refineries, and finally, 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 Iraq.

2. Oil Industry in Iraq: A Concise Background

Established in 1964, the Iraq National Oil Company (INOC) was intended to develop the concession areas taken over from international oil companies that had previously controlled Iraq's oil sector. The company was granted the exclusive rights by law to develop Iraq's oil reserves and granting new concessions to foreign oil companies was rendered illegal. Iraq realized that it needed to enhance the technical capabilities of INOC and sought assistance from countries that were not involved in the country's colonial history and the consortium Iraq Petroleum Company (IPC), which included the precursor companies to British Petroleum, Royal Dutch Shell, Exxon and Mobil Corporations and CFP of France, and had run Iraq's industry since the British colonial mandate in the 1920s. Iraq concluded a services contract with Entreprise Des Recherches et des Activites Petrolieres (ERAP) of France for technical assistance in Southern Iraq and the offshore. The agreement did not grant any concessionary rights to the French firm. In 1976 Iraq established a new Ministry of Petroleum, the Ministry was commissioned to perform functions of planning and direct construction of petroleum sector infrastructure. In 1987, a major reorganization of the oil sector took place and INOC became part of the Ministry of Petroleum itself.

In addition to being hurt severely during the Iraq-Iran war, and during the period of sanctions which followed the invasion of Kuwait by Iraq, the oil industry faced different problems immediately after 2003. According to Jaffe (2006) many oil reconstruction projects fell victim to insurgency attacks, such as a major damage has been sustained to the Baiji gas oil separation plant which halted the processing of 300 000 b/d via Turkey. Water injection activities at the Rumaila fields experienced prolonged delays. Lack of technical training and experience hindered the optimum implementation of water injection activities to boost production potential at the field. The lack of adequate security poses a major challenge for the government in the oil sector. Sectarian and regional strife undermines the ability to operate facilities or the sector as a whole either efficiently or effectively. Intimidation of key experts, either those trained abroad or those holding critical positions, has become a serious problem and hundreds of oil industry leaders have been killed or purged from the sector (Jaffe, 2006). Combining these factors with a looming gap in technical and managerial expertise due to Iraq's relative isolation over the past 25 years as the energy industry rapidly evolved, has seriously eroded the capacity of the Iraqi government to manage the oil sector.

In the present time, the Iraqi oil industry remains structured around both regional lines and functional duties based on the 1987 organizational plan. Generally speaking The Minister of Oil is the functional head of the industry, with several undersecretaries reporting directly to him. Below this hierarchy are state-run companies functionally defined, each led by a Director General and other senior staff (Jaffe, 2006).

With the exclusion of the Kurdistan Region, there are three national oil companies in Iraq:

- The North Refineries Company (NRC) runs six refineries: Salladin, Kirkuk, Baiji, Haditha, Kasak, and Qayarah.
- The Midland Refineries Company (MRC) manages four refineries: Dura, Najaf, Samawa, and Karbala.
- The South Refineries Company (SRC) directs three refineries: Basrah, Nassiriay, and Ammara.

The country's refining capacity is estimated at 600 000 b/d. Two major refineries are located at Baiji. Large oil refineries are also located at Dura. Iraqi oil refineries were seriously damaged during the years of war and the sector remains dilapidated and in need of massive repair (Jaffe, 2007).

3. DEA: A Theoretical Background

Data Envelopment Analysis (DEA) is an approach to measure the relative efficiency of Decision Making Units (DMU's) (Taylor, 2001). 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 (SCRC, 1997). Best practice could be identified at the organizational, national, and international levels. In essence, DEA attempts to measure the technical efficiency (TE). The later is expressed as the potential to increase quantities of outputs from a given quantities of inputs.

This approach was first proposed by Charnes et. al. (1978), and later extended by Banker, Charnes, and Cooper (1984). 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 (Tone et. al. 2000). 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. Farell'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.

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:

$$Efficiency = output(s)/input(s) \quad (1)$$

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 (Clark, 1978), it is possible to derive the regression line for the data presented by Table 1:

$$y = 0.67x \quad (2)$$

Where y is sales, and x is the number of workers. By plotting this line on Figure 1, we obtain Figure 2. 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 (Ghosh, 2008).

Farrell, also, proposed the Input-Oriented Measure of TE manifested in Figure 3. Here, a company uses two inputs X_1, X_2 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 the TE is somewhere between 0-1. Assuming the X_1,X_2 prices are fixed, then the distributed efficiency is represented by the ratio of OB/OC, and the distance BC is the amount by which the costs of inputs must be reduced to produce at p'. Furthermore, Figure 4 provides a schematic representation of Farrell's Output-Oriented Measure of Technical Efficiency where a company uses one input X_1 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 is 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 (Charnes et. al., 1978) 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 is defined as follows:

$$Technical\ Efficiency = \frac{weighted\ sum\ of\ outputs}{weighted\ sum\ of\ inputs} \tag{3}$$

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

$$\left.\begin{aligned} &\max \quad \frac{\sum_{k=1}^{s} v_k\ y_{kp}}{\sum_{j=1}^{m} u_j\ x_{ji}} \\ &s.t \quad \frac{\sum_{k=1}^{s} v_k\ y_{kp}}{\sum_{j=1}^{m} u_j\ y_{ji}} \le 1 \quad \forall i \\ &v_k, u_j \ge 0 \quad \forall k, j \end{aligned}\right\} \tag{4}$$

Where, $k=1$ to s, $j=1$ to m, i=1 to n, y_{ki} = amount of output k produced by DMU i, x_{ji}= amount of input j used by DMU i, v_k= weight assigned to output k, u_j= 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 (Talluri, 2000).

$$\left.\begin{aligned} &\max \sum_{k=1}^{s} v_k\, y_{kp} \\ &s.t. \sum_{j=i}^{m} u_j\ x_{jp} = 1 \\ &\sum_{k=1}^{s} v_k\ y_{ki} - \sum_{j=1}^{m} u_j\ x_{ji} \le 0 \quad \forall i \\ &v_k, u_j \ge 0 \quad \forall k, j \end{aligned}\right\} \tag{5}$$

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 (Cooper et. al., 2006).

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.

$$\left.\begin{aligned} &\min \quad \theta \\ &s.t. \quad \sum_{i=1}^{n} \lambda_i\ x_{ij} - \theta\, x_{jp} \le 0 \quad \forall j \\ &\sum_{i=1}^{n} \lambda_i\ y_{ki} - y_{kp} \ge 0 \quad \forall k \\ &\lambda_i \ge 0 \quad \forall i \end{aligned}\right\} \tag{6}$$

Where

$\theta = efficiency\ score$

$\lambda_s = dual\ variables$

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 (SCRC,1997). 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 CCR model 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 (Banker et. al.,1984).

According to Ghosh (2008), DEA has the following characteristics:

- It is a nonparametric optimization method that determines production frontiers.
- 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.
- 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.
- DEA considers multiple factors and does not necessitates parametric assumptions of traditional multivariate methods.
- Inputs and outputs may assume different units.

Furthermore, the following are some limitations of the DEA (SCRC, 1997) (Kuosmanen et. al., 2007):

- Since DEA is a deterministic model (and descriptive in nature) it therefore provides results that are sensitive to input measurements errors.
- 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.
- DEA results are sensitive to output and input specification, and the size of the sample. Large sample size tend 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.
- Since DEA is a non-parametric 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), 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 as shown in Figure (5).

4. 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 (Cooper et. al., 2004). The DEA applications were evident in service and manufacturing sectors.

Odeck & Alkadi (2001) attempted to evaluate the performance of Norwegian bus companies subsidized by the government. 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. 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 twenty eight industries from 1981-1996. 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. The author reports that the two approaches provided illuminating information about Acer's performance, and that other firms could benefit from both approaches. Oliveira et. al. (2007) mention that the last two decades were characterized by high oil prices, thus many countries in the world were vulnerable to this phenomenon. 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) argue that DEA has gained an immense popularity in the energy and environmental sectors in recent years. 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. 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 & Johnson (2009) used DEA as a method for evaluating the technical efficiency of 113 U.S. oil refineries in 2006 and 2007. 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. 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. 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 et. al. (2011) investigated the problem of separability in DEA where the number of DMUs is lower compared to the number of input and output. 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.

5. Research Problem and Objectives

The literature review provides DEA applications in different business sectors and in different countries. However, the authors did not encounter any study that measures and documents the performance of oil refineries in Iraq. Currently, the Office of the General Inspector (OGI) 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, the authors 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 Iraq.

The present research attempts to achieve the following objectives:

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

6. 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. (2007), Ajalli et. al. (2011), Mekaroonreung & Johnson (2009) and Ines and Martinez (2011) to measure the TE in the energy industry. The sample of the refineries studied consists of 12 refineries under the direction of NRC, MRC and SRC. For confidentiality purposes, the names of the refineries shall be referred to by DMU1, DMU2, …..DMU12. To measure the TE of the sample studied, the authors followed the following steps:

- Sample Selection: twelve out of thirteen refineries were selected for this study. One refinery was excluded from the study due to difficulties in data collection.
- Data Collection: for the purposes of this study, four inputs {crude oil (m^3), workforce (workers), electricity (Kw/h) and land (hectares) }, and four outputs {naphtha (m^3) , gasoline (m^3), kerosene (m^3) and fuel oil (m^3)} 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 2009, 2010 respectively.
- Model Selection: the DEA CCR with constant returns to scale model developed by Charnes & Cooper (1978) and presented by (4) is used to measure the TE of the refineries.
- Model Development: twelve models/year (one for each refinery) are developed to evaluate the relative efficiency scores of each DMU involved in the study during 2009 and 2010.

Several software packages are available to solve the DEA model such as DEA windows, Frontier Analyst, DEAFrontier, etc. (Lin et. al., 2009). In this study, we preferred to use more generic software to perform the calculation, therefore we selected the Excel 2003 Solver for this purpose.

7. DEA Application

Using the DEA CCR model with constant 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 2009 and 2010. For instance, the DEA model developed to compute the TE for DMU_2 in 2009 is presented below:

$$
\left.
\begin{aligned}
& Max\ Z= 111188x1+101833x2+64845x3+320098x4 \\
& \underline{S.T} \\
& 617740y1+270y2+6048y3+1110y4=1 \\
& 854368X1+452196X2+218503X3+1921998X4 \leq 3733935y1+4249y2+77900000y3+855y4 \\
& 111188x1+101833x2+64845x3+320098 \leq 617740y1+270y2+6048y3+1110y4 \\
& 81893x1+84833x2+48741x3+240454x4 \leq 482216y1+549y2+5135y3+323y4 \\
& 40100x1+38674x2+20764x3+119262x4 \leq 225340y1+182y2+2300y3+600y4 \\
& 1195126x1+1433560x2+823529x3+2646866x4 \leq 40359283y1+2980y2+12042000y3+2000y4 \\
& 761253x1+828516x2+569705x3+1898627 \leq 27231760y1+2220y2+57864000y3+1350y4 \\
& 4663x1+9268x2+3330x3+22573x4 \leq 347393y1+204y2+225000y3+80y4 \\
& 0x1+201068x2+211824x3+859847x4 \leq 10112105y1+247y2+360000y3+423y4 \\
& 2167x1+37063x2+0x3+89404x4 \leq 1127080y1+160y2+221000y3+128y4 \\
& 642100x1+1446603x2+591398x3+3492130x4 \leq 8019877y1+4510y2+100174y3+8000y4 \\
& 50849x1+168141x2+86832x3+673677x4 \leq 7136817y1+845y2+4712y3+4000y4 \\
& 648x1+180x2+107x3+197x4 \leq 4000y1+375y2+2700y3+600y4 \\
& x1, x2, x3, x4 \quad \geq 0 \\
& y1, y2, y3, y4 \quad \geq 0
\end{aligned}
\right\} \qquad (7)
$$

The computer output for this model is presented in Table 4. From this table it appears that the TE of this refinery is 1, which indicates that this refinery is using its resources efficiently and it could be used as a benchmark for other inefficient refineries. Thus, a total of 24 runs were conducted for all the refineries.

8. Results

Table (5) lists the refineries according to their TE calculated by the DEA models. It appears that 6 out of 12 (50%) refineries attained TE in 2009, while seven refineries (58%) were technically efficient in 2010. Some DMUs (refineries) were technically efficient in both years such as $DMU_{1,2,3,5,6}$. $DMU_{4,8,11,12}$ improved their efficiency in 2010 compared to 2009. In addition, $DMU_{7,9,10}$ experienced a decline in TE in 2010. The average TE of all the refineries in 2009 was 82%, while in 2010 the average TE was 87%, these results coincide with the estimates reported by Jaffe (2007). The annual average improvement achieved in 2010 was about 6%. The least TE in 2009 and 2010 was achieved by DMU_7. The inefficient refineries in 2010 (7,8,9,10 and 11) should reduce the use of their resources by 71%, 13%, 34%, 2%, and 40% respectively to reach the efficient production frontiers. The amounts by which resources should be reduced by the inefficient refineries are provided in Table (6). From this table, the total annual underutilization at the inefficient refineries from crude oil, workers, electricity and land is 6 637 308 m3, 1530 workers, 144 459 Kw/h and 3355 hectares respectively. To discriminate the efficient refineries, Hingsworth and Parkin (1995) suggest that it is worth identifying the number of times that an efficient DMU acts as a peer. In our case the peer refineries are those that scored efficient in both years ($DMU_{1,2,3,5,6}$), these DMUs can be considered as better performing units due to their outstanding operations.

To identify the causes of inefficient operations, the authors conducted several interviews with directors at the MOP. 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 equipments (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.

9. Conclusions

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, 50% of the refineries were efficient in 2009, while 58% of them were efficient in 2010. This may be due to the improvements in the security conditions realized in 2010. The overall efficiency of the refineries studied was about 82% and 87% in 2009 and 2010 respectively. It is interesting to note that the oil industry in Iraq 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.

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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	0.75	0.8	0.4	0.5	0.625

Source: Ghosh, 2008.

Table 2. Inputs and outputs for 2009

	Outputs*				**Inputs****			
DMUs	1	2	3	4	1	2	3	4
DMU1	368 854	452196	218503	1921998	3733935	4249	77900000	855
DMU2	111188	101833	64845	320098	617740	270	6048	1110
DMU3	81893	84833	48741	240454	482216	549	5135	323
DMU4	40100	38674	20764	119262	225340	182	2300	600
DMU5	1195126	1433560	823529	2646866	40359283	2980	12042000	2000
DMU6	761253	828516	569705	1898627	27231760	2220	57864000	1350
DMU7	4663	9268	3330	22573	347393	204	225000	80
DMU8	0	201068	211824	859847	10112105	247	360000	423
DMU9	2167	37063	0	89404	1127080	160	221000	128
DMU10	642100	1446603	591398	3492130	8019877	4510	100174	8000
DMU11	50849	168141	86832	673677	7136817	845	4712	4000
DMU12	648	180	107	197	4000	375	2700	600

Source: MOP.

*Outputs: 1=naphtha, 2=gasoline, 3=kerosene, 4=fuel oil

**Inputs: 1=crude oil, 2=workers, 3=electricity (Kw/h), 4=land

Table 3. Inputs and outputs for 2010

	Outputs*				Inputs**			
DMUs	1	2	3	4	1	2	3	4
DMU1	967667	652019	2728920	2396900	4687599	4321	77911296	855
DMU2	196213	187724	109763	605782	1123375	304	7086	1110
DMU3	158328	152452	85401	439386	861415	575	5451	323
DMU4	48098	60350	32220	170265	316388	256	2300	600
DMU5	1290367	1847619	959075	3165386	49422658	2899	105346000	2000
DMU6	1050931	900685	898346	2117908	31383883	2995	69830000	1350
DMU7	0	665	129	2030	9790	241	2250	80
DMU8	0	234040	211754	811115	9827616	290	360000	423
DMU9	0	64301	0	13926	1808842	142	221952	128
DMU10	348263	1545962	468384	3633443	8271227	102213	4590	8000
DMU11	181033	194931	9123	309512	7708797	4638	888	4000
DMU12	49500	60644	357	258465	12000	4000	400	600

Source: MOP.

*Outputs: 1=naphtha, 2=gasoline, 3=kerosene, 4=fuel oil

**Inputs: 1=crude oil, 2=workers, 3=electricity (Kw/h), 4=land

Table 4. Computer solution for DMU2-2009

Report Created: 7/13/2011 2:57:42 PM
Microsoft Excel 12.0 Sensitivity Report

Adjustable Cells

Cell	Name	Final Value	Reduced Cost	Objective Coefficient	Allowable Increase	Allowable Decrease
C20	x1= x1	1.30681E-06	0	111188	0	0
C21	x2= x1	1.93636E-06	0	101833	0	0
C22	x3= x1	5.68058E-06	0	64845	0	0
C23	x4= x1	9.03335E-07	0	320098	0	0
E20	y1= x3	1.88363E-07	0	0	0	0
E21	y2= x3	0.000887291	0	0	0	0
E22	y3= x3	0	0	0	0	1E+30
E23	y4= x3	0.000580245	0	0	0	0

Constraints

Cell	Name	Final Value	Shadow Price	Constraint R.H. Side	Allowable Increase	Allowable Decrease
L5	DMU1	4.969543981	0	0	1.35850828	1.185877638
L6	DMU2	1	1	0	0.31869405	0.219069229
L7	DMU3	0.765373537	0	0	0.132593301	0.113350852
L8	DMU4	0.352974994	0	0	1E+30	0.19910472
L9	DMU5	11.40682054	0	0	0.613091918	3.314325252
L10	DMU6	7.550470225	0	0	1E+30	0.332107724
L11	DMU7	0.063347137	0	0	1E+30	0.229515844
L12	DMU8	2.369352993	0	0	0.628619437	0.967747257
L13	DMU9	0.155360764	0	0	1E+30	0.273177528
L14	DMU10	10.15429152	0	0	2.29354365	1.417922429
L15	DMU11	1.493843312	0	0	1E+30	2.921211317
L16	DMU12	0.001981138	0	0	1E+30	0.679653384
M6	DMU2	1	1	1	1E+30	1

Table 5. Listing of refineries according to TE achieved in 2009 & 2010

DMUs	2009	2010
1	1	1
2	1	1
3	1	1
4	0.68	1
5	1	1
6	1	1
7	0.34	0.29
8	0.57	0.87
9	0.79	0.66
10	1	0.98
11	0.55	0.60
12	0.89	1

Table 6. Computation of wasted and target resources at the inefficient DMUs in 2010

DMU	Inputs	% of Wasted Resources	Amount Wasted	Target Resources	Actual Resources
DMU 7	**Crude oil m^3**	0.71	6951	2839	9790
	Workers	0.71	171	70	241
	Electricity (Kw/h)	0.71	1597	653	2250
	Land (Hectares)	0.71	57	23	80
DMU 8	**Crude oil m^3**	0.13	1 277 590	8 550 026	9 827 616
	Workers	0.13	38	252	290
	Electricity (Kw/h)	0.13	46 800	313 200	360 000
	Land (Hectares)	0.13	55	368	423
DMU 9	**Crude oil m^3**	0.34	615 006	1 193 836	1 808 842
	Workers	0.34	48	94	142
	Electricity (Kw/h)	0.34	75 464	146 488	221 952
	Land (Hectares)	0.34	43	85	128
DMU 10	**Crude oil m^3**	0.40	3 083 519	4 625 278	7 708 797
	Workers	0.40	355	533	888
	Electricity (Kw/h)	0.40	1855	2783	4638
	Land (Hectares)	0.40	1600	2400	4000
DMU 11	**Crude oil m^3**	0.02	1 654 245	6 616 981	8 271 227
	Workers	0.02	918	3672	4590
	Electricity (Kw/h)	0.02	20 443	81 770	102 213
	Land (Hectares)	0.02	1600	6400	8000

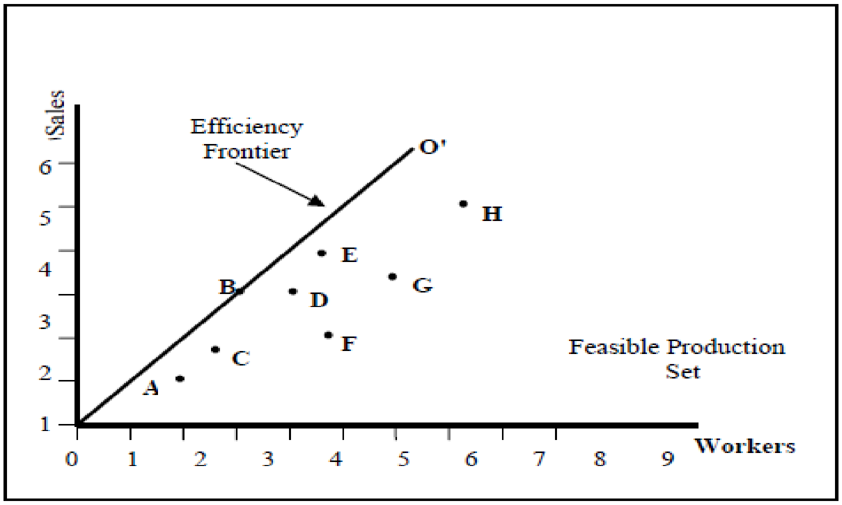

Figure 1. Efficiency frontier and feasible production set

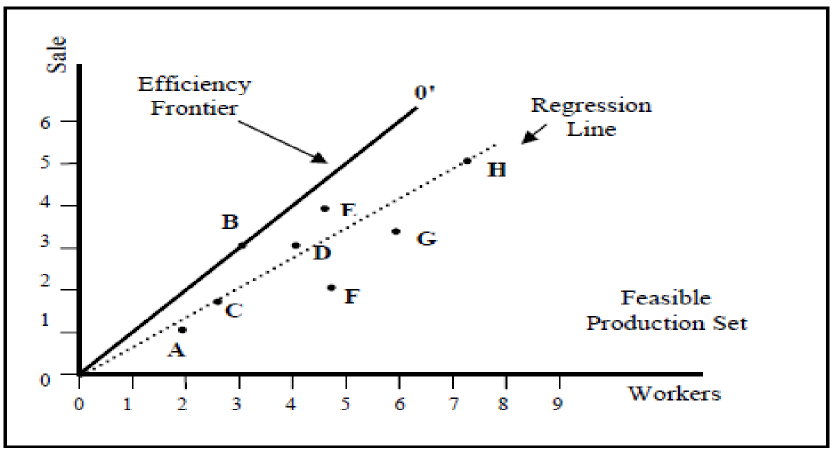

Figure 2. Regression line and efficiency frontier

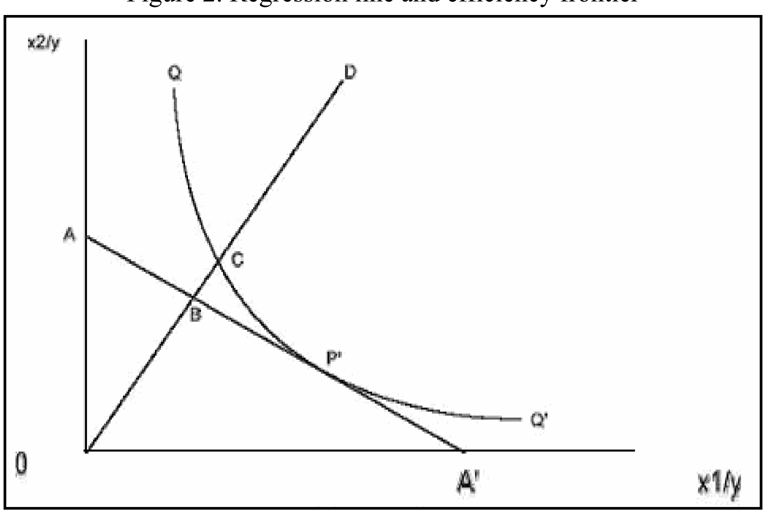

Figure 3. Input-oriented technical efficiency

Source: Ghosh, 2008,p. 51.

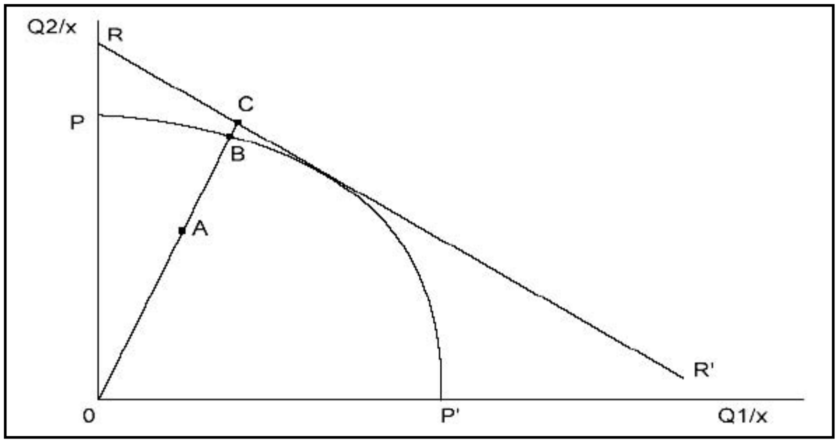

Figure 4. Output-oriented technical efficiency

Source: Ghosh, 2008, p.52.

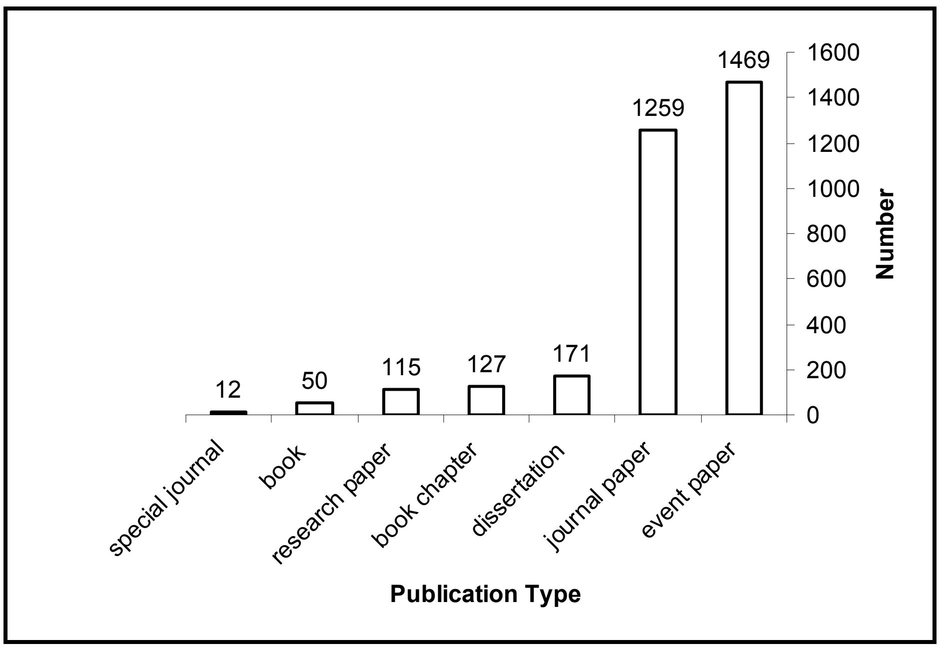

Figure 5. DEA publication number by type

Source: Tavares, 2002, p.4.