The DEA Process to the Planning of Well-Drilling Operations

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ABSTRACT

This paper simplifies the Data Envelopment Analysis (DEA) process to the planning of well-drilling operations. It presents an examination of the applicability of DEA to the better planning of well-drilling operations from the managerial point of view. The method can introduce preference individual input levels over alternative path to efficiency. The study focuses on three types of categorized indices in well-drilling program, represented by the well-drilling cost, time and depth for the determination of how far well-drilling resources can increase while still serving as efficient. The data analyses and results based on 35-drilled wells are presented along with their specifications.

KEYWORDS

Data Envelopment Analysis, Well-drilling, Oil and Gas industry.

1. INTRODUCTION

Drilling is a sub-system of the oil production chain and as an efficient operation raises the productivity of the prime factors of production (labour and capital) and the profitability of the drilling units, thereby, permitting higher levels of output, income, and employment. On the other hand, the continuous changes in the international drilling technology and management, to better meet the pressing needs of oil industries are resulting in an increasing pressure on companies to re-orient their roles and functions to meet the demands of such operational environment. Managers are often under great pressure to improve the performance of their companies. To improve their performance, drilling managers need to constantly evaluate operations or processes related to the provision of better services to the users. This entails the rethinking of developmental drilling strategies as well as implementing reforms in the legislative, regulatory, and managerial environment. Naturally, therefore, the efficiency of the drilling operations has become a critical factor for an oil company's competitiveness and its trade prospects. The better planning and monitoring of the drilling performance, in such a fast changing world, is very crucial in the measurement of its level of efficiency and thereby competitiveness. The application of traditional production function methodology to special production units, in order to find out the nature and strength of the explanatory variables, is not new, but beyond the conventional wisdom in production economics, drilling unlike other manufacturing decision making units (DMU), represents a special system that cannot be fully understood simply by investigating the quantity of labour or capital alone. Hence, well-drilling efficiency is expected to be highly dependent upon factors, which are not merely labour or capital. Thus, the mere amount of capital is not sufficient to ensure the efficiency of a drilling operation. What is important is how this capital is allocated and utilised in order to enhance performance. Therefore, the use of the Data Envelopment Analysis (DEA) is likely to better reflect the input-output relationships. The point is not that capital or labour is unimportant.

Performance evaluation and benchmarking are widely used methods to identify and adopt best practices as means of improving the performance and increasing productivity, and are particularly valuable when no objective or engineered standard is available to define an efficient and effective performance. For example, consider well-drilling operations. The major inputs include the drilling cost and time, and the output is the well depth. As a matter of fact, evaluation of the performance of well-drilling under such a complex environment is difficult. Therefore, benchmarking is often used in managing service operations, because service standards (benchmarks) are more difficult to define than manufacturing standards. Difficulties get further enhanced when the relationships between the inputs and the outputs are complex and

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involve many unknown tradeoffs. DEA is a tool that can evaluate the performance and benchmarking of well-drilling services in the context of multiple inputs and outputs.

The purpose of this paper is to introduce a new and alternative approach to measure the performance and efficiency of well-drilling operations, since efficiency ratings are likely to serve as a powerful tool for authorities in assessing the comparative performance of their operation on each well. The introduction of a safe interval for input's quantities at the beginning of drilling new wells also plays an important role for any activity, which needs to be programmed.

The paper is organised as follows. The following section outlines the concept and measurement of DEA. The one thereafter concentrates on data and model specification. Finally, computational results and conclusions are to be reported.

2. EVALUATION APPROACH

DEA, as developed by Charnes et al [1], is basically a linear programming application to measure relative efficiency among similar DMUs entailing multiple inputs and outputs. Suppose we have a set of n peer DMUs, which produce multiple outputs vector Y, through utilising observed multiple inputs vector X, respectively. The production possibility set F will then be defined as follows:

$$F = \{(Y,X) \mid X \; can\; produce\, \mathrm{Y}\}$$

An efficient frontier (or production technology) can be represented by a set of DMUs that satisfy efficiency conditions. This efficient frontier requires the following two basic assumptions. See [2].

First, the efficient frontier should satisfy the convexity assumption of the production possibility set F. This means that, for a DMU with a single input A and single output B, if

$$(y^A,x^A) \in F \; and \; (y^B,x^B) \in F, \; then$$

$$\{\lambda y^A + (1\text{-}\lambda)y^B, \lambda x^A + (1\text{-}\lambda)x^B, 0 \le \lambda \le 1\} \in F$$

where λ is a variable concerning the linear combinations of DMUs.

Second, the efficient frontier should satisfy the 'free disposability' assumption of inputs and outputs. This means that, for inputs, if $(y^A,x^A) \in F$ and $x^A \le x^B$, then $(y^A,x^B) \in F$, and for outputs, if $(y^A,x^A) \in F$ and $y^A \ge y^B$, then $(y^B,x^A) \in F$.

$$\begin{aligned} P_1 &: Maximize \quad UY_p \\ & s.t. \\ & VX_p = 1 \\ & UY_j - VX_j \le 0. \quad \forall j = 1,\dots,n \\ & U \ge \varepsilon 1, V \ge \varepsilon 1 \end{aligned} \tag{1}$$

Shephard [1] provided another functional representation of production technology defining a distance function as:

$$D(Y,X) = \min\{\theta \mid (X, Y/\theta) \in F\}$$

where θ is a variable representing the efficiency index and $D(Y, X)$ is an output-oriented distance function. To estimate such a distance function, Aigner and Chu [3] used linear programming, which later helped Charnes et al, [1], framing the DEA methodology displayed in the P_1. Interestingly, this optimal solution can be viewed as reciprocal of Farrell's technical efficiency estimates [4]. Here, in the envelopment model, P_1 and multiplayer models, P_2, we assume n units, each using m inputs to produce s outputs. We denote by y_{rj} the level of the r^{th} output $(r=1, 2,\dots, s)$ from unit j $(j=1, 2,\dots, n)$ and by x_{ij} the level of the i^{th} input $(i=1, 2, \dots, m)$ to the j^{th} DMU.

$$\begin{aligned} P_2 &: Minimize \quad \theta - \varepsilon(1s^+ + 1s^-) \\ & s.t. \\ & \theta X_p - X\lambda - s^+ = 0 \\ & Y\lambda - s^- = Y_p \\ & \lambda \ge 0, s^+ \ge 0, s^- \ge 0 \end{aligned} \tag{2}$$

ε is a very small positive number that prevents the weights from vanishing, see MirHassani and Alirezaee [5]-[6]. (formally, ε should be seen as a non-Archimedean constant), s_i^-, s_r^+ represent the slack variables and λ_j are variables whose optimal values will define an efficient production possibility minimising inputs DMU0 without detriment to its output levels. As a result, the optimal solution of P_1 and P_2 represents the estimated efficiency of DMU0. This model must be solved for each DMU. An integrated model was also proposed by MirHassani and Alirezaee [6] to calculate the efficiency of all the DMUs simultaneously.

These equations represent a CCR model, which considers the constant returns to the scale condition of the efficient frontier to retain the above two basic assumptions, whereas the constant returns to the scale condition means, for $k>0$, if $(Y, X) \in F$, then $(kY, kX) \in F$.

Adding the convexity constraint $\sum \lambda_j = 1$ to the traditional CCR model, the BCC model Banker et al.[7] estimates the pure technical and scale efficiencies, on the assumption that there exists variable returns to the scale in the production technology. Thanassoulis and Dyson [8] use DEA to estimate alternative input-output target levels to render relatively inefficient organisation units efficient. Thanassoulis et al. [9] find DEA suitable for setting targets in order for the units to become more efficient. This is mainly due to the fact that DEA takes simultaneous account of all the resources and outputs in the assessment of the performance. For application to other industries such as wood and container port industry see Diaz-Balteiro et al. [10] , and Cullinane et al. [11]

3. THE DATA AND MODEL SPECIFICATIONS

The challenges of drilling and setting the completion of oil wells are significant. The conventional well construction technology is limited and highly expensive. Well engineering and operations' planning are typically project-oriented, and the demands of personnel resources and necessary lead times vary a lot. The quality of the planning, ability to make necessary decisions and commitments, clear definition of interfaces and distribution tasks are critical aspects for the success of the project. All drilling and well operations shall be properly planned and executed to achieve the objectives of the activity, with a strong focus on the cost, time, and depth effectiveness.

The goals should be defined accordingly. The main goals must be set for individual drilling wells, and in a manner that enables measurement via clear performance indicators, and with the due consideration of the possible benchmarking purposes. The goals are supposed to address the objectives of the activity and the targets of the performance. A rig service and supply plan should be prepared when the details of the well design and the operations' program are about to be completed. The plan will typically identify the equipment, services and consumables needed for the various drilling hole, in order to support the operations without delay. Special requirements for the actual well must be identified per hole to be drilled. Each hole may require a special drilling fluid system. The number of systems per well will, however, be limited and the reuse of mud should be emphasized in order to maintain the total efficiency and reduced costs.

As part of the monitoring system, the National Iranian Oil Company (NIOC) is supporting a study to benchmark the current well drilling costs and technologies. This has been designed to provide current drilling technology and cost benchmarks as reference point for evaluating future cost improvement from any change in operation's management or technologies. For the purpose of this study, the 35 previously drilled-wells located on one field, drilled within the past 2 years, will be considered. The wells can be categorized based on their formation, geographical location, their pressure in reservoir and so on. As part of the ongoing drilling benchmark study, a data set of all wells within the area was extracted selecting only the wells that met the criteria. Information was collected through operation documentation, interviewing the operators that had prominent experience in drilling wells in a specific geographical area.

The first major challenge in the examination and comparison of the well costs was to establish a data management system that would categorize costs in a consistent manner across years. Once the costs were realized, the corresponding depths and times could be established. Since technology advances have had significant impacts in the reduction of the drilling costs and time, the wells drilled in the same area with the same target can have different time and cost requirements. In addition, an important innovation in the recent decades has been the extent of horizontal and directional drilling. Horizontal drilling refers to the ability to guide a drill-string to deviate at all angles from the vertical, which allows the well bore to intersect the reservoir from sides rather than top. This allows a much more efficient extraction of resources from thin or partly depleted formations.

The benchmarking costs of wells are of importance to industry and NIOC to identify the areas where new activities can culminate in the most impact and also to measure how much improvement can be achieved. A measure of the horizontal and directional drilling is used in the DEA framework to partition the impacts of the technological change into components associated with specific technological innovations. The DEA framework was used to measure the productivity change and to carry out the various decompositions described above, thereby contributing to a better understanding of the nature of the change for our application. DEA requires the data on the input usage and on the characteristics that determine the output. We take cumulative input value for horizontal & directional drilling. In the assessment of the operational efficiency of the drilled wells, the inputs might include the cumulative costs and time, while the output concerns the depth of the well. The data for DEA model is reported in Table 1.

Table 1:

Inputs and Outputs of Drilled Wells.

No.	Cost(mr)	Time(d)	Depth(m)
1	8994.614	3793	3990
2	7439.167	3020	3700
3	10947.09	4740	3839
4	6664.461	3152	2702
5	11564.33	4029	4178
6	4826.304	2557	3930
7	4519.758	2003	3862
8	10431.51	2068	3461
9	5626.535	2049.5	3885
10	6538.588	2432	3336
11	4470.351	2370	3893
12	4592.705	1635	3174

13	18180.65	4824	3724
14	10315.4	3840	4153
15	18000.16	5049	3934
16	6941.736	1886	3645
17	10172.97	3136	3580
18	17461.34	3435	4160
19	14195.08	2419	3990
20	10804.54	2299	3942
21	24706.61	2413	4155
22	12279.41	2120	3918
23	16772.09	2246	3856
24	17315.77	2280	3755
25	2745.381	1426	3783
26	3216.959	1402	2913
27	10861.68	3380	4062
28	12091.62	2600	3993
29	15074.48	3200	4235
30	13915.3	2205	3548
31	8811.021	1875	2930
32	28004.57	3736	4400
33	13130.2	2265	4230
34	13198.71	2159	4074
35	15658.19	2267	4210
36	?	?	D_{36}

Since all wells have been drilled in the same region and the variable cost is mostly greater than the fixed cost, the constant return to the scale model might appear plausible.

The first step towards conducting a relative efficiency analysis is to define the characteristics that best describe the drilling performance. To introduce the DEA model, *(i)* the aggregated cost including the cost of location preparation, rig installation, drilling operation, casing, coring, cement, formation evaluation, and well completion *(ii)* the total time, including the time spent on different holes and the waiting time have all been selected as inputs; *(iii)* the equivalent depth including the depth of all holes from 26 to 4.125 inches would stand for the outputs. These steps would be followed in the DEA method to measure the efficiency of the drilled wells and later to introduce safe intervals for the inputs of a well with a known depth.

Step 1: Measure the efficiency of all the previously drilled wells using the *CCR* multiplayer Model P_3 to find efficient cases in the previously drilled wells.

$$\begin{aligned} & P3: Minimize \quad \theta \\ & s.t. \\ & \sum_j x_{ij}\lambda_j \le x_{ip}\theta \quad i = 1,\dots,m \\ & \sum_j y_{rj}\lambda_j \ge y_{rp} \quad r = 1,\dots,s \\ & \lambda_j \ge 0 \quad j = 1,\dots,n \end{aligned} \tag{3}$$

Step 2: Calculate an interval for the cost and time of the next planed well, say W_{36} (with corresponding inputs C_k, T_k, $k=1,\dots,K$, and output D_{36}) to be in the production possibility set and efficient. To this end, we will set different values for the first and second inputs and calculate their efficacy, θ_k in presence of all the observed DMUs (35 previously drilled-wells). So for D_{36}, we have the C_k and T_k as its estimate total cost and time, respectively. This way, a set of virtual efficient DMUs (inputs C_k, T_k and output D_{36}, $k=1,\dots,K$) are generated that serve the production possibility set as well as being efficient. The algorithm is reported in Pseudo Code 1.

Step 3: Calculate the minimum or practicable cost and time where completing W_{36} drilling operation will be feasible. Since there is a fixed per day cost for rig service, so we are able to calculate the minimum cost of holding a rig T_k days in work. Also, there is a maximum drilling length per hour according to our experience on nearby wells, so we are able to calculate a minimum time required for drilling a well with a given depth, D_{36}.

Step 4: Determine an interval for the cost and time W_{36} to be efficient and feasible. Since the inputs calculated for some of virtual DMUs are not practicable. This is a filtering activity to be run after step 2 based on the results generated in step 3.

4. COMPUTATIONAL RESULTS

We use data reported in Table 1 from the 35 previously drilled wells to evaluate their efficiency. We incorporate the constrained multiplier, input-oriented DEA model described as P_3. This two-input, one-output model is measuring the efficiency of on going drilling process by incorporating the necessary inputs. The above inputs, Cost and Time for W_{36} are ranged over the intervals [2200, 3200] and [1350, 3000], respectively.

```
Read X
Read Y
P=36
Read MaxCost, MinTime, MaxK,
Dp
Xp1=MaxCost
Xp2=MinTime
Yp1=Dp
For k =1 to MaxK
Xp1=Xp1-Δc
Xp2=Xp2+Δt
Solve CCR Model P3
Save θk
Ck=θk *Xp1
Tk=θk *Xp2
Endfor
```

Pseudo Code 1

Running the pseudo code 1 for $K=30$ over the mentioned ranges, thirty couple of Cost and Time corresponding to the pre-specified Depth, D_{36} is obtained. The methods developed in the paper assume implicitly that a given level of resource has the same *potential* productivity at all DMUs. Thus, there is no reason why the same inputs cannot be used, in principle, to estimate the total resource required by the activity levels of any given DMU. Although each pair of these inputs with output D_{36} defines an efficient DMU, practically some of them are not feasible and practicable according to the minimum cost or time requirement. These situation s have been depicted as time diagram (Fig. 1) and cost diagram (Fig. 2). The plot provides a visual indication of how the various defined decision-making units (DMUs), which are located on the "efficient frontier" change and how they can move on the efficient frontier. The different combinations of costs and time are proposed in Table 2 where feasible and infeasible cases have been marked by "Y" and "N", respectively. Also, the safety intervals for costs and time are divided into two parts. In the first part, while time increases from 1465 to 1886 the total cost decreases from 2320 to 2301. In the second part, while time increases from 1421 to1600, the total cost would decrease from 3053 to 2855.

5. CONCLUSION

This study was meant to simplify the DEA analysis process including just the aggregated values of the drilling Cost, Time and Depth. In this paper, a technology forecasting system was designed to facilitate the analysis of the current efficient frontiers and technology trends. We used DEA to determine how far well-drilling resources can increase while still serving as efficient.

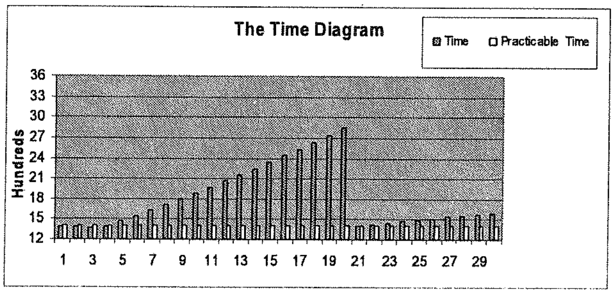

Figure 1:

The results would illustrate the usefulness and limitations of applying DEA to estimate the requirements of each well with a given depth to be drilled efficiently. The method is able to set realistic improvement targets and visualize important information to identify the under-achievers work-plans.

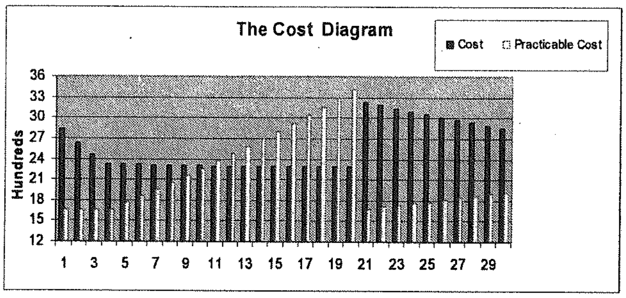

Figure 2:

Table 2:

Cost and Time corresponding to D_{36}.

k	Time(d)	Cost(mr)	Feasible
1	1387.36	2826.10	N
2	1382.07	2631.56	N
3	1377.40	2459.64	N
4	1383.47	2323.79	N
5	1464.54	2320.06	Y
6	1546.62	2316.28	Y
7	1629.73	2312.45	Y
8	1713.88	2308.57	Y
9	1799.11	2304.65	Y
10	1885.93	2301.28	Y
11	1973.91	2297.87	N
12	2063.08	2294.41	N
13	2153.45	2290.91	N
14	2245.07	2287.36	N
15	2337.95	2283.76	N
16	2435.66	2283.43	N
17	2535.03	2283.10	N
18	2636.10	2282.76	N
19	2738.91	2282.42	N
20	2843.50	2282.07	N
21	1398.28	3231.31	N
22	1420.69	3184.70	Y
23	1443.10	3139.42	Y
24	1465.52	3095.41	Y
25	1487.93	3052.62	Y
26	1510.34	3010.99	Y
27	1532.76	2970.49	Y
28	1555.17	2931.06	Y
29	1577.59	2892.66	Y
30	1600.00	2855.25	Y

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