

Approaches to Measuring Performance in Water Services

By Hasnul M. Salleh, BSc., MSc., PhD., MIEM, PE

Abstract : The measurement of performance has created uncertainty by the lack of an agreed appropriate analytical tool. The current method of evaluating and monitoring performance for example financial and operational, physical and personnel factors are made separately without bringing together the inputs and outputs into a single measure of performance.

Although companies were able to tell the level of activities undertaken they were less able to describe the level of achievement.

This paper (a) discusses a few models commonly used to measure efficiency (c) presents the concepts of effectiveness and efficiency and (d) proposes a Data Envelopment Analysis (DEA) approach to evaluate performance by combining inputs and outputs into a single efficiency score.

Introduction

Since time immemorial, people have been counting and recording results. It is a natural inclination to want to know 'How many' and 'how much'. The ability to compare is such an integral part of our daily life – 'Which brand is cheaper?', 'Who scored more goals?'- that we barely give it a thought. In government and business, on the other hand, a great deal of effort goes into this process of measuring and comparing. They are not so concerned with comparing but they will be more concerned with performance.

In the private sector, the overriding measure of performance is profit. Performance ratios are widely used throughout all sectors of business and commerce. The best known ratios are for financial and production. Ratios on its own conveys little information; it needs to be compared with, or put into the context of, some other number, measuring either a similar quantity in another organisation (or the same quantity for another time period) or a related quantity in the organisation.

Efficiency Measurement Techniques

Ratio Analysis

Ratio analysis represents a calculation of and attempts to understand the relationship between two variables. By nature, each ratio is limited to one output and one input and cannot easily

accommodate situations where multiple outputs are produced using multiple inputs. Using ratios, there is no objective way of pinpointing inefficient water companies. Typically, water companies with costs per cubic meter some distance above the mean cost might be considered potentially inefficient. There is currently no way, however to determine how far above the mean is efficient. It is conceivable that all water companies operating at the mean cost per cubic meter are also inefficient.

Ratio analysis is, however, very useful in identifying which aspect of a water company's operation are out of line with the norm. The appeal of ratio analysis is that it relies on simple mathematical concepts and can be useful in locating extremely good or poor operating relationships when interpreted by users cognizant of the limitation described above.

The econometric approach

The econometric approach¹ addresses the effects of different operating environments by statistically adjusting costs for the influence of factors which affect costs but are beyond managerial control.

As an example, we could plot the cost of providing water against an explanatory factor such as pumping head, which is the engineering measure both of the hilliness of a company's services area and the depth from which its raw water has to be pumped. This is demonstrated in the Figure 1. The diamonds represent the actual costs for several comparable water suppliers. We notice that, as pumping head increases total costs tend to rise, but the correlation is less than perfect: not all companies' costs increase exactly in line with pumping head.

¹ Cranfield University, Bedfordshire, UK. (1999). **Benchmarking Capital Maintenance Practices for The Water Industries**

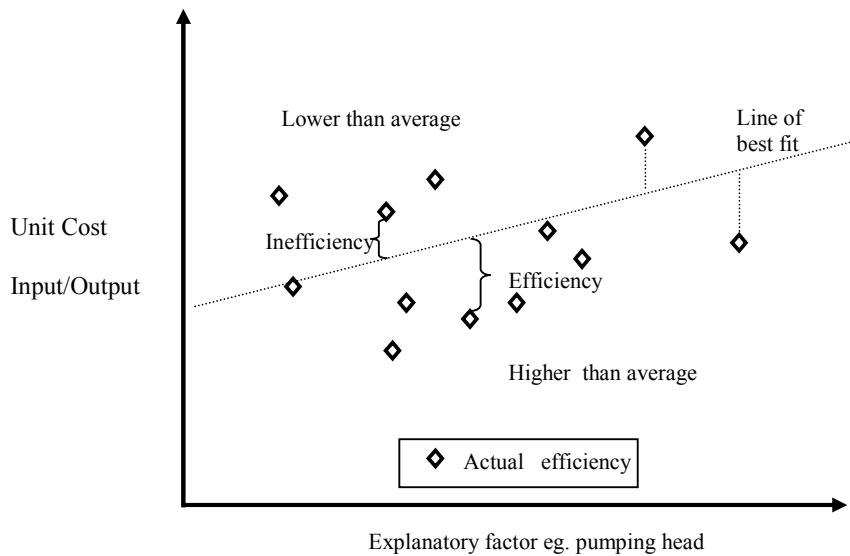


Figure 1: Measuring efficiency using the economic approach Source : Cranfield University, Bedfordshire, UK. (1999). **Benchmarking Capital Maintenance Practices for The Water Industries**

Statistical regressions measure how much cost is the direct result of the operating environment. A regression objectively fits a line through the actual data points, showing the level unit costs are expected to be given that on average each cubic meter of water needs to be pumped up X meters.

Companies with costs lower than we would expect (that is lying below the line of the best fit) are described as efficient; companies with cost higher than predicted – or explained – allowing for their operating environment, are less efficient. The measure of efficiency is the vertical distance between the actual cost point and the line of the best fit.

The econometric approach has been widely used by the economic regulators of the water and electricity industries in England and Wales, Ofwat and OFFER respectively.

Multifactorial Aspects of Performance

In the previous sections we have described some approaches to performance measurement, the measures that we have looked at are concerned either with certain facets of performance.

Detailed performance measures are very important at the micro level but they have limited value when comparing the operations of a number of composite units. For example, supposing a water company has identified three key performance ratios:

- i. Customer meter density (physical performance) - ratio 1
- ii. Water loss in distribution (Operational Performance) - ratio 2
- iii. Total Output treated Water per Employee (Service Performance) - ratio 3
- iv. Revenue per account (Financial performance) - ratio 4

It would be operationally meaningless to simply to add the four ratios to produce a composite overall measure. Some way is needed to be found to accommodate all of these individual measures so that some sort of comprehensive assessment can be made. One approach equivalent to the *z-score* model², would be to construct an expression in the form:

$$z\text{-score} = a + b(\text{ratio 1}) + c(\text{ratio2}) + d(\text{ratio 3}) + e(\text{ratio 4})$$

where a, b, c, d and e are constants. These constants would be forms of weighting factors that reflected the ‘relative importance’ of the individual ratios. It is very clear that generating a multifactoral measure of performance is difficult, both conceptually and mathematically. A more radical approach is called for.

Efficiency and Effectiveness

Before we proceed, we must first clarify some terminology so that we can be more precise in our language. There has been confusion and lack of consistency in the use of the term efficiency and effectiveness. Simply, effectiveness is associated with attainment of pre-determined goals (i.e. outputs) where else efficiency is related use of resources in the attainment outputs.

Figure 2 shows the various possible location of various water company. The target or goal is to be at location E on PQ (Efficiency frontier) and where the authority is both efficient and effective. At location F(the water authority is efficient and over effective) but at location D

² Norman and Stoker- Data Envelopment Analysis, Wiley and Sons

(the water authority is efficient but ineffective). Company C is neither efficient no effective, Company A is over effective but in efficient and company B is effective but inefficient.

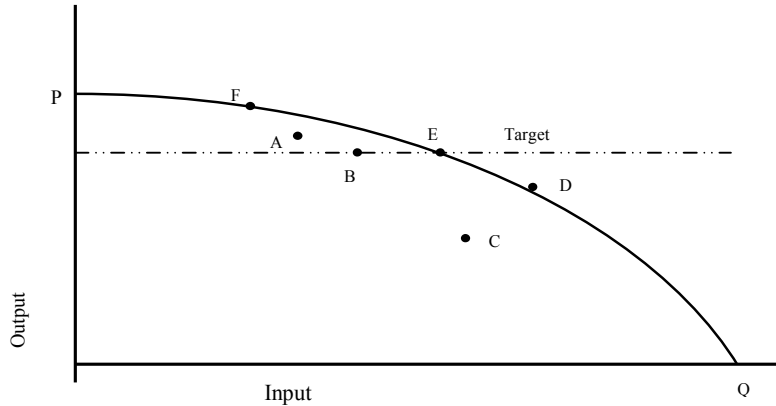


Figure 2 Efficiency and effectiveness Source :Bouchart, F. C., Hasnul, M.S., Sawkins, J. W. and Jowitt, P. W. (2001). *Leakage Targets and Socio-Economic Efficiency*. J. CIWEM, 15

Efficiency is related to performing a given task as well as possible with respect to a given performance criterion, and measures how well water companies are performing in utilising resources to generate outputs. Efficiency is the ratio of benefits achieved (outputs) to resources used (inputs).

$$\text{Efficiency} = \frac{\text{output}}{\text{input}}$$

Technical Efficiency

To illustrate technical efficiencies reference is first made to Figure 3 for the single input and single output case. In this example there are seven Decision Making Units DMUs, each consuming a single input (x) to produce a single output (y) which are assigned the co-ordinates which represent the corresponding DMUs. The inputs and outputs of the seven DMUs are P₁(2,2), P₂(3,5), P₃(6,7), P₄(9,8), P₅(5,3) P₆(4,1) and P₇(10,2).

The definitions of efficiency are made with reference to Constant Returns to Scale (CRS). With the CRS assumption, proportional changes in all input levels result in changes of equal proportion in output levels.

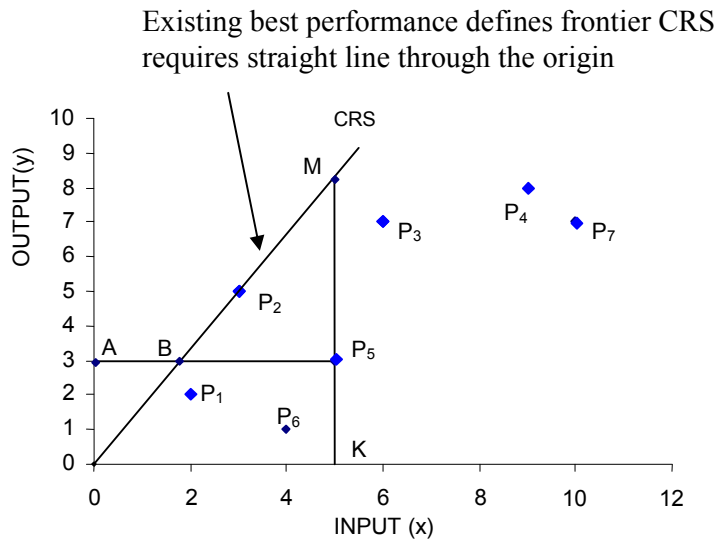


Figure 3 Efficiency Frontier-CRS

Consider the points $P_1 - P_7$ illustrated in Figure 3. The CRS efficiency frontier is established as the straight line through the origin and P_2 . P_2 is technically efficient. Technical efficiency is the ability to obtain the greatest possible output from a given input, or to produce a given output with the lowest possible amount of inputs. The theoretical consideration of technical efficiency has existed in the economic literature since 1951 Interest in this early theoretical work on technical inefficiency was renewed late in the 1970s with the development of DEA (Ruggiero, 2000). P_1, P_3, P_4, P_5, P_6 and P_7 are not technically efficient under the CRS assumption because these points are not on the frontier. The same output could be achieved with a lower input or conversely this input amount is capable of producing a larger output. For example for DMU_5 From Figure 3.

$$\text{Input saving technical efficiency} = E_1 = AB/AP_5$$

$$\text{Output increasing technical efficiency} = E_2 = KP_5/KM$$

Measures of Effectiveness

Effectiveness is defined as the ability of water utilities to achieve a specific objective. A water utility's objectives in terms of adequacy and safety of supplies may not be enough when reduction of leakage is also a concern. Thus, the ability to actually achieve the stated objective

(for example leakage target) is a measure of water utility's effectiveness. In this case, effectiveness is the ratio of leakage reduction achieved to the leakage target set.

$$\text{Effectiveness} = \frac{\text{Leakage achieved}}{\text{leakage target}}$$

The distinction between effectiveness and efficiency needs to be emphasised in evaluating DMU performance, for example, leakage reduction. Consider the following definitions for some company j.

CRS^T	is the efficiency frontier for year 1
CRS^{T+1}	is the efficiency frontier for year 2
P_j^1	actual (observed) value for year 1 for company j
P_j^2	actual (observed) value for year 2 for company j
T_j^1	Target value for year 1 for company j
T_j^2	Target value for year 2 for company j
Y_j^1	Potential Output for year 1 for company j
Y_j^2	Potential Output for year 2 for company j
R_1^1	Company R_1 as reference for year 1
R_2^2	Company R_2 as reference for year 2

The CRS efficiency frontiers in year 1 and 2 are defined by reference points corresponding to some company R_1 in year 1 and some company R_2 in year 2 (R_1 may or may not be the same as R_2). The efficiency frontier is represented by the line through R_1^1 and O. It gives information about performance on how well a company is performing and what its potential is. The output OY_j^1 (see Figure 4) represents the potential or target performance in terms of efficiency of a company to achieve the best leakage reduction given its current level of input. Hence point B is the potential leakage reduction achievable in relation to reference company R_1^1 (efficient).

Now consider Figure 4 in terms of effectiveness for some company j. Effectiveness measures can be based on the observed or potential outputs and are termed as the actual and potential effectiveness respectively, defined as follows:

$$\begin{aligned}
\text{Actual Effectiveness} &= \text{Actual Leakage Reduction/ Leakage Target} \\
&= OA_j^1 / OT_j^1 \quad (\text{Year 1 for company } j) \\
&\text{or} \\
&= OA_j^2 / OT_j^2 \quad (\text{Year 2 for company } j) \\
\text{Potential Effectiveness} &= \text{Actual leakage Reduction/Potential Leakage Reduction} \\
&= OA_j^2 / OY_j^1
\end{aligned}$$

The Actual Effectiveness in any particular year is a measure of how well a water utility does in relation to its target. Potential Effectiveness is a measure of how well the company does in meeting its output target in a particular year given how well it could have done in the previous year if it had been maximally efficient.

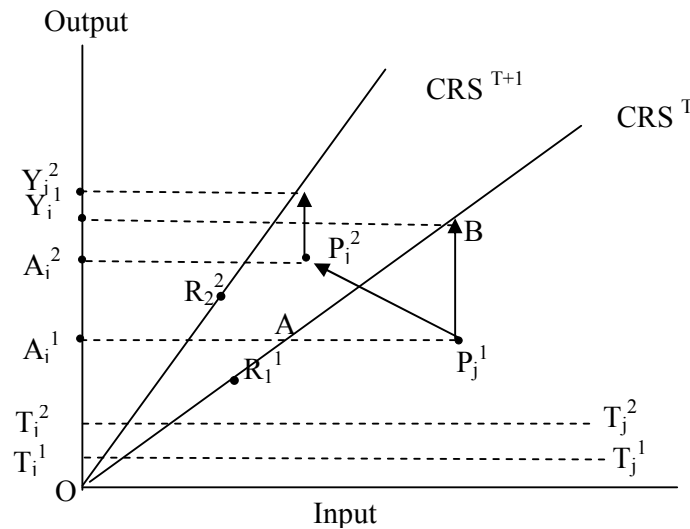


Figure 4 Measure of Effectiveness. Source: Hasnul, M.S., (2000) Evaluation of Non-Revenue Water and Leakage in Public and Private Water Supply

Generally speaking efficiency measures need to deal with multiple outputs as well as multiple inputs and the explicit weights or relative importance of these factors are generally not available. To avoid any need for using a priori weights the approach of Charnnes, Cooper, and Rhodes (1978) is followed which is based on the concept of Pareto Optimality. This idea is used in Data Envelopment Analysis (DEA) to avoid making a priori assumptions about the weights to be assigned to different outputs and inputs.

DEA Application

Data Envelopment Analysis (DEA) has proven to be a powerful tool for the analysis of the magnitude and cause of inefficiency. It is now widely applied to performance analysis in such diverse fields. DEA uses linear programming to establish an ‘efficiency frontier’ from the most efficient utilities in our data set. The boundary is created by linearly linking the observed performance of the best performing companies in the sample, and is determined by the relationship between their inputs and outputs (Figure 5). Utilities that form the efficiency frontier use the minimum quantity of inputs to produce the same quantity of outputs as other, similar utilities.

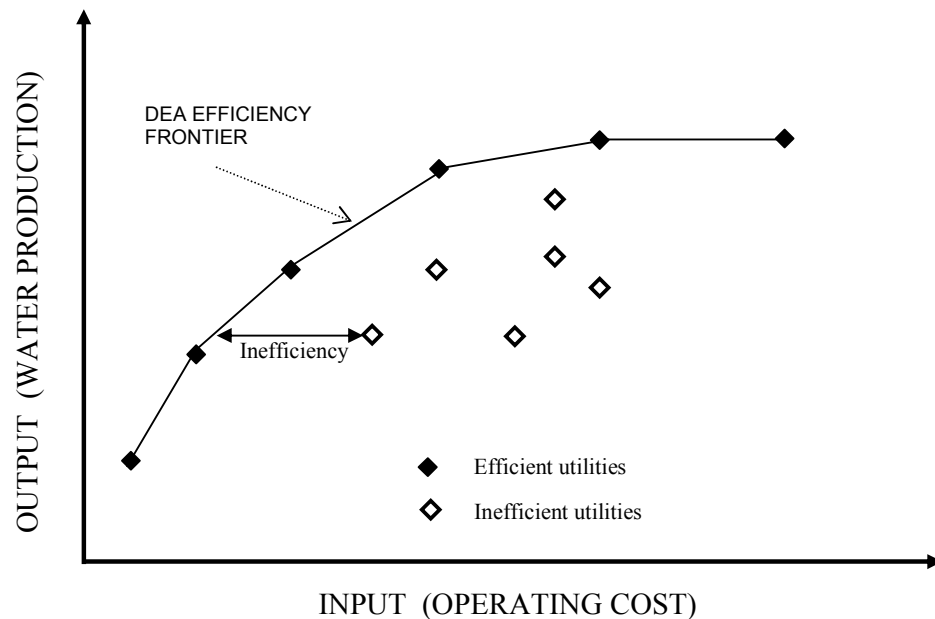


Figure 4: Fitting Frontier using DEA Source : Cranfield University, Bedfordshire, UK. (1999). **Benchmarking Capital Maintenance Practices for The Water Industries**

DEA is a procedure that has been developed to measure relative efficiency in situations where there are multiple inputs and outputs. It is a procedure designed to evaluate relative efficiency of public sectors Decision Making Units (DMUs) performing similar missions for which actual measures of inputs and outputs are available.

The relevant inputs and outputs factors and the numerical measures for the factors identified were used to formulate the linear programming model. Using input and output factors in Table 1 simple DEA models are formulated. To see the structure of a typical DEA model more clearly, consider the model illustrated in Table 1, which has 5 DMUs, each with with 3 input factors x_1, x_2, x_3 and outputs factors y_1, y_2, y_3 .

DMUs	Input factors			Output factors		
	x_1	x_2	x_3	y_1	y_2	y_3
1	x_{11}	x_{21}	x_{31}	y_{11}	y_{21}	y_{31}
2	x_{12}	x_{22}	x_{32}	y_{12}	y_{22}	y_{32}
3	x_{13}	x_{23}	x_{33}	y_{13}	y_{23}	y_{33}
4	x_{14}	x_{24}	x_{34}	y_{14}	y_{24}	y_{34}
5	x_{15}	x_{25}	x_{35}	y_{15}	y_{25}	y_{35}

Table 1 Inputs and Output Factors

For example;

$x_{11} \dots x_{35}$ represent input factors for $DMU_1 \dots DMU_5$

$y_{11} \dots y_{35}$ represent output factors for $DMU_1 \dots DMU_5$

$x_1 \dots x_3$ represent input factors 1...3.

$y_1 \dots y_3$ represent output factors 1...3.

$\mu_1 \dots \mu_3$ represent output weights.

$v_1 \dots v_3$ represent input weights.

Now consider the efficiency of DMU_1 :

Using the CRR³-Ratio Model

$$\text{Efficiency of } DMU_1 = \frac{\text{outputs}}{\text{inputs}} = \frac{\mu_1 y_{11} + \mu_2 y_{21} + \mu_3 y_{31}}{v_1 x_{11} + v_2 x_{21} + v_3 x_{31}}$$

$$\max h_o = \frac{\sum_r^s \mu_r y_{ro}}{\sum_i^m v_i x_{io}}$$

What is now sought is the set of weighting factors μ and v which maximise the efficiency measure to subject to constraints on the efficiency of the other 4 DMUs. This lead to the Non Linear Program.

³ Charnes, A., Cooper, W.W. and Rhodes

$$\frac{\sum_r \mu_r y_{rj}}{\sum_i v_i x_{ij}} \leq 1; j = 0, 1, \dots, n$$

$$\mu_r \geq 0; r = 1, \dots, s$$

$$v_i \geq 0; i = 1, \dots, m$$

This can be linearised by applying a normality constraint on the weighted inputs and arranging the other constraints. The output can be maximised after constraining the weighted inputs to unity. Therefore,

$$\begin{array}{ll} \text{Maximise} & \mu_1 y_{11} + \mu_2 y_{21} + \mu_3 y_{31} \\ \text{Subject to} & v_1 x_{11} + v_2 x_{21} + v_3 x_{31} = 1 \end{array}$$

For the constraint on DMU₁

$$\frac{\mu_1 y_{11} + \mu_2 y_{21} + \mu_3 y_{31}}{v_1 x_{11} + v_2 x_{21} + v_3 x_{31}} \leq 1$$

$$\mu_1 y_{11} + \mu_2 y_{21} + \mu_3 y_{31} \leq v_1 x_{11} + v_2 x_{21} + v_3 x_{31}$$

$$-\mu_1 y_{11} - \mu_2 y_{21} - \mu_3 y_{31} + v_1 x_{11} + v_2 x_{21} + v_3 x_{31} \geq 0$$

$$\therefore \text{DMU}_1 : -\mu_1 y_{11} - \mu_2 y_{21} - \mu_3 y_{31} + v_1 x_{11} + v_2 x_{21} + v_3 x_{31} \geq 0$$

$$\mu, v, \geq 0$$

Similarly for DMU₂...DMU₅

$$\therefore \text{DMU}_2 : -\mu_1 y_{12} - \mu_2 y_{22} - \mu_3 y_{32} + v_1 x_{12} + v_2 x_{22} + v_3 x_{32} \geq 0$$

$$\therefore \text{DMU}_3 : -\mu_1 y_{13} - \mu_2 y_{23} - \mu_3 y_{33} + v_1 x_{13} + v_2 x_{23} + v_3 x_{33} \geq 0$$

$$\therefore \text{DMU}_4 : -\mu_1 y_{14} - \mu_2 y_{24} - \mu_3 y_{34} + v_1 x_{14} + v_2 x_{24} + v_3 x_{34} \geq 0$$

$$\therefore \text{DMU}_5 : -\mu_1 y_{15} - \mu_2 y_{25} - \mu_3 y_{35} + v_1 x_{15} + v_2 x_{25} + v_3 x_{35} \geq 0$$

Thus

Maximise $\mu_1 y_{11} + \mu_2 y_{21} + \mu_3 y_{31}$

Subject to:

$v_1 x_{11} + v_2 x_{21} + v_3 x_{31} = 1$ (Constraints on Weighted Inputs)

$-\mu_1 y_{11} - \mu_2 y_{21} - \mu_3 y_{31} + v_1 x_{11} + v_2 x_{21} + v_3 x_{31} \geq 0$ (DMU₁)

$-\mu_1 y_{12} - \mu_2 y_{21} - \mu_3 y_{32} + v_1 x_{12} + v_2 x_{22} + v_3 x_{32} \geq 0$ (DMU₂)

$-\mu_1 y_{13} - \mu_2 y_{21} - \mu_3 y_{33} + v_1 x_{13} + v_2 x_{23} + v_3 x_{33} \geq 0$ (DMU₃)

$-\mu_1 y_{14} - \mu_2 y_{21} - \mu_3 y_{34} + v_1 x_{14} + v_2 x_{24} + v_3 x_{34} \geq 0$ (DMU₄)

$-\mu_1 y_{15} - \mu_2 y_{21} - \mu_3 y_{35} + v_1 x_{15} + v_2 x_{25} + v_3 x_{35} \geq 0$ (DMU₅)

The above formulation can be used to calculate efficiency involving combination of various inputs and outputs.

Single Input and Multiple Outputs - Mathematical Development.

In this example, data from Table 2 will be used for the illustration. Five water companies produce two outputs (y_1, y_2), from a single input (x). The output is divided by the input and expressed as output per unit input. This has the effect of normalising the output levels of the water companies and making it possible to compare the normalised output level across the

Company	Costs (x)	Mains Replaced (O ₁)	Comm. Pipes Replaced (O ₂)	Mains Replaced/ Costs (y ₂)	Comm. Pipes Replaced/ Costs (y ₁)
A	19.5	2105	22080	107.9	1132.3
B	16.4	4806	112128	293.0	6837.1
C	10.3	4346	47932	421.9	4653.6
D	8.9	327	6132	36.7	689.0
E	6.0	399	14137	66.5	2356.1

Table 2 Single Input and Multiple Outputs

Efficiency of Company D = $OY/OZ = OE/OF = 77/696.6 = 0.111$

For Company E,

Efficiency = $OS/OP = OR/OQ = 2356/6837 = 0.3446$.

For multiple inputs and multiple outputs the problem can not be represented graphically. The linear programming have to be formulated and solved by simplex method. This is illustrated in Figure 7, where relative efficiency is evaluated by measuring its performance relative to the efficiency frontiers.

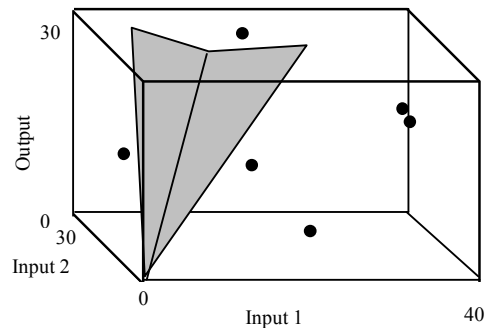


Figure 7 Constant Returns To Scale Envelopment Surface

Malmquist indicators⁴

Malmquist indicators are a development of DEA efficiency measures which calculate past rates of progress of the efficiency frontier in an industry in order to predict future rates of

⁴ Cranfield University, Bedfordshire, UK. (1999). **Benchmarking Capital Maintenance Practices for The Water Industries**

shift. Companies can thus separate their future efficiency targets into a catch-up component and a frontier-shift effect:

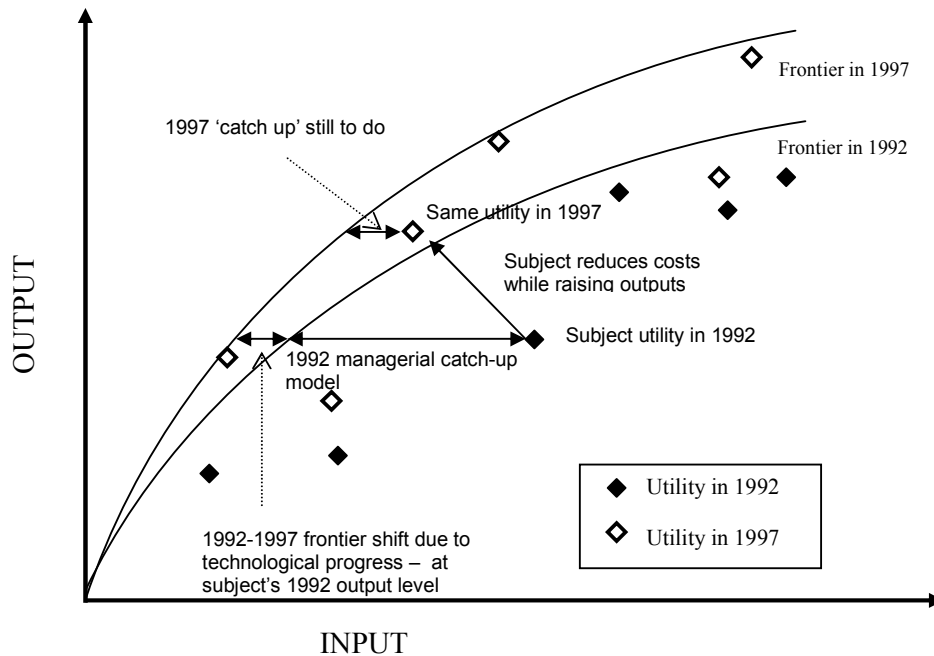


FIGURE 8 MALMQUIST INDICATORS-Source : Cranfield University, Bedfordshire, UK. (1999). **Benchmarking Capital Maintenance Practices for The Water Industries**

In the example above (Figure 8) a utility in 1992 was fairly inefficient. Over the next five years it achieved the difficult feat of reducing its costs while increasing its outputs. In 1997 it was approaching a different part of the efficiency frontier but still had some managerial catch-up to do. However at its new output level technological progress is driving the efficiency frontier considerably faster than it was at the old output level.

Conclusions

The appropriate approach to performance measure depends on the purpose of the exercise. DEA is a promising tool to evaluate hospital efficiency. This method is particularly useful in water industry application because it can simultaneously accommodate multiple outputs and inputs. Water companies located as inefficient are strictly inefficient and there is no problem of false identification efficient water company as inefficient provided that all relevant outputs and inputs are included in the data set. DEA indicates the general magnitude of inefficiencies. A key ingredient in the DEA evaluation is the location and measurement of the relevant inputs and outputs. The advantage of DEA over other techniques is that each input and output can be measured in its natural physical unit without the need to apply a weighting system. DEA is therefore, proposed as a useful complement to, rather than replacement for, other technique.

References

- 1 Cranfield University, Bedfordshire, UK. (1999). **Benchmarking Capital Maintenance Practices for The Water Industries,**
- 2 Akosa, G., Franceys, R., Barker, P., and Weyman-Jones, T., (1993) **Journal of Infrastructure Systems.**
- 3 Sherman , D. H., **Hospital Efficiency Measurement and Evaluation.**(1984) Medical Care, Vol 22, No 10.
- 4 Stoker, B and Norman, M(1991). **Data envelopment Analysis: The Assessment of Performance.** J. Wiley and Sons.
- 5 Hasnul, M.S., (2000) Evaluation of Non-Revenue Water and Leakage in Public and Private Water Supply. Heriot Watt University.
7. Bouchart, F. C., Hasnul, M.S., Sawkins, J. W. and Jowitt, P. W. (2001). **Leakage Targets and Socio-Economic Efficiency.** J. CIWEM, 15.
8. Fried, H.O., Lovell, C.A.K. and Schmidt, (1993). **The Measurement of Productive Efficiency.** (edited) 1993, Oxford University Press.
9. Charnes, A.,Cooper, W.W. and Rhodes, E., (1978). **Measuring the Efficiency of Decision Making Units.** Journal of Operational Research . Vol. 2,(6),439-444.
10. Ruggiero, J., (2000). **Theory and Methodology Measuring Technical Efficiency.** European J. of Operational Research, 121,138-150