Measuring Quality Cost Effects on Productivity Using Data Envelope Analysis

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Abstract

Quality has become more important than ever in the production of goods and services. Money spent on quality must ultimately contribute to increased productivity within the firm. Quantifying the benefits of quality costs with respect to increased productivity is an elusive proposition. This paper describes the use of a linear programming technique called data envelopment analysis (DEA) to measure the effects of appraisal and prevention costs on productivity. DEA provides additional information to the normal profit driven performance measures and can be used to determine strategies to help improve the efficiency of money spent on quality.

Introduction

Over the last several years, firms have faced increased competition from both domestic and foreign companies. Perceived and real superiority of the quality of foreign products has forced domestic firms to address the problems of productivity and quality. Failure to do so has led to both product and firm failure.

With an increased emphasis on quality comes an increase, at least in the short run, in quality costs. But money spent indiscriminantly on something even as important as quality can lead to inefficient spending and higher costs than necessary. A method is needed to measure the efficiency of money spent of quality, especially as it relates to increased productivity.

The purpose of this paper is to discuss a method for helping managers evaluate the efficiency of quality costs as it relates to productivity. This method is called data envelopment analysis.

This paper has three main parts. The first part describes the concepts of quality and quality costs. The bulk of this discussion is derived from Morse, Roth and Poston, *Measuring, Planning and Controlling Quality Costs*, 1987. The second part presents an overview of data envelopment analysis, and how it relates to measuring the efficiency of quality cost spending. Part three presents an example of using data envelopment analysis to capture quality cost efficiency as it relates to productivity.

The Concept of Quality

An operational definition of quality is how a product meets its requirements or specifications. This is referred to as quality of conformance. If a shoe manufacturer specifies that there should be no scuff marks on the final product, a quality inspector would classify a scuffed shoe as nonconforming.

The costs of quality are the costs that exist because poor quality may or does exist. Quality costs are the costs associated with the creation, identification, repair and prevention of defects. These costs can be classified into four categories: prevention costs, appraisal costs, internal failure costs, and external failure costs. Because things may go wrong, a company incurs prevention and appraisal costs. When things do go wrong, a company experiences failure costs.

Prevention costs are incurred to prevent defects in the products, or services being produced. Prevention costs are incurred in order to decrease the number of nonconforming units. Examples of prevention costs are quality engineering, quality training programs, incremental costs of superior materials, higher wages paid to more highly skilled workers, supplier evaluations, quality audits, and design reviews.

Appraisal costs are incurred to determine whether products and services are conforming to their requirements. Examples include inspection and testing of raw materials, packaging inspection, supervision of appraisal activities, supplier verification, and field testing.

Internal failure costs are incurred because nonconforming products and services are detected prior to being shipped to outside parties. These are the failures detected by appraisal activities. Examples of internal failure costs are scrap, rework, reinspection, and retesting. If no defects exist, these costs are zero.

External failure costs are incurred because products and services fail to conform to requirements after being delivered to customers. Examples include warranty costs, lost sales, returns and allowances due to poor quality, and product liability costs.

Productivity and Quality

Productivity is a measure of the efficiency of resource use. It relates to all types of organizations. It is typically measured by computing the ratio of outputs to inputs. The higher the ratio, the higher the productivity and the more efficiently resources are being used.

Quality experts have had to battle against the common belief that high quality costs means lower productivity. But in reality there may be no lower cost way to improve productivity and reduce manufacturing costs than to institute a strong error prevention or zero defects system. A key tool for gaining commitment to a quality improvement effort is calculating the cost of quality. Another expert says that an organization can increase profits by five to ten percent of sales by focusing on increased quality (Zemke, 1990).

The relationship of quality, productivity and production costs is as follows: higher quality means lower rejection rates, which means less waste of inputs (material labor, and overhead), which leads to more output for the given level of inputs, lowering unit cost.

Quality Cost Reports

Current methods of monitoring quality costs deal primarily with measuring actual costs versus a predetermined budget or standard amount. Variances can be measured against standard, for virtually any time frame. Trends can be analyzed and long run performance measured against target costs can be evaluated. A common rule of thumb among quality experts seems to be that the sum of all quality costs should be no more than 2.5% of sales.

Although the analyses discussed above are useful, it would also be useful if an overall measure of quality costs as they relate to changes in productivity could be developed for a given time period. This measure would consider the relevant categories of quality costs and the output for the period simultaneously. The measure employed would then be able to give a quantified measure of how efficiently quality costs were being spent. This measure would be analagous to the return on investment measure used in profit centers. Data envelopment analysis can provide this overall measure of efficiency.

Data Envelopment Analysis

Data envelopment analysis (DEA) is a linear programming-based technique that converts multiple input and output measures into a single comprehensive measure of efficiency (Charnes et al., 1978). This is accomplished by the construction of an empirically based production possibility frontier and the identification of similar or peer groups. An example would be departments in a production process. Charnes labeled these groups decision making units (DMUs). Each unit is evaluated by comparing to a composite unit that is constructed as a linear combination of other DMUs in its peer group (Banker and Morey, 1986a).

As originally developed, DEA compares a specific DMU to a similar set of DMUs to determine whether any in the set are relatively more efficient than the specific DMU being evaluated. As such, DEA is a measure of relative efficiency. An efficient DMU is defined as one that is able to produce the same level and mix of products or services as other DMUs in the analysis, but using fewer inputs. Examples of inputs are materials, labor and technology.

In this paper, DEA will be used as a time series measure. That is, rather than comparing efficiency between production departments, DEA will be used to measure the efficiency of a specific department through time. DEA can be used to compare the performance of a particular unit over time by adopting the convention that the same DMU is to be regarded as a different entity in each relevant time period (Charnes et al., 1978).

The reason for using DEA over time is that departments may not be similar enough in nature to warrant direct comparisons. Departments may be so different in size, complexity and procedures that comparisons between them become irrelevant. Quality control systems should be tailored to the needs of individual departments, with the department managers involved in deciding what they need from it (Whitehall, 1986).

Graphical Example

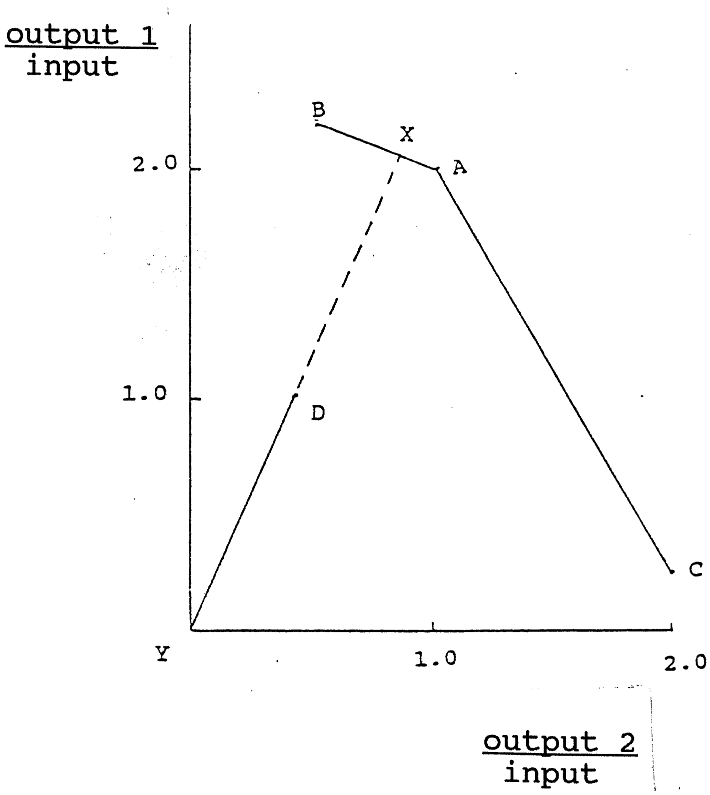
To illustrate the basic idea of DEA, Table 1 shows inputs and outputs for four DMUs, labeled A, B, C, and D (Tomkins and Green, 1988). The output/input ratios of each DMU with respect to both outputs have been used to locate each DMU on Figure I.

Table 1
Inputs and Outputs for DEA Example (Figure 1)

DMU	Output 1	Output 2	Input	Output1/ input	Output2/ input
A	2000	1000	1000	2.00	1.0
B	2200	500	1000	2.20	0.5
C	500	4000	2000	0.25	2.0
D	2500	1000	2500	1.00	0.4

Figure I

The Concept of DEA



Movement upward to the right represents greater efficiency. Figure I indicates that DMU D is less efficient than A, B and C, while A, B, and C are relatively efficient. DMUs which are relatively efficient generate an efficient linear combination or efficiency frontier with respect to the set of DMUs under consideration. In Figure I this combination or frontier is represented by line ABC.

DMUs on the efficiency frontier are defined as having an efficiency measure of one. Each DMU not on the frontier has its efficiency measured relative to its comparable efficient linear combination and will have an efficiency rating of less than one. The farther away from the efficiency frontier, the lower the efficiency level. Graphically, this distance is measured with a straight line originating from the origin through the DMU data point to the efficiency frontier. The relative efficiency of DMU D is YD/YX in Figure I. The larger this ratio, the closer the DMU is to the efficiency frontier and to an efficiency level of one.

One may refer to the efficient DMUs that provide an efficient linear combination for a DMU as the reference set for that DMU. Thus, the reference set for DMU D is DMU A and DMU B. This reference set will ultimately provide guidelines for improvement in the DMU under consideration. This will be discussed in detail later.

Previous Applications of DEA

As originally developed, DEA was used in the public, not-for-profit sector. Since then, it has been extended into the private, for-profit arena. In the non-profit sector, DEA has been tested empirically as an efficiency measure in hospitals, (Banker, 1984; Banker et al., 1986; Sherman, 1984), rural health care, (Huang and McLaughlin, 1989), nursing service, (Nunamaker, 1983; Lewin, 1983), education, (Bessent and Bessent, 1980; Bessent et al., 1983; Charnes et al., 1981; Ludwin and Guthrie, 1988), Medicaid reimbursement policy, (Capettini et al., 1985), social welfare agencies, (Heffernan, 1991), social insurance systems, (Bjurek et al., 1990), highway maintenance patrols, (Cook et al., 1990) and the courts, (Lewin et al., 1982).

In the for-profit area, empirical tests have been done on fast food operations, (Banker and Morey, 1986b), pharmacies, (Banker and Morey, 1986a), manufacturing maintenance departments, (Turner, 1989), banking, (Sherman and Gold, 1985; Vassiloglou and Giokas, 1990; Oral and Yolalan, 1990), and internal auditing, (Sherman, 1984a).

DEA and Performance Evaluation

DEA has the following advantages for measuring efficiency (Epstein and Henderson, 1989):

1. Multiple outputs and inputs may be included simultaneously in a single measure. Efficiency is not often a simple or singular measure. DEA can help avoid the ambiguity that can arise with simple measures such as ratio analysis or cost variances.

2. A priori weights are not required for outputs or inputs. It is not necessary to specify the importance, rank or weight for either outputs or inputs.

3. A management strategy to improve efficiency may be developed, if controllable inputs are included. Output increases, input reductions or both needed to achieve efficiency can be determined.

4. DEA focuses on achievable, best performance. Each DMU is compared to other DMUs, or itself over time, not a hypothetical ideal or average performance. DEA provides a meaningful and defensible standard based on best observed practice. By providing a mechanical and replicable measure of performance, DEA can help standards be fair and objective.

5. Noncontrollable variables can be accounted for.

6. The reduction of multiple variables to a single performance measure reduces cognitive complexity.

In summary DEA provides a technique for assessing relative efficiency in contexts where there are multiple incommensurate outputs and inputs and also provides an indication as to how a DMU should attempt to vary its inputs and outputs so as to achieve a performance comparable to the best observed.

DEA - Technical Formulation

In technical terms, DEA is a mathematical program developed as an ex-post efficiency measurement for DMUs (Charnes et al., 1978). The DEA efficiency measurement is obtained as the maximum of a ratio of weighted outputs to weighted inputs subject to the condition that the ratios for every DMU be less than or equal to one.

The basic, simplified formulation is as follows (Ludwin and Guthrie, 1989):

$\text{Max } E = \Sigma UrYro/\Sigma ViXio.$

Maximize the ratio of the sum of the total outputs (Y) to the total inputs (X) for DMU o under consideration.

Subject to: $\Sigma UrYrj/\Sigma ViXij <= 1$

The Yrj, Xij values represent the known outputs and inputs for the jth DMU. The U and V values are the weights or virtual multipliers for each of the individual outputs and inputs (designated by the r and i subscripts respectively) in the ratio. The solution of the DEA formulation results in multipliers for each DMU such that E is maximized. If the DMU is efficient, the virtual multipliers will cause E to be equal to one. For less efficient units, E will be less than one. Thus, E is the efficiency rating assigned to the DMU under evaluation.

The above formulation involves a nonlinear nonconvex programming problem. Charnes et al., 1978 showed that the problem may be stated as a linear programming formulation. This new formulation is as follows:

Objective Function:

Maximize the sum of the weighted individual outputs ($\Sigma UrYro$) for the DMU being evaluated.

Subject to:

1. The sum of the individual outputs ($\Sigma UrYrj$) minus the sum of the individual inputs ($\Sigma ViXij$) for each separate DMU must be less than or equal to zero. This constraint will be entered for each DMU in the analysis.

2. The sum of the inputs ($\Sigma ViXio$) for the DMU being evaluated must equal one.

In formula form, the model looks as follows:

$\max \ \Sigma UrYro$

subject to:

a) $\Sigma UrYrj - \Sigma ViXij <= 0$ (for each DMU in the model)
b) $\Sigma ViXio = 1$

This formulation will be numerically illustrated below:

In effect, each DMU is invited to specify the set of weights to apply to its inputs and outputs to determine its maximum relative efficiency, subject only to no other DMU having a relative efficiency greater than one having those weights. One can therefore use this approach to calculate the relative efficiency of each DMU, or the same DMU over time, by solving the linear programming formulation.

Data Development Guidelines

The following guidelines should be used for accumulating the data for measuring quality, efficiency and productivity:

1. The relationship between the output and the related inputs should make economic sense. Output will normally be good or conforming output. But total output by itself is not the best measure. There could be a period of heavy output that generated heavy waste. So a better measure of output might be total good output as a percent of total output. Output then would be a percent measure between 0 and 100%.

2. There may be lags in the use of inputs to produce outputs. Quality costs incurred today may not take effect until future periods. This is probably more true with respect to prevention costs than appraisal costs. So care must be taken to properly match up costs with output. Some subjectivity as far as timing the costs and the benefits in terms of good output may be unavoidable.

3. Ideally, outputs and inputs should be measured in physical units. This helps prevent distortions due to inflation. With quality costs however, dollar amounts may be the only available unit of measure. Using percents may be a way around this problem. Output can be expressed as a percent of good output to total output. Inputs can be expressed as a percent of some relevant activity level. Examples of this include total standard manufacturing costs, total labor costs, or total overhead costs.

4. The data used in the analysis should be checked for consistent reporting. If the company has changed its classification and measurement of a particular input or output, this must be accounted for in the analysis. With DEA being implemented for the first time, classification of quality costs must be carefully and consistently applied.

5. Along with consistent reporting, the relationship between the inputs and output should also stay consistent. Major changes in the production process can have an influence on productivity that is not measured in the quality cost model. If new equipment is introduced into the process, quality before and after the purchase will be different based not only on quality costs, but also on the new equipment.

6. The data must be checked for unusual conditions, such as a strike, a special one-time rush order, or operating inefficiencies caused by excess capacity.

7. To insure reliable results, Lewin et al.(1982) suggest a step-wise regression of potential variables. Incorporating only the most statistically significant variables helps in determining those inputs most closely associated with efficiency. While statistical significance does not in itself indicate or measure efficiency of the inputs, including non-significant variables may lead to taking action on inputs that will have little benefit to the department.

8. With respect to the number of inputs and outputs to measure, there is no ideal quantity. DEA is, however, better able to locate inefficiencies when the number of periods is greater then the number of inputs and outputs combined.

9. Finally, the observation period should be the shortest period for which all the inputs and outputs are recorded. This would give the most rapid feedback with respect to efficiency.

As can be seen from the above points, discretion is necessary to properly evaluate and use data for the model. Still, this is no different from many other reporting processes.

Example

For this paper, the outputs and inputs for the model will be based on percentages. As was discussed above, this helps to adjust for problems arising from dollar measures. The output will be the percent of good or conforming output to the total equivalent units of output for a given time period for a specific production department. The time period will be monthly, as this is probably the most common time frame.

For simplicity, output for the department will be aggregated. DEA can handle as many separate outputs as desired.

There will be two inputs used in the example. As with outputs, DEA can handle as many inputs as desired. Two inputs were chosen to allow a graphical view of the example.

The inputs used are:

I1: total prevention costs as a percent to total standard production cost.

I2: total appraisal costs as a percent to total standard production costs.

These two categories of inputs are aggregates of all the costs classified in these two categories. These categories should be recorded in accordance with the data guidelines discussed above.

Prevention and appraisal costs are used because they are production costs incurred to increase quality. These are discretionary or voluntary. In general, prevention and appraisal costs will initially increase as conforming output increase. In line with the requirements of the model, the inputs should reflect the resources required to produce the outputs such that an increase (decrease) in output levels is expected to result in an increase (decrease) in the amount of inputs used.

Failure costs, both internal and external are after the fact costs that result from nonconforming output. These are not a planned part of the production process. These costs tend to decrease as the percent of conforming output increases. As this model is developed, they will not be included.

Table 2 shows the data used for the example:

analysis can use a moving average technique, dropping the oldest month while adding the current month. This time frame was chosen for explanatory purposes. Different time frames can be used provided that each period meets the data requirements discussed above. December is examined in detail.

To help visualize the example, examine Figure II. Each axis represents the value of the percent of good monthly output divided by each quality cost category as a percent of their respective standard production costs. This data is shown in Table 2.

Figure II indicates that the months February, April, and May were the most efficient months in the analysis. A line connecting these points represents the production possibility frontier. If DEA was run on these months, their efficiency measure would be one. The other months, including December, are less efficient, as they fall below the frontier.

To run the analysis, what is needed is a personal computer, an elementary knowledge of linear programming, and software to run a linear programming model. The software used in this paper is called Quantitative Systems for Business (Chang and Sullivan, 1989). It is readily available and inexpensive.

Table 2
Artificial Data Set: Schedule of Output and Inputs

	Output	--Inputs----		-Figure II Data-	
Column(*)	(1)	(2)	(3)	(4)	(5)
January	88	6.0	5.1	14.67	17.25
February	84	5.7	4.3	14.74	19.53
March	87	6.0	4.6	14.50	18.91
April	90	5.7	4.9	15.79	18.37
May	86	5.4	4.9	15.93	17.55
June	88	6.0	4.8	14.67	18.33
July	91	6.4	5.1	14.22	17.84
August	87	5.9	4.8	14.75	18.13
September	92	6.2	5.0	14.84	18.40
October	96	7.3	5.3	13.15	18.11
November	90	6.1	5.0	14.75	18.00
December	92	6.7	5.2	13.73	17.69

(*)Column 1: % good output to total output
Column 2: % prevention costs to total standard manuf costs
Column 3: % appraisal costs to total standard manuf costs
Column 4: column1/column2
Column 5: column1/column3

The hypothesized data set show the results for all twelve months of a particular year, beginning with January and concluding with December.

These inputs were regressed against the output and were found to be statistically significant ($p=.05$). This is in conformity with data guideline seven.

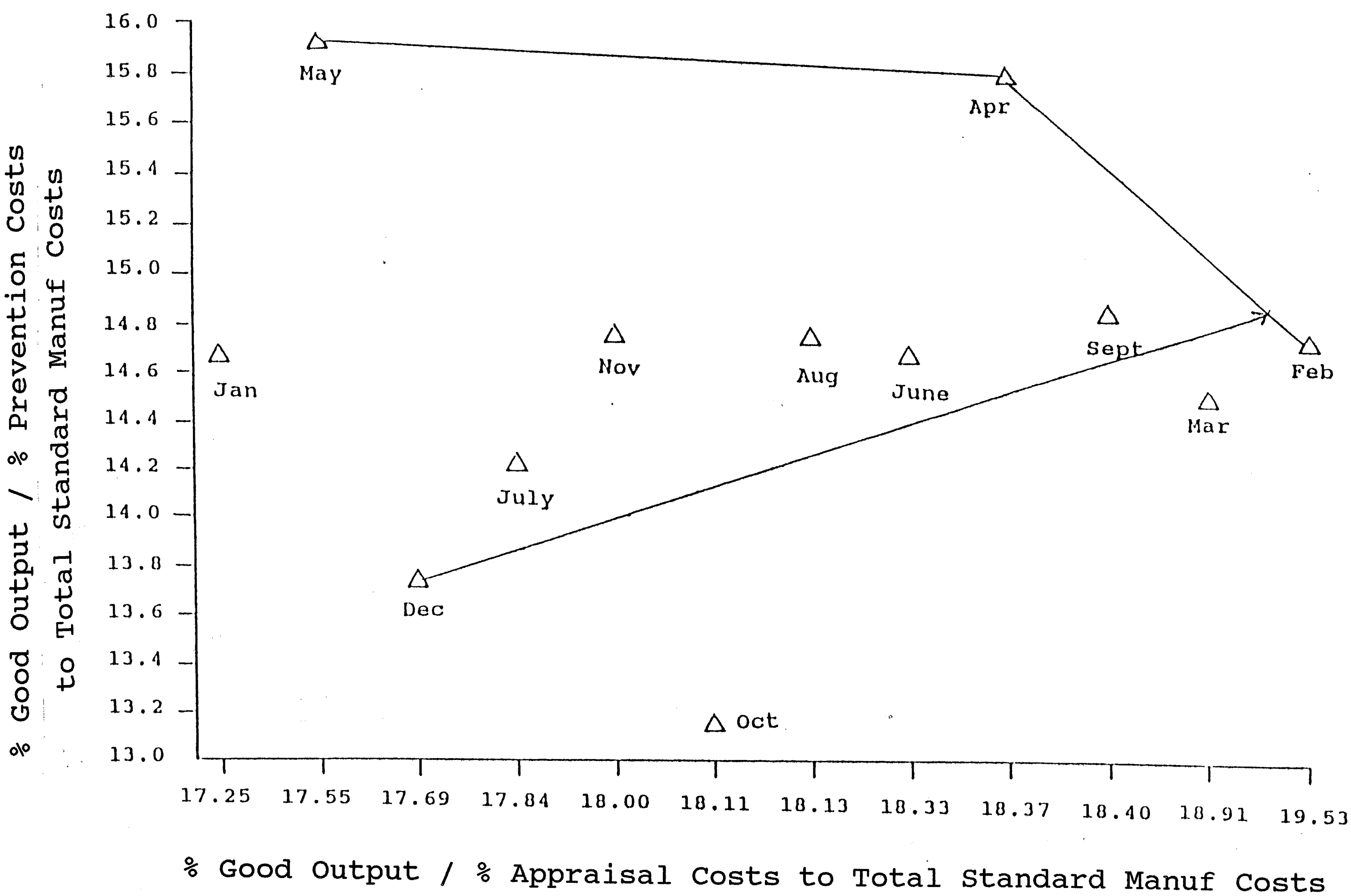
Data for the past eleven months is used as a basis for measuring the current month. For future periods, the

Model Formulation

Using the information from Table 2, the DEA linear programming model can be formulated.

Figure II

Artificial Data Set



The objective function will be set up to maximize the efficiency of the month being analyzed. The total number of constraints will be equal to the number of months in the analysis plus one. The total number of constraints, then, will be 12 + 1 = 13.

To run the model for December, the following objective function would be used: maximize: 92 O1

As mentioned earlier, the output is the percent of good or conforming output. This is an aggregate for the department. The DEA model allows output to be broken down between the different products. For example, if there was a second output that was 90 percent good, the objective function would be: maximize 92 O1 + 90 O2.

subject to the following constraints:

a) 92 O1 - 6.7 I1 - 5.2 I2 <= 0

I1 are prevention costs and I2 are appraisal costs.

The sum of the outputs for the month minus the sum of the inputs used must be no greater than zero. This constraint form will be used for each period. There will be twelve of these in total, one for each month, including the month being analyzed.

b) 6.7 I1 + 5.2 I2 = 1

This constraint consists of the inputs of the specific month being measured (December). It is used to limit the maximum efficiency value to one. This constraint will be changed each month to use the inputs for the month being measured.

The month being evaluated will have a derived efficiency rating of one if it is relatively efficient or less than one if it is relatively inefficient. If the efficiency rating calculated under DEA is one, then the month being measured is at least as efficient as any other month in the analysis. If the value is less than one, then it is relatively inefficient as compared to other months.

Results and Interpretation

The final solution from the linear programming model for December is shown in Table 3.

The variables labeled S represent slack variables. A slack variable, as the name implies, represents unused resources. Slack variables are added to constraints that have a less than or equal to (<=) relationship. This is done because, mathematically, it is easier to solve a system of equations rather than a system of inequalities. Constraints one through twelve each had a slack variable added to them. These constraints correspond to months one through twelve in the analysis. So S1 represents the slack variable for January, S2 for February, and so on. If there is an opportunity cost present, that is, a value greater than zero, then that particular month is in the efficiency reference set of the month being evaluated. In Table 3, the values of .8565 for S2, and .2228 for S8 indicate that February and April is the efficiency reference set for December. This is shown graphically in Figure II.

Table 3
Summary of Linear Programming Results for December

Variable name	Solution	Opportunity cost	Variable name	Solution	Opportunity cost
O1	0.00998	0.0000	S7(Jul)	0.06023	0.0000
I1	0.07179	0.0000	S8(Aug)	0.03432	0.0000
I2	0.09981	0.0000	S9(Sep)	0.02591	0.0000
S1(Jan)	0.06146	0.0000	S10(Oct)	0.09490	0.0000
S2(Feb)	0.00000	0.8565	S11(Nov)	0.03870	0.0000
S3(Mar)	0.02153	0.0000	S12(Dec)	0.03152	0.0000
S4(Apr)	0.00000	0.2228			
S5(May)	0.01839	0.0000			
S6(June)	0.08177	0.0000			

MAXIMIZED OBJECTIVE FUNCTION (EFFICIENCY RATING) .918228
Based on an efficiency rating set of February and April

The results indicate that based on an efficiency reference set of February and April, December had an efficiency rating of approximately .92. Performance for this period was relatively inefficient as compared to the efficiency reference set of February and April. Generally, this means that inputs could have been reduced by about 8% (100 - 92) in December without reducing output levels and be as efficient as its efficiency reference set.

Detailed Analysis

Examine Table 3. The individual solution values for the respective output (O1) and inputs (I1 and I2) are calculated to assign the month being evaluated the maximum efficiency rating possible, given its output/input mix. Individually, these values have no specific relevance to the analysis. As mentioned above, DEA compares inefficient periods with a data reference set of other selected months, all of which have efficiency values of one. To determine the efficiency reference set for December, examine the column labeled opportunity cost. This value indicates how much the value of the objective function, that is, efficiency, would be improved if inputs were reduced by one unit.

DEA can provide additional insight about the degree of inefficiency beyond just identifying inefficient months and their reference sets. To understand how this is done, examine the data shown in Table 4.

This table shows the amount of inefficiency identified for December as compared with its efficiency reference set for February and April. In particular, examine the values in column E. The composite is constructed by applying the weights from columns A and C (opportunity cost in Table 3), to the actual output and inputs of February and April (columns B and D).

Column G represents the difference between the actual output and inputs for December as compared to the composite values determined from the efficiency reference set. The data in this column indicates that there was no difference in output for the month of December as compared to the efficiency reference set.

Table 4
December Compared with its Efficiency Reference Set, February and April

	A(*)	Feb(**) B	C(*)	Apr(**) D	Composite .8565B+ .2228D E	Dec Actual F	Excess Inputs E-F G	% Diff H
(O1)	0.8565	84	0.2228	90	92	92	0	0
(I1)	0.8565	5.7	0.2228	5.7	6.15	6.7	.55	9
(I2)	0.8565	4.3	0.2228	4.9	4.77	5.2	.43	9

(*) Opportunity costs from DEA, Table 3
(**) Actual outputs and inputs from Table 2

This result is consistent with efficiency measure, that is, looking at how efficiently the actual output was produced.

Actual inputs used in December were more than the derived composite efficiency reference set. This was true for both of the inputs used in the analysis. Specifically, column G indicates that output for December could have been achieved using less prevention and appraisal costs. Both inputs were about 9% greater than the composite group would consider efficient.

To summarize the results, operations in December spent more on quality costs as a percent of total standard production costs than it should have to produce its given good output. Since inefficiency is shown in the use of both quality cost categories, they should both be investigated for possible reductions.

Following Month Setup

For January of the next year, assume the following; O1 = .91, I1 = 6.8 and I2 = 5.4 The objective function will become: Maximize 91 O1

The constraint for January of year one would be dropped and the current month (January of the current year) would take its place. The constraint would be added as follows:

a) 91 O1 - 6.8 I1 - 5.4 I2 <= 0 Additionally, the unity constraint would be changed to:

b) 6.8 I1 + 5.4 I2 = 1

Analysis Limitations

Although the above information is useful for analysis purposes, it should be used with care. It is important to remember that DEA does not supplant, but is rather highly dependent on, judgment and knowledge of the environment. Discretion is important in analyzing DEA results. Indeed, a low efficiency rating only signifies potential problems.

There are limitations to DEA. It is not a measure of absolute efficiency. A department that has a efficiency measure of one for any given period is only efficient relative to the other periods in the analysis. Also, DEA does not measure effectiveness. For example, in production, being effective means producing at the planned output. While the department may or may not have been efficient with respect to actual output, as measured by DEA, DEA does not measure whether the anticipated production level has been met.

Conclusion

This paper is an attempt to evaluate the efficiency of incurring quality costs with respect to increasing productivity. Quality costs well spent can bring big rewards to a company, both measurable and some immeasurable. Used in conjunction with other performance measures, such as the quality reports mentioned above, DEA can provide additional insight into the effects that the money spent on quality has on productivity. If the technique yields additional insights and helps evaluators to sharpen their focus of enquiry and debate, DEA is useful. DEA, carefully and sensitively used, can offer additional insights on performance which are not available from other methods of assessment.

Suggestions for Future Research

This paper begins a process of measuring relationships between productivity and quality. Clearly there is much still to be done. From an accounting perspective. the use of DEA as a control and evaluation tool needs refinement. Interpreting the data for management purposes could be enhanced through the use of graphics and additional summary statistics. These techniques would have to be developed. DEA's effects on manager's actions and motivations will need further investigation. Also, refinements in the output and input data should help make the model more useful for decision making.

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