The Hypothetical Efficient Organization: Exploring The Diagnostic Value of Data Envelopment Analysis

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Abstract: Data envelopment analysis produces a hypothetical efficient target model which relatively inefficient organizations may wish to emulate. This article demonstrates the use of the target model and discusses certain limitations as well as epiphenomenal benefits of the related analytical process. Cooperative distributors of electric energy are encouraged to explore the potential benefits of this analytical technique.

Introduction

Data Envelopment Analysis (DEA) has been employed in a broad range of applications as a measure of the relative efficiency of not for profit, for-profit and public sector agencies.[1] In addition to providing a measure of relative efficiency among organizations, DEA can be utilized to produce other useful managerial information. Specific suggestions for improving efficiency of relatively inefficient organizations can emerge from the process. A hypothetical, perfectly efficient target model for the organization under analysis can be derived from the linear combination of actual historical operations of similar others based on weights produced by the DEA algorithm.

This target model does not suffer the inherent limitations of efficiency goals based solely on suboptimal historical performance or highly touted stakeholder hopes. Comparisons are based on actual best practices, not average performances as with regression and other models of performance measurement (Ludwin and Guthrie,1989). The technique has the ability to demonstrate to less efficient operators that more efficient operations are actually attainable (Thomas, Greffe and Grant, 1986) and, significantly, it "leads naturally to highly specific managerial strategies for improving the efficiency of an inefficient DMU by indicating which inputs are being overutilized, which outputs are being underproduced, and in each case by how much." (Sexton, 1986, p. 12)

In a previous work reported here[2], relative efficiency scores for twenty South Carolina electric cooperatives were calculated based on self-reported operating results published by the Rural Electrification Administration (1993). In that study, a methodological point of view was taken with the consistent reliability of DEA as a measure of relative efficiency being the focal issue. Specifically, content validity [3] of DEA as a measure useful for ranking organizations on their relative efficiency was questioned; and, important constraints on the technique when used for that purpose were demonstrated. In summary, it was shown that DEA as a measure of organizational efficiency is extremely sensitive to choices of different sets of organizational inputs and organizational outputs. The choice of different inputs and outputs resulted in significantly different relative efficiency scores for participating organizations.

On its face, this seems problematic and tends to impugn DEA as a useful management tool. For example, one organization, reported to rank as most efficient in the initial analysis of the South Carolina distributors, moved to least efficient in the second analysis. And, this was the direct result of the analyst merely choosing a different set of inputs and outputs from the 1992 data and not from any real differences in distributor operations. While other changes in relative efficiency scores across the two DEA runs were not as extreme as this example, scores for several South Carolina electric distributors changed significantly. On the other hand, some distributors maintained virtually the same relative efficiency ranking in both analyses.

Suggestions were made for understanding and overcoming this prima facie dilemma; and, a rather significant observation relevant to managerial diagnostics emerged: the real question of importance when measuring relative efficiency in organizational analysis is not "how efficient?", per se; rather, the important question should be framed in terms of the outcome of the activity and would thus be stated, "relatively efficient for what purpose?"[4] Even when not explicit, this perspective is at least, by implication, reflected in the choices of inputs and outputs used in any computation of relative efficiency.

Ludwin and Guthrie (1989), faced with justifying the set of inputs and outputs used in a DEA application to measure the relative efficiency of community schools in Fort Wayne, Indiana, make a rather profound observation that seems helpful with respect to the choice of inputs and outputs to be used in efficiency analysis. They say,

> We do not argue that we know which variables are most important. Our argument is minimalist: we have found general agreement that those used in this analysis are not unimportant. This is sufficient for examining the efficiency of the FWCS elementary schools based on the inputs and outputs chosen. [emphasis added] (p. 367)

The minimalist position taken by these writers makes eminently good sense, and its extension expands the usefulness of DEA over a wide variety of combinations of inputs and outputs, any one of which might be useful with respect to evaluating the relative efficiency with which a particular organizational goal is accomplished.

Furthermore, while the computation of relative efficiency scores for a set of organizations is one important output of the DEA methodology, there is a closely related use for DEA which proves to be an intriguing, diagnostic application that, although impacted by the sensitivity of the methodology to choices of inputs and outputs, is actually enriched by that characteristic. Here, DEA proves useful in the decision making process when the management purpose is to allocate resources (inputs) and modify goals (outputs) for a relatively inefficient organization in order to move toward optimal efficiency levels. Illustration of this management application is the purpose of the present article.

The Hypothetical, Perfectly Efficient Organizational Model

When DEA methodology is used to compute the relative efficiency of a set of organizations, coincidentally, the output of the algorithm can also be used to model a hypothetical, perfectly efficient, ideal "target" organization for each "inefficient" organization in the analysis. This target model provides guidance to managers in making changes in resource allocation decisions.

> In the process of calculating the relative efficiency scores of the decision making units (DMUs)...[which in this case are cooperatively owned distributors of electric energy]...a subset of perfectly efficient DMUs is identified for each inefficient distributor. These distributors make up the "efficient reference set" for the specified inefficient distributor, and they can be thought of as those to which it was compared to obtain the efficiency score. These are also those distributors which, hypothetically, the inefficient distributor should emulate to move toward more efficient operations. (Tankersley and Tankersley, 1996)

Assuming there is consensus that the set of inputs and outputs chosen for use in the analysis is comprised of important elements that are causally related, the reference set of perfectly efficient DMUs produced by DEA can be used by each relatively inefficient distributor to develop a "first cut" prescription for potential adjustments to actual inputs and outputs to improve operating processes and move toward a state of "perfect" relative efficiency as defined by DEA.

One straightforward approach to estimation of this target model is provided in "The Methodology of Data Envelopment Analysis" (Sexton, 1986) where the dual[5] of the DEA linear program is used as a source of the needed information. Sexton notes,

> ...whenever a DMU is less than perfectly efficient, DEA indicates a subset of perfectly efficient DMUs (we will call this the "efficient reference set") and a set of associated multipliers that can be used to formulate managerial strategies for improvements. (p. 11)
>
> ...the input and output levels of the hypothetical DMU are linear combinations of the input and output levels of [the DMUs in the reference set]. The question is, what are the coefficients of that linear combination? (p. 23)
>
> The answer lies in the solution to the dual of the linear program...the dual variables identify the efficient reference set for an inefficient DMU and also provide the multipliers needed to produce the input and output levels of the hypothetical DMU. (p. 23)

Table One displays first, the relative efficiency scores obtained in the analysis of South Carolina electric distributors, second, the distributors who are included as members of the reference set for each inefficient distributor and, finally, the multipliers to be used in estimating the hypothetical, perfectly efficient, target DMU for each distributor. Note that only four DMUs (i.e., No. 5, No. 9, No. 12 and No. 16) are included in the Efficient Reference Sets for the several inefficient DMUs. These are the four distributors who obtained a perfect relative efficiency score of 1.000 in the DEA analysis.

An Illustrative Example

A practical example using the data from Table One is helpful in demonstrating the computation of the hypothetical perfectly efficient target model for an inefficient DMU. Consider DMU 13, the South Carolina distributor that obtained a relative efficiency score of .9040.[6] Note that the reference set of distributors for DMU 13 includes all four of the distributors who

Table One — Relative Efficiency Scores and Efficient Reference Set Weights

DMU Number	Relative Efficiency Score	Weights to Apply to the DMUS in the Efficient Reference Sets: DMU No. 5	DMU No. 9	DMU No. 12	DMU No. 16
1.	.7747		.44449	.04812	1.4239
2.	.8097		.64166		.75667
3.	.9051		.21894		.82016
4.	.9528		.08572		1.2450
5.	1.000	1.0000			
6.	.8103		.84551		2.4005
7.	.8352		.20311		1.5427
8.	.7336				.60692
9.	1.000		1.0000		
10.	.9311	.15361	.03551	.29960	.96708
11.	.9061		.01001		.83775
12.	1.000			1.0000	
13.	.9040	.27145	.08635	.07865	.44353
14.	.8543				1.3552
15.	.8542		.18468		.30211
16.	1.000				1.0000
17.	.8977		.65274	.13637	.75362
18.	.8625		.10356	.48024	2.5575
19.	.8592		.33770	.33197	1.4579
20.	.8362				2.1694

Notes:

1. See "Relative Efficiency of Electric Cooperatives in South Carolina: An Application and Test of Data Envelopment Analysis", William B. Tankersley and Julia E. Tankersley, Coastal Business Review, Vol. 5, (1996), pp. 41-48 for the source and a discussion of these relative efficiency scores.

2. As shown, some combination of DMUs No. 5, No. 9, No. 12 and No. 16 are included in the efficient reference sets for each relatively inefficient DMU in the study. Each of these four DMUs achieved a relative efficiency score of 1.00, ranking them the most efficient in the set of twenty electric distributors included in the analysis.

obtained a perfect relative efficiency score of 1.0000.

The computation of the hypothetical, target model for DMU 13 based on this reference set is displayed in Table Two. Included here are the names and values for each of the four inputs and the two outputs for the DMUs in the efficient reference set along with the multipliers (titled Reference Set Weights) used to weight actual inputs and outputs to develop the ideal target inputs and outputs for the hypothetical perfectly efficient target model. Also shown are the changes in inputs (in dollars as well as percent) that are required to bring DMU 13 to this hypothetical state of perfect relative efficiency. Note that no increase in outputs is suggested by the target model.

Simply put, the Perfectly Efficient Model for DMU 13 displayed in Table Two is a weighted average of the values shown for the four DMUs included in the Reference Set. For example, $868,800 is the suggested target value for Distribution Expense which, if attained, will move the distributor toward a condition of relative perfect efficiency with respect to the other organizations included in the DEA study. Suggested changes for the other inputs include a reduction of 9.6 percent for Administration Expense and Plant In Service while Consumer Expense requires an adjustment downward of 19.6 percent to match the target established by the model. Based on operating results accomplished by the perfectly efficient distributors included in the efficient

TABLE TWO Computation of the Perfectly Efficient Model for DMU No. 13

	Efficient Reference Set Members for DMU 13				Perfectly Efficient Model*	DMU 13 Original Inputs/ Outputs	Implied Change for DMU 13 to become Relatively Efficient (reduction)	Implied Change In Per Cent (reduction)
	DMU 5	DMU 9	DMU 12	DMU 16				
INPUTS								
Distribution Expense (000)	1,087	2,474	1,751	501.5	868.8	961.1	(92.3)	(09.6)
Consumer Expense (0,000)	68.1	104.7	109.1	25.6	47.5	59.08	(11.58)	(19.6)
Administration Expense (0,000)	81.64	187.1	113.2	62.36	74.9	82.83	(7.93)	(09.6)
Plant In Service (00,000)	351.2	557.5	585.8	183.7	271.0	299.8	(28.8)	(09.6)
OUTPUTS								
Number of Distribution Line Miles	2,819	4,604	3,110	1,618	2,125	2,125	(00.0)	(00.0)
Number of Customers (00)	145.3	339.9	281.1	97.4	134.1	134.1	(00.0)	(00.0)
REFERENCE SET WEIGHTS								
	.27145	.08635	.07865	.44353	n/a	n/a	n/a	n/a

* The Perfectly Efficient Model for DMU 13 is a weighted average of the values shown for the DMUs in the Reference Set using the respective DMU weights produced by the linear programming dual calculation discussed in the article.

reference set for DMU 13, the efficient target model not only suggests that operating expenses and plant in service could be reduced while providing the same outputs, it also implies that Consumer Expense warrants special attention.

Modelling Different "Efficient Reference Sets"

It has been noted that relative efficiency scores for entities evaluated with the DEA methodology may be significantly impacted when the set of inputs and outputs used in DEA analysis is varied. While this is troublesome with respect to confidence in the content validity of the resulting relative efficiency scores produced by an application of DEA, this property actually adds richness to the procedure when it is used as a diagnostic tool for locating prospective adjustments to inputs or outputs to improve operating efficiency.

The ability to develop several "efficient reference sets" by varying the set of inputs and outputs included in the managerial analysis can be understood as analogous to viewing the same organizational processes from different analytical perspectives or intellectual constructs. In one sense, this may be thought of as a mathematical version of what is commonly promoted as metaphorical analysis by writers in the literature of organizational theory (e.g. Morgan, 1986). In that body of literature, it is proposed that the metaphor one adopts determines to a great extent what is seen in a particular organizational situation. By changing metaphors, the management analyst is able to raise the salience level of different features of the same organizational situation, thus possibly exposing very different alternatives for improvement.

In many cases the conceptual bases for these different perspectives are logically exclusive of each other due to the fact that they are based on very different values, norms and assumptions about the nature of organizational reality and the consequent organizational mission and goals. This, however, does not mean that all alternatives for change which may be suggested by metaphorical analysis are necessarily mutually exclusive. At this level of analysis, one is not searching for ultimate organizational truths; rather, one seeks different "ways of understanding" the same situation. The analyst is seeking practicable improvements in operations measured by an extant value system (or multiple systems) which may be paradoxical and contain contradictory values.

Similarly, the DEA approach is a mathematical process that allows for the recognition that different input/output ratios are of varying importance in the eyes of different stakeholders. Consequently, the product of the analysis is not necessarily impaired by the existence of different stakeholder interests, nor does the process require agreement among all stakeholders with respect to ultimate values. Some operating alternatives that become salient may offer improvements common to the demands of several stakeholders who harbor very different interests.

DEA assists in the discovery and quantification of just such alternatives. By varying the combination of inputs and outputs in DEA analysis, different possibilities are disclosed for improving relative efficiency with respect to consumption of selected inputs and production of particular outputs any of which may be valued differently by different stakeholders. Furthermore, the possibility for accomplishing such a wide ranging analysis is enhanced due to the fact that different inputs and outputs are not required to be measured in common units. While certain measurements may appropriately use dollars as the unit of measure, others may be stated in different units (e.g. mWh, number of customers, manhours, miles of line, etc.).

The DEA Process: Epiphenomenal Benefits and Important Constraints

It is generally recognized in management literature that activities such as strategic planning and program evaluation offer latent organizational benefits that rival the importance of the manifest outcomes of these organizational activities. That is, the process involved in analysis is, itself, important. A conceptual framework is developed, a common language useful for discussing the subject of interest is built, communication is enhanced, decision-making is improved, and participation in the process tends to stimulate personal ownership of organizational decisions.

Likewise, implementation of DEA can produce similar epiphenomenal benefits. This is especially true of the analytical effort required to choose between possible alternative, yet important, sets of inputs and outputs for inclusion in the DEA model. And, this is also true for the diagnostic activity required in the comparison of the organization to its various "efficient reference sets." Discussion and improved understanding of the causal relationships between the organization's inputs and resultant outputs, consideration of the nature of the inputs (e.g., fixed or variable factors) and determination of the level of controllability that management has at its discretion with respect to input allocation and output production are all items important to organizational performance. The DEA conceptual framework provides management with a good forum for such discussion.

An example of this is seen in Sherman's (1986) work. Here, he reports benefits from followup efforts by administrators familiar with the operations of one hospital which was included in the application of DEA to a set of teaching hospitals in Massachusetts. The effort to explain its relatively inefficient score resulted in the location of significant cost allocation errors. Likewise, upon closer scrutiny, it became evident that the data reported for bed days for the hospital were inaccurate. Thus, the focus of attention required to explain the organization's DEA scores relative to those of its "efficient reference set" resulted in increased attention to accounting records and internal information controls and subsequently, to their improvement.

Likewise, administrators familiar with operations of an organization that receives a poor DEA score will be motivated to examine any quality of service or customer mix differences among DMUs to determine that these have been captured by the DEA outputs utilized in the analysis. If levels of quality of service or customer mix are discretionary, it is important to be aware of the relevant decisions that are impacting these outcomes. If they are not discretionary, then resulting differences between the DMU under analysis and those included in its target model must be taken into account and appropriate allowances made.

While both of these variables were considered likely candidates as factors that would explain the outcome in Sherman's (1986) hospital study, upon examination, neither was deemed particularly contributory to the poor outcome of the hospital under analysis. Sherman does note, however, that it was discovered that personnel levels were maintained at higher levels than others. "This was the result of a conscious decision to maintain a relatively large staff so as to provide relatively personalized patient care" (p. 42). It seems obvious that DEA followup analysis would tend to focus attention on operational variations between the members of the "efficient reference set" and the "inefficient" DMU in order to identify justifiable differences in performance results as well as locate potential adjustments.

Perhaps more importantly, management must recognize uncontrollable factors that may completely contravene proposed changes emerging from the hypothetical targets reported by DEA. These include, for example, the effects of regulatory requirements, physical constraints or market realities to which the mathematical analysis is not sensitive. Real world constraints in many cases may render impractical, and thus useless, theoretically based models of perfect efficiency which initially emerge from the DEA mathematical algorithm. Some inputs and outputs are susceptible to hypothetically prescribed change, others, upon closer examination, simply are not.

An example of just such a result is found in the target model proposed for DMU 6 (see Table One). Here, the projected efficient target is based on a reference set of DMUs comprised of DMU 9 and DMU 16. Based on the weights assigned to reference set elements, the output, Number of Distribution Line Miles for DMU 6, would hypothetically be increased from the existing 3,611 miles of line to 7,774 miles. Given the institutional and physical environments in which cooperative electric distributors operate, this result seems patently unrealistic, even pathological, from an operations standpoint. To the contrary, higher customer densities have historically been associated with greater operating efficiency in the distribution of electricity.

Thomas, Greffe and Grant (1986), in their analysis of cooperative electric distributors operating in the State of Texas, adopted a unique approach to solve the particular problem which results from existing output constraints. Three outputs were used in that study including, 1) total number of consumers, 2) distribution line miles, and 3) new service connections per year. These analysts note, however, that,

> Although co-ops can exert some influence over the customer density and growth within their service territories, such influence is both limited and long-term in nature. With this in mind, it was decided to define the outputs used in the model as nondiscretionary. Although these outputs are used in arriving at an efficiency rating, the Value if Efficient will always equal the Value Measured for each of the outputs. With the output data elements fixed in value, the model could be viewed as a cost minimization model. (p. 11)

In other words, the hypothetical increases in outputs produced in the study were not considered valid by these analysts. Extending this logic, the inference might be made that, in general, a straightforward solution to the problem posed by impracticable suggestions which initially emerge from the hypothetical, perfectly efficient target model, is simply to ignore them. Use whatever practicable insights are forthcoming and move on. Perhaps this is the best approach; it would seem useful in cases where the set of inputs and outputs are clearly relevant to the analysis but proposed changes in outputs cannot be implemented, for example, due to institutional or physical factors not captured in the model.

CAVEAT: Beware Armchair Prescriptions and Monday Morning Theoreticians Who Were Never On the Field

The purpose here has been to add richness to the discussion of the application of data envelopment analysis to distributors of electric energy by providing an illustrative example applying the methodology to existing distributor operations. Suggestions for substantive changes in distributor operations are not intended or implied by this discussion. It is important to realize that operational changes cannot be prescribed with any confidence until the prescriptions are first tested against the working knowledge of managers and operating personnel who know the characteristics and special circumstances surrounding the operations of the organization from direct, hands-on experience. To do otherwise would be armchair management in its most developed form - carried on by an analyst sitting behind a computer screen armed only with published data taken from government reports. Substantially more knowledge, experience and direct involvement in the operating environment under review is required to avoid misguided and patently incorrect suggestions for change.

Conclusion

An analysis such as the one demonstrated here can be utilized as a preliminary step in the continuing process of examining marginal changes that are likely to produce more efficient operations by electric distributors. The demonstration, although elementary, is conceptually non-trivial and is not without value. Carried out and extended by experienced, on-site, managerial personnel, the application of DEA to distributor operations could provide very useful discussion and guidance leading to positive change.

While the first application of DEA to electric cooperatives was by Thomas in 1985 (Thomas, Greffe and Grant, 1986), the technique does not seem to have been widely adopted by distributor managers or electric industry regulators. The exploration and further development of the unique capabilities of this technique as a supplement to the operating ratios and regression models presently used in the electric distribution sector seems warranted. Without question, DEA has the ability to pinpoint items for further discussion. Perhaps this is its greatest virtue.

Endnotes

1. For a comprehensive discussion of DEA and its continuing refinement, the interested reader is referred to J.A. Ganley and J.S. Cubbin, *Public Sector Efficiency Measurement: Applications of Data Envelopment Analysis* (1992), Amsterdam: North-Holland, and A. Charnes, W.W. Cooper, A. Y. Lewin, and L.M. Seiford (editors), *Data Envelopment Analysis: Theory, Methodology and Applications* (1994), Boston: Kluwer Academic.

2. See "Relative Efficiency of Electric Cooperatives in South Carolina: An Application and Test of Data Envelopment Analysis," William B. Tankersley and Julia E. Tankersley, *Coastal Business Review*, Vol. 5, (1996), pp. 41-48.

3. For an interesting discussion of content validity of measures and the more general concept, operational validity, see E. O'Sullivan and G. R. Rassel, *Research Methods for Public Administrators* (second edition), (1995), White Plains: Longman.

4. Two classic works in American public administration that address the concept of administrative efficiency are Dwight Waldo, *The Administrative State* (second edition), (1984), New York: Holmes & Meier and Herbert A. Simon, *Administrative Behavior: A Study of decision-Making Processes in Administrative Organization* (third edition), (1976), New York: Free Press.

5. For discussion of linear programming techniques and related theory regarding the dual of linear programs, see standard operations research texts, e.g., D.R. Anderson, D.J. Sweeney, and T.A. Williams, *Introduction to Management Science: Quantitative Approaches to Decision Making* (fourth edition), (1985), New York: West. More advanced treatment is found in R. Dorfman, P.A. Samuelson, and R.M. Solow, *Linear Programming and Economic Analysis* (1986), New York: Dover.

6. The computation of this efficiency score is reported in "Relative Efficiency of Electric Cooperatives in South Carolina: An Application and Test of Data Envelopment Analysis," William B. Tankersley and Julia E. Tankersley, *Coastal Business Review*, Vol 5, (1996), pp. 41-48.

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