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ABSTRACT

The Data Envelopment Analysis (DEA) model, a conceptual model for measuring productivity and efficiency, is presented and applied in this report. First, the DEA model is described, and three of its properties that make it particularly useful are identified; i.e., it measures efficiency of units relative to each other rather than to absolute criteria; it permits the use of multiple inputs and outputs; and it provides management information relative to the inputs and outputs of particular units. After detailing the theory and method of the DEA, the report applies it to measure the efficiency of 22 occupational programs in a comprehensive community college. First, the college setting is described, and then its decision-making units (DMU's) are identified, output and input measures currently used to make program and budgeting decisions are defined, and the results of the analysis are presented and discussed, with particular emphasis on the information produced by the analysis that has administrative significance. Examples of the use of such information are provided for three allied health programs. Finally, the limitations and requirements of the DEA technique are considered, as well as theory extensions that are under development. A technical appendix, specifying the mathematical model, and an extensive bibliography are included. (Author/KL)

PRODUCTIVITY IN COMMUNITY COLLEGE PROGRAMS: A TECHNIQUE FOR DETERMINING RELATIVE EFFICIENCY

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ABSTRACT

Community college administrators have been pace-setters in efforts to increase productivity of education, but their efforts have been hampered by the lack of theory and methodology for measures of productivity. In this paper, the Charnes, Cooper, Rhodes efficiency model is presented as a promising advancement in the state-of-the-art for measuring productivity or efficiency in not-for-profit enterprises. The CCR efficiency model provides an explicit formulation of productivity which considers multiple inputs and outputs simultaneously and allows computation of a single efficiency index for each operating unit.

The theory and method which are presented in an intuitive, non-technical manner, are widely applicable and hold promise for studying production in several areas of post-secondary education. An example of one application for occupational-technical programs in a community college is presented and discussed.

In the example chosen, data from twenty-two occupational-technical programs are analyzed. Inputs and outputs selected are those in current use by the college to make program and budgeting decisions. One index of comparative efficiency is calculated as measured by outputs produced for the amount of combined inputs.

Included in the discussion of the results for the worked example is a review of information provided by the analysis which has administrative significance. How a decision maker could use such information is illustrated for three programs in one occupational area -- allied health.

Finally, the limitations and requirements of the technique are presented, along with promising extensions of the theory which are under development. For readers interested in the technical aspects of the model presented, a technical appendix is included specifying the mathematical model and an extensive bibliography is included.

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INTRODUCTION

Community college administrators have been pace-setters in efforts to increase productivity of education. Individual colleges like the one reported later in this paper and college networks such as the League for Innovation and the Community College Productivity Center have pioneered in field testing new ways to increase productivity in teaching and management. Some of these efforts have emphasized better use of input resources and some have sought ways to increase outputs such as student learning or better retention rates. In any event, the administrator directing such projects is often hampered by lack of a productivity measurement or index which would indicate how much productivity is being achieved or what the increase in productivity has been.

Perhaps the time is right to explore ways to measure productivity and to begin the development of a productivity or efficiency[1] index which can be applied to programs in community colleges. A beginning has been made in management science techniques for not-for-profit-enterprises and is extended in this paper to community college applications.

The intention in this paper is not to present a ready-made solution, but to point out a promising direction and make administrators aware of advancements in the state-of-the-art.

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[1]Productivity and efficiency are used interchangeably in this presentation although more formal economic theory may differentiate between the two terms.

In this spirit we present a technique for quantifying efficiency of not-for-profit enterprises. The theory was developed and named Data Envelopment Analysis (DEA) by A. Charnes, W. W. Cooper and E. Rhodes [11, 12] and applications in the education sector have been reported by A. Bessent, W. Bessent, J. Kennington and B. Reagan [4, 5] through collaboration with Charnes and Cooper in the Center for Cybernetic Studies at The University of Texas at Austin. Although we present a non-technical discussion of DEA, the theory is rigorously developed in the sources referenced.

Briefly stated, the quantitative model employed in DEA makes it possible to compute an index of efficiency for each one of several operating units which are engaged in the production of the same valued outputs. The resulting index provides an explicit formulation of productivity which considers multiple inputs and outputs simultaneously and allows computation of a single efficiency index for each operating unit.

The theory and method are widely applicable and hold promise for studying production in several areas of post-secondary education. For example, in this paper, an analysis of the efficiency of occupational-technical programs in a community college is reported. The results are used to illustrate the method and to consider some of its management applications and limitations.

Other uses of DEA have been the study of elementary school efficiency reported by Bessent and Bessent [4], Sherman's study of surgical units in hospitals [21], and Charnes, Cooper and Rhodes' study of Program Follow Through, a major national experiment [11, 12].

A CONCEPTUAL MODEL FOR
MEASURING PRODUCTIVITY IN EDUCATION

In accord with its usual non-technical meaning, we can think of productivity as the amount of valued outcomes realized for the quantity of inputs employed; as a measure of efficiency in the production of these outcomes, we can think of an index which is the ratio of units of output to units of input. The problem of how to compute the index is solved by the DEA model which has certain properties that make it particularly useful for our purpose:

1) It measures efficiency of units relative to each other rather than to some absolute criterion.
2) It permits the use of multiple inputs and outputs.
3) In addition to the efficiency index, the solution to the model provides management information relative to inputs and outputs of individual units.

Let us illustrate the importance of the properties mentioned above with a couple of familiar indices of efficiency: miles per gallon rating of automobiles and batting average of baseball players. These efficiency measures are ratios indicating units of output per unit of input; viz., miles travelled per gallon of gasoline and hits per time at bat.

Even though these two indices are similar and both were developed as indicators of performance quality, batting average conveys more information than miles per gallon; that is, a batting average of .500 means that the player hits half the time or hits half as often as a "perfect" player. Thus batting

average as an efficiency index is a comparative measure in which a player's performance is expressed as a proportion of perfect or criterion performance. An index of 20 miles per gallon on the other hand simply means that, on the average, there were 20 miles travelled for each gallon of gasoline consumed, and without more information, one would not know whether 20 indicated "good" performance or "poor." To make such a judgement, one would need to know at least the type of car so that some kind of criterion could be inferred. For example, 20 miles/gallon might be good for a large truck and poor for a small, compact car.

The additional information could be obtained if there were a perfect car or a criterion performance for cars, e.g. 25 mpg. If there were such a criterion, then miles per gallon could easily be converted to the batting average type of index which would have the same straight-forward type of interpretation. That is, $\frac{20}{25} = \frac{4}{5} = .80$ which means that for the gasoline consumed, the car only travelled 80% as far as the criterion car.

With both of the examples discussed above, neither criterion is realistic or sufficient for making judgements or decisions about players or cars. In both examples, more than one indicator of desired performance is necessary and more than one input requirement must be taken into account.

In the first case, a player's efficiency or value to a team is based on performance in the field as well as at bat. Thus, a single criterion is inadequate. Likewise, a consumer evaluating a car purchase might want to consider cost, comfort, dependability, and maintenance in addition to fuel economy. At this point, it should be clear that both of these commonly used

efficiency indices would have a greater impact on related decisions if they were based on a more complex, realistic model of needed inputs and desired outputs. In the following we show how this can be accomplished.

First we identify organizational units such as colleges, or sub-units of organizations such as programs within colleges, or perhaps class sections of a course. We will call these decision making units (DMUs) to convey the meaning that managerial decisions are made to allocate resources, and to organize the processes by which the unit carries out its functions to accomplish specific objectives.

Secondly, we identify for the set of like units common objectives which can be expressed in terms of measurable outputs. For example, community colleges have outputs in common which are expressable in such terms as college transfer preparation, occupational-technical preparation and personhood development. Or, to take an example at the sub-unit level, community college development skills programs have even more explicit outcomes such as verbal, and quantitative basic skills and successful integration into regular program offerings.

Finally, we must specify resources which are allocated to the DMUs to enable them to carry out their work. Such things as personnel, equipment, supplies, facilities and time schedules are all inputs to the accomplishment of objectives.

Thus, we have DMUs with multiple inputs and multiple outputs. There is nothing new about the input-output perspective just described.

What distinguishes the Data Envelopment approach from other input-output models, however, is the method for comparing outputs and inputs of one DMU with the other like units.[2] We turn to that now.

There are several steps in the analytical process which are presented in a general and incomplete form below. For a definitive presentation, see the mathematical model in Appendix A.

To determine an efficiency rating for the DMUs under review, a separate calculation must be made for each one. However, since all such calculations are performed in exactly the same way, we present the technique for only one DMU in the set. Which one is selected for discussion does not matter, so for conversational convenience, we will refer to this Decision Making Unit as DMU k.

As in the case of cars, we wish to compare the performance of DMU k with criterion DMU(s) which have similar goals and resources. That is, we do not wish to compare truck performance to that of an economy car. Further we wish to express the performance of DMU k as a proportion of the performance that the "appropriate" criterion DMU(s) were able to attain--thus insuring that criterion performance is attainable by DMU k. Since at the outset it is not known which of the DMU(s) are appropriate

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[2] Others have used similar formulations for seeking "industry-wide" production functions in education. For example, see Levin [18, 19]. Many studies have used regression methods to investigate input-output relationships. See Averch [21], Boardman [6], Bowles [7,8] and Hanushek [15].

criterion performers relative to DMU k, we must allow for any of the DMUs to be criterion units (including DMU k which might itself be a criterion performer).

The specification of the potential criterion DMU(s) is accomplished through what is technically termed a constraint set which is nothing more than everal mathematical relationships that must be simultaneously satisfied. These relationships are as follows:

efficiency ratio for DMU 1 is less than or equal to 1
efficiency ratio for DMU 2 is less than or equal to 1

⋮

efficiency ratio for DMU n is less than or equal to 1,
where DMU n is the last one in the set under review.

Since all of the above mathematical relationships are simultaneously satisfied in the solution, then those DMUs with efficiency indices equal to one[3] are criterion DMUs. But to be meaningful, the value of all the efficiency indices must be relative to DMU k--the unit being assessed. Therefore, the constraint set, o ne set of all possibilities must be related to DMU k. This is done via what is technically termed an objective function.

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[3]It may not be clear to the reader why 1 is the maximum value for efficiency indices or why a DMU is a criterion unit if its efficiency index = 1. If the ratio: attainment/"best" attainment by a similar DMU is equal to 1, then attainment is equal to "best" attainment by a similar DMU, and hence the associated DMU is a criterion unit.

To use the car analogy, if 40 miles/gallon were the best ratio obtained by any economy car in our comparison set, and car k obtained 40 miles/gallon, then car K's efficiency index is 40/40 = 1, and car k is a criterion car.

The purpose of the objective function is to provide the necessary decision rules as to how to select the criterion units for a particular decision making unit with particular objectives and resources for accomplishing those objectives. As with the constraints, the objective function is the mathematical expression: Maximize the efficiency ratio for DMU k. Thus, to solve the model, criterion units are selected which result in the maximum efficiency rating for DMU k, given that 1 is the largest value possible for any efficiency index.

Consequently, if the efficiency index for DMU k = 1, then DMU k is said to be efficient in that no other decision making unit with similar inputs and objectives obtained higher output levels. If the efficiency index for DMU k is less than 1, then the value of the index can be interpreted as the proportion of attainable output levels that DMU k did, in fact, achieve.

The consequence of this two part model, i.e. objective function and constraints, is to compare trucks with trucks and economy cars with economy cars even though a given set of DMUs includes both types of vehicles. This is possible because trucks and economy cars have different patterns of inputs and different transportation purposes for the two classes of vehicles to serve.[4]

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[4]The decision variables represented by u_r and v_i in the technical representation of the model which has been included in the appendix are the means by which the various output/input patterns are recognized and appropriate comparison units are selected by the model. The resultant values for these decision variables are called multipliers and they provide useful managerial information. This will be discussed relative to the application presented in the next section.

The objective function specifies the desired output/input pattern while the constraint set defines possible output/input patterns for meaningful comparisons.

To complete the model, we require that all DMU k are being compared on the basis of the same kinds of resources to produce the same types of outputs. For example, trucks and economy cars both use gasoline, motors, seating capacity, luggage capacity, etc. to produce miles travelled, passengers carried, cargo delivered, etc. The mathematical expression of this necessary condition is that all input and output measures must be greater than zero.

Summarizing the model discussed above, we have:

Maximize the efficiency index for DMU k.

> Given the constraints that (a) the efficiency indices for all DMUs be less than or equal to one and (b) all input and output measures for all DMUs be greater than zero.

In the next section, an application of the Data Envelopment Analysis is presented for twenty-two occupational-technical programs in a community college.

AN OCCUPATIONAL-TECHNICAL PROGRAM APPLICATION

We now present an application of DEA to measuring the efficiency of occupational-technical programs in a comprehensive community college. First the setting will be described, then the decision making units are identified, output and input measures are defined and results are presented and discussed.

The Setting

Data were collected from occupational-technical education program areas in a large urban community college we will call Metro. The college has 22 such programs serving about 8,000 students out of a total college enrollment of over 21,000.

The mission of Metro Community College is strongly committed through its programs to be an institution of community education. This commitment led to a continuing community needs assessment and a follow-up on students which made the necessary data readily available.

Metro, like other public community colleges in Texas, has independent local taxing authority, but receives most of its revenues from state funds. The state appropriations are based on contact hour formula rates which differ for programs depending upon audited cost data in the previous year for all community colleges in the state.

Decision-Making Units

The occupational-technical program areas with line decision authority with respect to curriculum and budget were selected as the decision-making units. Each unit has an administrative head responsible for supervising teaching staff,

curriculum and expenditures. In addition, there is a Director who coordinates all the programs, allocates resources, evaluates existing programs and approves new programs, administers the budgetary process and coordinates information collection and analysis for the labor market in the region. Programs are identified by number in Table 1 to preserve confidentiality of source information. Note that there are several programs in each area. For example, Allied Health fields has three programs which are administered by either the area chairperson (#5 and #16) or a subordinate program director (#13).

Table 1

DECISION MAKING UNITS

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Output Measures

Three outputs were selected which were used by the Director in the planning process each year. All the data elements were available and current and each represented an important objective used in evaluating programs. Moreover, the outputs were appropriate for all the 22 program areas and were collected in a consistent manner across programs.

Output 1 - Revenue earned by contact hours through state funding formulas. The formula varies according to historical records at the state level so that more expensive programs, in general, receive more money per contact hour.

Output 2 - The number of students completing programs or who are far enough advanced to get a

job who are employed directly in their field of training. Data are collected from student follow-up three times a year for each program area.

Output 3 - Employer satisfaction with occupational training of students employed. Satisfaction is indicated by total score on a rating scale for the technical skills common to all program areas. The use of five areas and a five point scale for each yields a 25 point "satisfaction" scale.

Input Measures

Through consultation with the Director concerning the resources ordinarily considered in the annual review of program, four inputs were selected which met the following criteria:

1) they were used by the Program Director for planning and budgeting,
2) they were available in current institutional records,
3) they represented resources employed for the provision of instruction, and
4) they were collected in a common manner across all programs.

Input 1 - Student contact hours generated by each program (lecture and laboratory hours X number of students X number of weeks of instruction).

Note that this might be considered to be an output in other uses. Here it represents an input to the revenue generated output and numbers of students employed and is utilized to "control" for program size.

Input 2 - Number of full-time equivalent instructors in each program. FTE was based upon a 12 credit hour load for part time staff members.

Input 3 - Facilities allocation as determined by square feet assigned to each program for classroom, office and laboratory use. Metro is crowded and space is a scarce resource to be allocated with competition between both existing and proposed new programs.

Input 4 - Direct instructional expenditures in each program including salaries, equipment (exclusive of initial capital outlays for new programs), and instructional supplies. Note that if the local accounting system had provided the data, amortized capital expenditures could provide an additional input variable.

RESULTS AND INTERPRETATION

Data for inputs and outputs were collected by the Director and analyzed at The University of Texas using a highly efficient code documented in J. Kennington [16] and I. Ali, A. Bessent, W. Bessent and J. Kennington [1]. First we present distributions of the input and output measures and the obtained efficiency index for each program. Finally, the complete results for three programs in one area are given to show the management information obtainable.

Overall Efficiency of Programs

In Table 2 the data for twenty-two programs are given for the three outputs and four inputs defined in the previous section. Measures with large values were rescaled to bring them all within a zero to 100 range. For example, revenue generated is given in $10,000 units and employer satisfaction is in 100's. One can readily see in Table 2 that the information employed by the Director for program review provides little help in its raw form for making decisions about which programs are most productive. Program 4, for example generates the most revenue but it also costs the most. Further, it has fewer students employed than program 2.

Table 2

DISTRIBUTION OF INPUTS, OUTPUTS

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As was discussed earlier, DEA allows us to compute an efficiency index--shown in the last column of Table 2--which takes all outputs and inputs into account simultaneously.

Thus the programs which are the most productive of the 3 outputs for the inputs they have are given an efficiency value of 1.00. Others have an efficiency value proportional to the units with maximum efficiency. For example, in Table 2, we see that program #16 in the allied health field is only 57% as efficient as program #13 in the same field, and program #20 is less than one-half as efficient as eight other programs in the college.

The efficiency value provides a summarizing index for the overall relationsnip of inputs to outputs but additional computations are needed to discover which inputs are poorly utilized and what output levels are necessary to bring the unit to the same efficiency level as other programs with similar inputs. The management information provided by DEA for individual inputs and outputs is presented in the following section.

Before going ahead, however, let us clarify that we are not assuming a direct cause-effect relationship even though it clearly exists in relationships such as contact hours (input) which produce revenues (output) because of funding formulas. In other cases, the causal relationship if it exists, is indirect--for example, number of FTE staff and number of students employed. The obtained correlations in Table 3 indicate that outputs are related to inputs, but we need make no assumption about causality. In addition, it is of interest to observe in Table 3 that the efficiency value is unrelated to individual outputs. This reinforces our earlier observation that the Director of Occupational and Technical Education cannot compare program efficiency by looking at how much they individually produce.

Table 3

CORRELATION COEFFICIENTS

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In the following section we proceed to an example of the management information needed to further explain the sources of efficiency/inefficiency of individual programs at Metro Community College.

PLANNING AND GOAL SETTING AT THE PROGRAM LEVEL

In this section, we will illustrate how managers might use results for setting program goals and planning for the achievement of these goals. The three allied health programs will be used as the basis for discussion. Model solutions and interpretations for these programs are presented in Tables 4-5. Program 5 (see Table 4) will be fully discussed first followed by a brief discussion of the other two programs.

Program 5: Increasing Efficiency by Improving Inefficient Aspects of Programs

Prior to the DEA analysis, the Director of Occupational-Technical Programs at Metro Community College described this program as being, "one that was built for more students than we have from current demand." Thus, the Director of Occupational-Technical Programs initially believed that there was some possibility that space was being "wasted."

Table 4

DECISION MAKING UNIT 5

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Examining the columns of multipliers in Table 4 supports the Director's initial opinion in that the multiplier for square feet of allocated space is the smallest possible number that satisfies the condition that all multipliers be positive. Note that in planning to increase efficiency, there are only two ways that this ratio could increase: (1) increasing combined outputs and/or (2) decreasing the combined inputs.

For the moment, consider the inputs only. If a larger multiplier is applied to allocated space, then one or more multipliers for the other inputs must be reduced or else some other program will have an index greater than 1 which violates one or more of the constraints. The overall result would be a reduced efficiency index for Program 5, in that the combined inputs in its index would be larger than that obtained due to its use of a larger amount of space relative to the other inputs and to space allocated to the other programs.

A similar argument can be made for combined outputs. Revenues and employer satisfaction are associated with larger multipliers than students employed because, relatively speaking, Program 5 is a "better producer" of these two outputs. Thus, if Program 5 could better utilize allocated space in such a way that more students would be employed in the area of their training, then a reanalysis would result in larger multipliers for allocated space and students employed. The result being a larger efficiency index for Program 5.

If it should turn out that there is no way to improve utilization of space to accomplish the stated objectives, then possibly the space might benefit Metro Community College overall if it were reassigned to another program. The recipient program might be one not now in existence for which there is a large community demand or one of the existing programs in need of space. If space allocated to Program 5 were to be reduced by more than 325.3 square feet, (an analytical result not shown in Table 4), then a new set of multipliers would result and the efficiency index for Program 5 would be increased if all else remained the e.

Program 5: Increasing Efficiency by Capitalizing on Efficient Aspects of Program

In the preceding discussion, the efficiency index for Program 5 was shown to be .84. What would be the best strategy for increasing this index? The values of the multipliers provide information about the amount of increase in the output sum per unit increase in the output, and we have already noted above that revenues and employer satisfaction contribute the greatest increase in efficiency per unit increase in the output. In addition, revenues are functionally related to contact hours which means that revenues cannot be increased without an associated increase in contact hours, thus reducing the impact on efficiency. However, the number employed and employer satisfaction could possibly be improved without associated increases in the measured inputs. If so, this would result in a more efficient program.

Program 13

Since Program 13 is currently an efficient program, a focus on the improvement of the least efficient aspects of the program would be the most beneficial. On the input side, these are cost and allocated space (low value for associated multipliers).

Table 5

DECISION MAKING UNIT 13

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On the output side, employer satisfaction could be improved. Perhaps the staff could devise ways to improve technical and personal skills of students through more effective utilization

of space and cost. The improved student skills then should result in increases in employer satisfaction and possibly number of students employed in program-related occupations.

Program 16

Program 16 is the least efficient of the allied health programs. This program has a certification requirement of 1 instructor for every 10 students. Consequently, the number of staff is large which in turn results in a large total cost. Both of these inputs are associated with multipliers of low numerical value, a fact that is not surprising given the mandated staffing requirement.

Table 6

DECISION MAKING UNIT 16 Refer to Page 32

What is surprising is that student skills are not being developed by this relatively large faculty that result in large employer satisfaction. Since the staffing and costs cannot be reduced if accreditation is to be maintained, the most viable strategy is to improve staff utilization for (a) employing more students in program-related occupations and (b) improved satisfaction on the part of employers.

Summary

We have illustrated somewhat superficially in the foregoing discussion how model solutions can be used for setting goals and planning for goal accomplishment. Program productivity can be increased through improvement of relatively inefficient program aspects or through extended use of relatively efficient program aspects. The former is viable for both efficient and

inefficient programs, while the latter would seem to be a stopgap strategy for inefficient programs.

APPLICATIONS AND LIMITATIONS OF DEA FOR EFFICIENCY ANALYSIS USING DEA FOR CONSIDERING PROPOSED PROGRAMS

Continuing the example used earlier, Metro Community College has requests for 15 new program areas but restricted monies, facilities and availability of new staff members limit the number of new programs that can be implemented.

In the proposal for the new programs, estimates of inputs and outputs could be required as part of the presentation. Outputs could be set as goals for the new program and inputs could be estimated on the basis of what resources are being requested to achieve the program's goals.

Thus, DEA could be used to compute the efficiency of the proposed program with existing programs as comparison units. If the resulting analysis indicated that the new program would be efficient, this would be an important consideration in recommending it for adoption. If it were more inefficient than existing programs, this might indicate that it should be rejected or if not then DEA would provide replanning information. For example, the Director might suggest that planned staff be reduced for the new program in order to make it more acceptable or that program goals are set too low in the proposal.

Limitations of DEA

Like any other quantitative technique, the DEA model has requirements that must be met. Unlike many such models, however, the limitations are few enough to permit many useful applications for management purposes. In this section, we will enumerate the limitations for such use.

1. There must be a number of decision making units all producing the same outputs and employing the same inputs. Further, the number of units must be greater than the number of inputs and outputs. At present, no theoretical basis for the ratio has been proved, but a working estimate used by the authors is that there should be at least twice as many decision making units as there are inputs and outputs combined. Fewer units result in misclassifications; i.e. insufficient validity for assessment or planning.
2. All inputs and outputs must be greater than zero. In general, one would assume from the nature of allocatable resources that it would be unlikely that a program would have none of some resources although occasionally this may happen. When this occurs, a small non-zero value must be supplied for that input or output.
3. There must be measurable or countable outputs which are valued as indicators of performance of the units being analyzed.

   In a general sense, education is a life experience

that defies definition. Even the more limited meaning of the term "schooling" as a set of formal processes provided by formal organizations, the concept includes cognitive, affective and skill dimensions too diverse for complete specification and often too subtle for measurement. We can, however, factor out from the whole learnings or behaviors that can be observed as evidence of the attainment of specific objectives of a school program. So, for example, the number of students completing a two-year program for electronic technicians is an acceptable output specification, as is the number passing the licensing examination, or the number actually employed as technicians upon completion of the program. Any one, or all three could be used as output measures depending upon the expectations expressed in stated objectives of the program for preparing these students. Note that such specification, though useful for the program, is incomplete in that it lacks information concerning possible increases in other outputs such as work motivation or human relations skills.

The perspective advanced in this paper is that an efficiency index using outputs which are primary stated objectives of an educational program is useful even though these are incomplete specifications of the total output of the program.

4. There must be measurable or countable inputs to the process being studied that are expressed at the

decision level used by the decision-maker. These must be scaled such that increases in input measurement are expected to be associated with increases in one or more of the output measures. In management of education we employ teaching staff, provide facilities, buy equipment and supplies and organize time as administrative inputs to our processes. We assume that the way those inputs are utilized will make a difference in the outcomes of our programs. Our assumption may not be correct, of course, but we cannot suspend operations while waiting for that proof. In the meantime, we observe the products of the process and if they are discrepant with expectations, we may alter the inputs or the processes or both.

5. Units of measurement expressed as ratios such as pupils per teacher or dollars per pupils are familiar to administrators in schools but they may disguise possible differences in economies of scale for large versus small units [21]. In several applications the authors have not found a difference between ratio measures and raw scale units, but this caution is presented since a theoretical basis exists.

SUMMARY

We have discussed the problems of constructing an operational measure of community college productivity and have proposed a solution by means of a procedure called Data Envelopment Analysis. The procedure can be used to measure efficiency of a number of college sub-units such as programs or departments which have the same outputs and inputs at some meaningful level of aggregation.

An application in occupational-technical program was used as a worked example to illustrate the rich management data provided by the technique. In 22 program areas, 8 were termed efficient in that they all had index values of 1.0 for their outputs produced and the inputs utilized. The others were inefficient with values ranging down to a program which was only 47 per cent as efficient as any one of the 8 efficient units.

An examination of the results of the analysis provided management information for devising alternate strategies for increasing the efficiency of programs.

The resulting analysis was employed by the Director of Occupational-Technical Education at the real college disguised as "Metro" to protect data sources. The results were helpful to the Director in evaluating budget requests and in assessing the productivity of program areas. A possible extension to assessing the addition of new programs was discussed.

Table 1

Decision Making Units, Department and Decision Maker

Program Unit	Occupational Area	Decision Maker
1	Business & Technology	Chairperson
2	Business & Technology	Chairperson
3	Social Services	Chairperson
4	Business & Technology	Chairperson
5	Allied Health	Chairperson
6	Building Trades	Chairperson
7	Business & Technology	Chairperson
8	Business & Technology	Program Director
9	Public Affairs	Program Director
10	Building Trades	Program Director
11	Business & Technology	Program Director
12	Social Service	Chairperson
13	Allied Health	Program Director
14	Business & Technology	Chairperson
15	Social Service	Chairperson
16	Allied Health	Chairperson
17	Public Affairs	Program Director
18	Public Affairs	Program Director
19	Public Affairs	Chairperson
20	Public Affairs	Chairperson
21	Business & Technology	Chairperson
22	Business & Technology	Program Director

Table 2

DISTRIBUTION OF INPUTS, OUTPUTS AND EFFICIENCY INDEX VALUES FOR 22 PROGRAMS

	OUTPUTS			INPUTS				
Program	Revenue Generated ($10,000)	Students Employed	Employer Satisfaction (100)	Contact Hours (10,000)	Number of FTE Staff	Facility Allocation (1,000 Sq. Ft.)	Expenditures ($10,000)	Efficiency
1	12.5	15	2.85	6.65	4	4.02	11.02	.66
2	100.6	180	34.20	48.88	32	9.52	70.07	.87
3	28.2	52	10.56	10.28	13.5	4.02	19.13	.91
4	158.5	114	23.26	25.93	25	4.44	93.36	1.00
5	10.1	16	3.52	3.62	3.1	1.75	7.30	.84
6	32.4	28	5.82	14.06	11	8.3[illegible]	27.62	.64
7	30.1	40	8.80	12.21	8.1	8.40	22.23	.83
8	5.2	11	1.90	2.03	2.5	.56	4.44	.81
9	4.3	35	8.75	3.51	3	.15	6.00	1.00
10	26.2	29	6.38	15.76	10.1	3.44	17.35	.75
11	6.0	12	2.64	3.83	2.5	.13	2.50	1.00
12	1.1	3	.45	.64	3	.31	2.27	.59
13	4.1	12	2.64	1.99	1.1	1.65	4.63	1.00
14	39.5	89	20.11	25.52	16.5	.43	25.67	1.00
15	2.5	8	1.68	1.07	2	1.12	4.82	.89
16	72.7	71	12.71	23.55	4.5	12.19	82.44	.57
17	13.6	51	12.75	11.99	7.2	.77	18.28	.74
18	4.5	0	0	1.31	3	.77	2.48	.98
19	2.6	7	.91	2.66	1.1	1.25	1.07	1.00
20	5.2	3	.54	2.81	4	1.25	6.06	.48
21	6.3	22	3.75	2.49	2.5	9.60	9.08	1.00
22	7.2	27	5.40	5.18	4	.1	3.65	1.00

Table 3

CORRELATION COEFFICIENTS FOR OUTPUTS WITH INPUTS AND EFFICIENCY INDEX VALUES FOR 22 PROGRAMS

INPUTS \ OUTPUTS	Revenues Generated	Students Employed	Employer Satisfaction
Contact Hours	.81	.96	.95
Number of FTE Staff	.80	.79	.75
Facility Allocation	.50	.47	.41
Total Expenditures	.95	.82	.80
EFFICIENCY INDEX	.04	.12	.15

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Table 4

Metro College Occupational-Technical Program Review

Decision Making Unit 5

Decision Maker: Chairman, Allied Health Programs

Efficiency - .84

	Value Measured	Units of Measure	Multipliers
OUTPUTS			
Revenues	10.1040	$10,000	.0692
Employed	16.0000	# of Students	0.00001
Employer Satisfaction	3.5200	100 Points	.0855
INPUTS			
Contact Hours	3.6240	10,000 hrs	.0356
# Staff	3.1000	FTE	.1008
Sq. Ft. Space Allocation	1.7500	1,000 Sq. Ft.	0.00001
Total Cost	7.2991	$10,000	.019

Summary Interpretation: An efficiency rating of .84 was obtained from the utilization of contact hours, number of staff, and total cost in the production of revenues and employer satisfaction. Results indicate that the square feet of space need to be more productively employed and more students need to be employed.

Indicated Problem for Administrative Review: How to better utilize allocated space to increase the number of students employed.

Table 5

Metro College Occupational-Technical Program Review

Decision Making Unit 13

Decision Maker: Director of Program 13, a Subordinate of Allied Health Programs Chairman

Efficiency = 1.00

	Value Measured	Units of Measure	Multipliers
OUTPUTS			
Revenues	4.0972	$10,000	.0746
Employed	12.0000	# of Students	.0579
Employer Satisfaction	2.6400	100 Points	0.00001
INPUTS			
Contact Hours	1.9872	10,000 hrs	.2240
# Staff	1.1000	FTE	.5045
Sq. Ft. Space Allocation	1.6500	1,000 Sq. Ft.	0.00001
Total Cost	4.6301	$10,000	0.00001

Summary Interpretation: This program is an efficient program. The efficient classification was derived from the employment of contact hours and number of staff in the production of revenues and number of students employed.

Possibilities for Improving Utilization of Resources: Even though this program is as efficient as any program at Metro, could allocated space and cost be better utilized to increase employer satisfaction?

Table 6

Metro College Occupational-Technical Program Review

Decision Making Unit 16

Decision Maker: Chairman, Allied Health Programs

Efficiency = .57

	Value Measured	Units of Measure	Multipliers
OUTPUTS			
Revenues	72.7590	$10,000	.0074
Employed	71.0000	# of Students	.0065
Employer Satisfaction	12.7100	100 Points	0.00001
INPUTS			
Contact Hours	23 5524	10,000 hrs	.0738
# Staff	45.0000	FTE	0.00001
Sq. Ft. Space Allocation	12.1910	1,000 Sq. Ft.	.0005
Total Cost	82.4434	$10,000	0.00001

Summary Interpretation: An efficiency rating of .57 was obtained from the employment of contact hours and square feet of space in the production of revenues and number of students employed.

Indicated Problem for Administrative Review: How to better utilize staff and cost to improve employer satisfaction and the number employed.

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APPENDIX A

A MATHEMATICAL MODEL FOR REPRESENTING THE RATIO OF MULTIPLE OUTPUTS AND INPUTS

To represent the models algebraically, the Charnes, Cooper, Rhodes notation will be used so that references can be easily related to this paper.

Since there are multiple inputs to be considered

let $x_{ij} > 0$ represent the measured amount of the ith input used by the jth unit.

Also, multiple outputs may need to be included so

let $y_{rj} > 0$ be the amount of the rth output produced by unit j.

Then using this notation $\sum_{j=1}^{s} y_{rj} \Big/ \sum_{i=1}^{m} x_{ij}$

would be a "miles per gallon" type index for unit j if output and input units of measure were such that inputs and outputs could be added. But, since different kinds of inputs and outputs are measured in units that are quite different, e.g., pupils and dollars, multipliers are needed to transform the data so that a ratio with associated measurement unit is formed. Thus,

let $u_r > 0$ represent the multiplier for the rth output

and

let $v_i > 0$ be the multiplier for the ith input so that the Charnes, Cooper, Rhodes (CCR) efficiency index for j is

$$\sum_{r=1}^{s} u_r y_{rj} \Big/ \sum_{i=1}^{m} v_i x_{ij}$$

Once it is understood how the index is to be formed, the problem of a criterion still remains. In addition, the criterion or reference points need to be attainable if the information is to be useful for assessment and planning. This problem is "solved" by the addition of a set of constraints which specify the "best producers" in the set of units under review as the criterion set. Thus, the CCR efficiency index for all units is relative to the empirically derived criterion set. Using the notation defined above, the efficiency model for assessing the efficiency of unit k is given below.

Maximize

$$\sum_{r=1}^{s} u_r y_{rk} \Big/ \sum_{i=1}^{m} v_i x_{ik}$$

Subject to the following constraints:

$$\sum_{r=1}^{s} u_r y_{rj} \Big/ \sum_{j=1}^{s} v_i x_{ij} \leq 1$$

$$\text{for } j = 1, \ldots, n$$

$$y_{rj},\ u_r > 0 \quad \text{for } r = 1, \ldots, s; \quad j = 1, \ldots, n$$

$$x_{ij},\ v_i > 0 \quad \text{for } i = 1, \ldots, m; \quad j = 1, \ldots, n$$

Note that the constraint set includes an efficiency ratio for each unit under review including the unit (k) currently being evaluated. Further, 1.0 is the maximum value that any ratio can take on since all constraints must be simultaneously satisfied.

The algorithm for solving the model presented above will search for positive values of the set of multipliers u_r and v_i that result in the greatest possible value of the CCR efficiency index for unit k that the set of constraints will allow. If values for u_r and v_i result in a ratio equal to one, then unit k is obtaining a combination of output values as high as any other unit with similar inputs; that is, unit k is efficient. Or, stated another way, all available resources (inputs) are effectively employed in the production of the valued outputs. If the resultant ratio is less than one, then unit k is inefficient in a relative sense, and the value of the ratio can be interpreted in a manner similar to batting average; that is, the proportion of outputs attained by unit k relative to the most productive units that are similar to unit k.

An efficiency model is solved for each of the j = 1, .. , n units thus identifying all of the efficient (criterion) units in the set of units under review. These efficient units can subsequently be used to determine output and/or input values an inefficient unit would need to have if it were to be efficient. This provides administrators with information which can be used for assessment and planning for improved utilization of available resources.