Assessing Hospital Efficiency over Time: An Empirical Application of Data Envelopment Analysis

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ABSTRACT

Organizations require software support for their transaction and management information systems. One of the primary responsibilities of information technology (IT) managers is to oversee the development (or purchase) of software that supports the information systems throughout the organization. Within this component of the IT manager's responsibilities, he or she must identify the information needs throughout the organization, and provide for these needs. In other words, the IT manager must develop the data bases and software to provide the information that is needed within the organization.

Data envelopment analysis (DEA) is an efficiency measurement procedure. It is a very powerful tool that IT managers can make available to organizational management to better assess their performance. Knowledge of this tool can benefit IT managers by allowing them to improve their job performance (i.e., they will be able to improve the manner in which they fulfill the responsibilities of their job). They need to be aware of techniques such as DEA so that they can provide the kind of systems and software that are appropriate for gathering and analyzing data. For example, IT managers may want to provide an interactive system so that DEA analysis can occur on a regular basis. Additionally, IT managers should find DEA useful in evaluating the productivity of information systems (Elam & Thomas, 1989).

This study examines the DEA methodology and its ability to determine the relative efficiency of each of the latest twenty-two months of available data for a mid-sized nonprofit hospital in the Southeast United States. DEA was able to simultaneously consider multiple inputs and outputs (five of each) with which it classified months as efficient or inefficient. The specific inputs and outputs that caused a month to be considered inefficient were identified as well as the magnitude of the excess inputs or insufficient outputs.

The results were discussed with hospital management. They considered DEA an efficient and effective tool. The efficiency ratings assisted their decision making as to which time periods and areas to investigate for inefficiencies, and was considered to be a potential device for assisting in reducing hospital costs.

INTRODUCTION

Various major reforms in national healthcare will be before Congress in 1994 and 1995. No matter which reforms are enacted, the most efficient healthcare organizations have the best chance of obtaining the greatest benefits (Davis, 1993). As firms attempt to become more efficient, the effectiveness of their information systems (Sethi et al., 1993; Hard, 1993) and information management (Brooke, 1992; Barrett, 1993) becomes critical. Further, information technology (IT) can be used to gain a competitive advantage by improving operational efficiencies (Cragg & Finlay, 1991) or reducing inefficiencies (Clemons & Row, 1993). Thus, IT and the effective use of information systems can improve operational efficiency in healthcare organizations.

The use of information systems requires the development of various tools such as analytical procedures to benefit from the data that is collected. One such procedure that has the potential for improving operational efficiency is data envelopment analysis (DEA). DEA is an ex post efficiency measurement procedure. It is capable of estimating the relative efficiency of decision-making units (DMUs) within a group or of a single DMU over time. DEA has been employed in the evaluation of efficiencies in such diverse areas as airlines (Schefczyk, 1993), banking (Oral et al., 1992), education (Bessent et al., 1982), equipment maintenance (Charnes et al., 1985; Turner, 1990; Clarke, 1992), health care (Borden, 1988; Banker et al., 1989b; Pina & Torres, 1992; Valdmanis, 1992; Finkler & Wirtschafter, 1993), court systems (Lewin et al., 1981), military recruiting (Lewin & Morey, 1981), pharmacies (Capettini et al., 1985; Banker & Morey, 1986a), and retail outlets (Banker & Morey, 1986b).

This paper examines the ability of DEA to identify inefficiencies within a hospital environment. A hospital provides an excellent example for the application of DEA. Hospitals typically are nonprofit organizations. As such, the accomplishments of the organization cannot be measured using the usual indicators of performance (sales, profit, return on investment, etc.). However, the efficiency with which a hospital operates is one of the most relevant measures of its accomplishments, and DEA will provide this information. Additionally, hospitals have multiple inputs (e.g., nurses, supplies, capital, etc.) and multiple outputs (e.g., various types of patient care). DEA is capable of simultaneously considering such input/output situations.

Managers of non-profit organizations have a primary responsibility to be efficient with respect to resource utilization (Committee on Accounting for Not-for-profit Organizations, 1971). In order to improve the efficiency of operations, management must decide where to focus their investigative efforts. That is, they must decide which time periods or areas are likely to be inefficient. The purpose of this paper is to examine the benefits of DEA in assisting the management of a non-profit hospital in this decision. DEA is applied to a single hospital over a period of time (twenty-two months). The information that is obtained from the DEA output is used to classify units (months) as efficient or inefficient. As will be demonstrated later, management can determine the specific inputs and outputs and the amounts that cause a month to be considered inefficient. This assists the hospital's management in identifying inefficient operational practices which should be modified or discontinued. Additionally, efficient practices are identified which should be continued in the future.

The organization of this paper is as follows. First is a review of the related literature. It focuses on the DEA model and prior DEA applications. Second, the application of the DEA methodology to an actual hospital situation is discussed. It includes an identification of relevant inputs and outputs, as well as the analysis and interpretation of the results. The final section discusses the practical implications of this study.

THEORETICAL ISSUES

The DEA Model

The DEA methodology was first proposed by Charnes et al. (1978) and is based on the Farrell (1957) efficiency measure. DEA is a linear-programming based method of determining the relative efficiencies of multiple DMUs. Within the hospital environment, the DMUs can be hospitals operating within a given area, units within a single hospital, or it is possible to examine the efficiency of a single unit/hospital with respect to itself over time (Lewin & Morey, 1981). Since this paper examines a single hospital over time, the discussion that follows will assume a DMU to be a relevant time period (month) for the hospital.

A hospital's efficiency for a given month is defined as the maximum of a ratio of the weighted sums of the patient-outputs to the weighted sums of the production factor-inputs. Thus, the efficiency of a month is determined as follows:

$$\text{Maximize} \quad \frac{\sum_{r=1}^{s} U_r Y_{ro}}{\sum_{i=1}^{m} V_i X_{io}} \tag{1}$$

subject to:

$$\frac{\sum_{r=1}^{s} U_r Y_{rj}}{\sum_{i=1}^{m} V_i X_{ij}} \leq 1; \quad j=1, \ldots, n \tag{2}$$

$$U_r, V_i \geq 0; \quad r=1, \ldots, s; \quad i=1, \ldots, m \tag{3}$$

The Y_{rj} and X_{ij} are the ^{rth} output and the i^{th} input for the j^{th} month. Both Y_{rj} and X_{ij} are known and positive. The U_r and V_i are weights (implicit prices) assigned to the inputs and outputs. In the DEA application that follows, these will be defined to be strictly positive. They are determined by the linear programming solution using the input-output ratios for all months under consideration. The particular month being evaluated as to its relative efficiency is assigned the subscript 0 in equation (1). All n months, including the one under evaluation, are used in determining the n constraints. This is necessary so that no month will be assigned an efficiency rating of more than 100%.

For each month under consideration, an efficiency rating will be determined. This will be a relative rating in the sense that the observation is compared to all other observations being examined. Month 0 will be considered inefficient if, in comparison to other months, the hospital "could have reduced input usage with no reduction in outputs or produced more outputs with no reduction in inputs or both reduced inputs and increased outputs." (Callen, 1991, p.37) See Appendix A for a simplified DEA illustration.

The DEA model described in Equations (1) through (3), above assumes constant returns to scale. However, it is possible to modify the model to accompany increasing or decreasing returns, should these conditions be determined to exist (see Banker et al., 1989a; Banker & Morey, 1989; Callen, 1991).

Advantages of DEA Over Alternative Measures of Hospital Efficiency

Two alternative approaches to evaluating hospital efficiency are widely used (Sherman, 1984a). They are ratio analysis and econometric regression analysis.

Ratio analysis is the examination of the relationship between one input and one output variable at a time. An attempt is then made to find relationships that are not within the norm, or to aggregate the ratios to get an overall efficiency measure. The most critical disadvantages of ratio analysis are the large number of ratio measures that result from the multiple inputs and outputs of hospitals, and the lack of an objective method to combine ratios. For a hospital with M input measures (e.g., nursing services, purchased services, supplies, capital, etc.) and N output measures (e.g., patients, nurse training, etc.) it would require the calculation of M times N ratios. Since many of the ratios would necessarily be interrelated, the proper interpretation of any single ratio would be difficult. For example, in month A the amount of nursing services per patient may be high compared with month B. However, no statement as to the relative efficiency of the months could be made without consideration of the other inputs such as the amount of purchased services per patient in the two months.

Econometric techniques are based on ordinary least squares (OLS) regression analysis. Such regression is capable of simultaneously handling the many inputs and outputs that hospital efficiency analysis requires; however, other problems arise. Many times the data are not appropriate for the required specification of a parametric functional form (e.g., not normally distributed). No assumptions about the form or distribution of data are required using DEA. Furthermore, the regression output provides an estimate of average (mean) relationships, which are not directly useful in identifying the inefficiencies within a hospital (Sherman, 1984a). An arbitrary cutoff for efficiency levels must be assigned.

In summary, DEA is superior to other common efficiency measurement techniques used for hospitals (specifically, ratio analysis and econometric regression analysis) because:

1. It is consistent with economic theory since it locates technical or parieto inefficiencies rather than measuring efficiency based on averages.
2. It does not require the establishment of arbitrary cutoff points for classifying efficient and inefficient hospitals.
3. It can simultaneously consider multiple inputs and multiple outputs, and direct management's attention toward the particular factor(s) that exhibit(s) the greatest effect on operational efficiency.
4. It does not require a common measurement unit for inputs and/or outputs such as "dollars" (especially important for nonprofit organizations such as hospitals). Similarly, it is not necessary to establish relative weightings for the inputs or output measures.
5. It does not require specification of a parametric functional form.
6. It is flexible (able to handle various economies of scale) and robust as to variations in model specifications.
7. It can be used in a sensitivity analysis to determine where resources might best be applied in order to reduce inefficiencies.

DEA is the "only viable methodology that links *all* factors of efficiency by evaluating the relationships between each input and output to arrive at a scalar measure of performance." (Schefczyk, 1993, p. 313)

Prior DEA Applications to Hospitals

Sherman (1984a) is the first noted application of the DEA methodology to hospitals. He applied DEA to the medical-surgical area of seven teaching hospitals in Massachusetts. The inputs were defined as non-surgical full-time equivalents (FTEs), supplies, and bed-days available. The outputs were defined as patient days for two age groups, nurses trained, and interns and residents trained.

Two of the hospitals were identified as relatively inefficient. Two "hospital experts" agreed with the DEA assessment. The management of one of the inefficient hospitals was able to find some of the probable causes of inefficiencies. Thus, using cross-sectional data, Sherman was able to demonstrate the ability of DEA in directing management efforts in improving hospital efficiency.

Banker et al. (1986) compares both DEA and econometric (translog cost function) methodologies. The study examined 114 North Carolina hospitals. Inputs were defined as nursing services, ancillary services, general and administrative services and beds available. Outputs considered included patient days for three age groups. The two methods produced similar measurements of efficiencies with one exception.

The translog model's results produce an averaging effect for economies of scale, thus suggesting overall constant returns. The DEA model was able to identify cases of both increasing and decreasing returns. Decreasing returns were found for hospitals with higher proportions of elderly patients.

Borden (1988) used the DEA methodology to examine the efficiency of 52 New Jersey hospitals. Medicare reimbursement for all hospitals was Diagnosis-related groups (DRG) based by 1982. Some hospitals began using DRGs as a patient billing basis at an earlier date. Borden used DEA to examine the hospitals' efficiency. The input measures were total FTEs, nursing FTEs, number of beds, and other nonpayroll expenses. The number of cases treated in each of nine DRG-based categories was used as an output measure. The DEA solution suggested that hospitals operating under the DRG-based reimbursement system for a longer period of time were more efficient than hospitals that had not operated under the DRG system as long. No significant difference was noted using the ratio or regression methodologies.

Banker et al. (1989b) demonstrates how DEA can be used in setting cost standards for hospitals' use in variance analysis. They examined 111 North Carolina hospitals. The inputs of the hospitals were defined as the cost of each of five departments: nursing, laboratory and professional, household and maintenance, administration, and dietary services. Outputs were defined as patient-days of each of eight specialty areas: medicine, surgery, obstetrics, gynecology, psychiatry, eyes-ears-nose-and-throat, urology, and orthopedics. The study demonstrated how using DEA to set cost standards allows for standards that can be 100% efficient based. Alternatively, standards may be set at more relaxed levels of efficiency, say 90%. Typically, standards have been set at less meaningful levels such as average efficiency levels or some other arbitrary amount

Critique of Prior Studies

The most direct measure of a hospital's output can be obtained by calculating the number of patients treated within various diagnostic groups (Banker et al., 1989b). A most critical compromise exists in using output measures that are not DRG based (classifications that group patients by similarity of diagnosis) — (Sherman, 1984a; Banker et al., 1986). While Sherman (1984a) and Banker et al. (1986) used age groupings and Banker et al. (1989b) used specialty-based groupings, only Borden (1988) made use of DRG output measures in a DEA application.

Although suggested in the research (Charnes et al., 1978; Lewin & Morey, 1981; Sherman, 1984b; Turner, 1990; Callen, 1991), none of the prior hospital DEA studies have examined an application of DEA over time. For a hospital to measure its level of efficiency, both cross-sectional and time-series applications of DEA are necessary. The cross-sectional data application will produce an indication of the hospital's level of efficiency relative to other comparison hospitals. However, the other comparison hospitals may not be efficient. Equally important to a hospital's level of efficiency is its efficiency over time. Even if a hospital is rated by the DEA output as 100% efficient relative to other comparison hospitals, time-series data will likely be able to identify periods of inefficiency for the hospital. This will assist in improving the hospital's overall efficiency.

AN EMPIRICAL TIME-SERIES APPLICATION OF DEA

This section presents the application of the DEA methodology to an actual hospital situation. The hospital examined is a mid-sized nonprofit hospital in the Southeastern United States.

Identification of DMU Sample, and Relevant Inputs and Outputs

Units of time make up the DMU sample in a time-series application of DEA. In this study, the time units were defined as months. The data was obtained for the latest available twenty-two month period. Therefore, each month within this period was considered to be a DMU.

Care should be taken in the proper identification of inputs and outputs for DEA application. It is the inputs and outputs that are used to model the organization's activities and are the basis for determination of efficiency. It has been suggested that organizational management should be consulted in the process of input and output selection (Thanassoulis et al., 1987; Bowlin, 1989). This is because they are likely to be in the best position to determine the types of services that are provided (outputs) and what resources are used to provide them (inputs). Hospital management was involved in the selection of inputs and outputs for this study.

In general, using a greater number of input and output measures will allow for a more accurately defined model of the organization's activities. However, there are drawbacks to having too many measures. Increasing the number of input or output measures may allow for relatively inefficient months to be rated as efficient. This is because a given month's observations will have a greater probability of finding an available set of weighted inputs and outputs of other months from which it can be shown to be efficient. Therefore, "the number of inputs and outputs in a DEA assessment should be as small as possible, subject to their reflecting adequately the functions performed by the units being assessed." (Thanassoulis et al., 1987, p. 399) A general rule of thumb is there should be at least twice as many DMUs as inputs plus outputs (Golany & Roll, 1989). The current study contains twenty-two DMUs (observations) and has five inputs plus

Table 1

Summary of Inputs and Outputs Selected

Measure	Description
Inputs:	
Nursing Services (N)	The number of hours worked by nursing service personnel
Ancillary Services (A)	The number of hours worked by ancillary service personnel which includes non-room and board medical services for physical therapy, radiology, pharmacy, etc.
Support Services (S)	Total number of hours worked by support service personnel including housekeeping, dietary, laundry, business office, medical records, security, etc.
Temporary/Purchased Services (T)	The total cost of temporary nursing contract services including telemetry, oncology, intensive care, etc.
Patient Supplies (P)	The total cost of patient supplies used in dollars
Outputs:	
Major Diagnostic Category 5 (MDC5)	The number of cases treated in the diagnostic category for diseases and disorders of the circulatory system
Major Diagnostic Category (MDC4)	The number of cases treated in the diagnostic category for diseases and disorders of the respiratory system
Major Diagnostic Category 6 (MDC6)	The number of cases treated in the diagnostic category for diseases and disorders of the digestive system
Major Diagnostic Category 8 (MDC8)	The number of cases treated in the diagnostic category for diseases and disorders of the musculoskeletal system and connective tissue
All Other MDCs (O)	The number of cases treated in the remaining MD categories

five outputs. Previously noted hospital DEA applications have used from three to six inputs and from three to ten outputs.

The inputs and outputs used is this study are presented in Table 1. The inputs include (1) nursing services (in hours), (2) ancillary services (in hours), (3) support services (in hours), (4) temporary or purchased services (in dollars) and (5) patient supplies (in dollars). The inputs used in this study are similar to those used by Conrad and Strauss (1983), Sherman (1984a), Borden (1988) and Banker et al. (1989b). However, capital was omitted as compared to prior studies because, although capital varies in cross-sectional data, capital generally remains stable in a short-term time-series application of DEA.

As previously discussed, most prior hospital DEA research has compromised results due to the use of inappropriate output measures. Primarily, this was because of the unavailability of data. The output measure used in this study is the number of patients treated within various diagnostic categories. This is suggested as the appropriate output measure by Sherman (1984a), Banker et al. (1986) and Banker et al. (1989b). There are 25 possible major diagnostic categories (MDCs). However, for the hospital examined in this study, the four most common MDCs accounted for most (58.3%) of the patients treated. They are: (1) MDC 5—circulatory system diseases and disorders (21.6%), (2) MDC 4—respiratory system diseases and disorders (12.7%), (3) MDC 6—digestive system diseases and disorders (12.4%) and (4) MDC 8—musculoskeletal system and connective tissue diseases and disorders (11.6%). No other MDC accounted for more than 7.3% of patients treated. Therefore, all remaining MDCs were grouped as a single additional output.

Although some of the prior research studies used patient-days instead of patients treated as an output metric, patients treated is used in this study. Patients treated is in the process of becoming the standard measure in the medical care industry. It is preferred by medicare and insurance companies over patient days because in order for a hospital to be efficient they must cure patients (patients treated), not just keep patients for a longer period of time (patient days).

Hospital management was consulted, and agreed that the five inputs and five outputs identified in Table 1 define the hospital's activities in a fair manner.

The DEA Results

Each of the twenty-two months under examination was identified using a number (from Month 1 to Month 22). The results of the DEA analysis are summarized in Table 2. Four months were classified as relatively inefficient as compared to the remaining months. They are Month 9 (91.5% efficient), Month 11 (87.5% efficient), Month 19 (99.4% efficient) and Month 20 (97.7% efficient). Each relatively inefficient month has a set of comparison months from which it is determined to be inefficient. These comparison months are referred to as the efficiency reference set (ERS).

By combining the weighted inputs and outputs of the ERS months, a hypothetical composite month is created that would produce greater or equal outputs with fewer or equal inputs. The appropriate weights for producing an ERS-composite month are provided in the DEA output and are included in Table 2.

A comparison can be made between the inputs and outputs of the ERS composite with the inefficient month to determine the magnitude of inefficiency that exists. The two months (Month 9 and Month 11) were considered to have significantly large inefficiencies. That is, they have efficiency ratings of less that 97.7%, a level that appears to be a reasonable cutoff point. These two months were compared

Table 2

Comparison of Monthly DEA Results

Month	DEA Efficiency Rating	Efficiency Reference Set and Weightings
1	1.000	*
2	1.000	*
3	1.000	*
4	1.000	*
5	1.000	*
6	1.000	*
7	1.000	*
8	1.000	*
9	.915	(.7274 Month 3 + .0190 Month 6) +.1003 Month 16 + .0403 Month 17 +.0004 Month 21)
10	1.000	*
11	.875	(.7770 Month 3 + .0703 Month 12 +.0101 Month 16 + .0011 Month 17)
12	1.000	*
13	1.000	*
14	1.000	*
15	1.000	*
16	1.000	*
17	1.000	*
18	1.000	*
19	.994	(.3208 Month 3 + .0387 Month 5 +.3028 Month 16 + .3867 Month 17)
20	.977	(.1418 Month 1 + .0445 Month 4 +.0194 Month 5 + .5400 Month 12 + .0150 Month 16 + .3382 Month 21)
21	1.000	*
22	1.000	*

* Month is relatively efficient.

Table 3

Comparison of Month 9 With Its Efficiency-Reference-Set Months

	(a) Month 3	(b) Month 6	(c) Month 16	(d) Month 17	(e) Month 21	(f) Composite= (.727387 (a) +.019010 (b) +.100323 (c) +.040308 (d) +.000389 (e)]	(g) Month 9 (Actual)	(h) Month 19– Composite (g) – (f)
Inputs:								
N	23,280	25,835	27,435	28,242	26,710	21,326	23,313	1,987
A	38,473	40,677	37,922	40,064	37,911	34,192	37,378	3,186
S	27,922	29,518	26,647	27,451	25,712	24,661	26,959	2,298
T	47,144	100,670	53,150	75,274	20,454	44,580	48,734	4,154
P	226,542	215,475	267,569	311,398	228,223	208,364	248,186	39,822
Outputs:								
MDC5	100	107	89	105	69	88	68	–20
MDC4	66	60	60	54	42	57	47	–10
MDC6	54	65	53	63	35	48	39	– 9
MDC8	53	48	60	62	45	48	48	0
O	185	217	184	193	178	165	165	0

N = Nursing Services (Hours)
A = Ancillary Services (Hours)
S = Support (Hours)
T = Tempory/Purchased Services ($s)
P = Patient Supplies ($s)
MDC5 = Circulatory System Diseases and Disorders
MDC4 = Respiratory System Diseases and Disorders
MDC6 = Digestive System Diseases and Disorders
MDC8 = Musculoskeletal System and Connective Tissue Diseases and Disorders
O = All Other MDCs

with their ERS composite. This comparison is shown in Tables 3 and 4.

Analysis and Interpretation of Results

As previously indicated, Month 9 and Month 11 were identified as the two months with relative inefficiencies that were considered to be significantly large. Therefore, they are the months used in the further analysis that follows. The set of months from which they were determined to be inefficient include Months 3, 6, 12, 16, 17 and 21. Many causes for the inefficiencies are possible. Discussions with hospital management revealed several potential explanations.It appears that an overriding factor related to efficiency may be occupancy rates. Of the twenty-two months under examination, the two most "inefficient months" (Month 9 and Month 11) ranked eighteenth and twenty-first, respectively relative to occupancy levels. During slower months, there is idle capacity since many of the nurses and other staff are on duty regardless of the level of occupancy. However, occupancy rates are only a possible and partial explanation for the inefficiencies associated with Months 9 and 11.

Another potential explanation for why Months 9 and 11 were inefficient relative to Month 3 (the month with the highest ERS weighting) relates to an incentive offered to the hospital's nurses. During Month 3 (and continuing through Month 8) an incentive plan was initiated whereby the nursing staff received additional pay for increased production. This incentive was used in an attempt to reduce the need for temporary nursing services during the high occupancy season. Of the months under the incentive plan, only Month 3 is included in both ERSs. Therefore, it would appear that the incentive plan had only a short-term effect on the efforts of the nursing staff, or at least that the greatest effect of the plan occurred in its first month of implementation.

Although output inefficiencies were shown to exist, they are somewhat less interesting than the input inefficiencies in a hospital DEA application. Primarily, this is due to their less controllable nature. Hospitals have substantially greater

Table 4

Comparison of Month 11 With Its Efficiency-Reference-Set Months

	(a) Month 3	(b) Month 12	(c) Month 16	(d) Month 17	(e) Composite= (.776961 (a) +.070281 (b) +.010148 (c) +.001059 (d)]	(f) Month 11 (Actual)	(g) Month 11– Composite (f) – (g)
Inputs:							
N	23,280	24,768	27,435	28,242	20,137	23,018	2,881
A	38,473	39,974	37,922	40,064	33,129	37,869	4,740
S	27,922	28,370	26,647	27,451	23,988	27,420	3,432
T	47,144	37,456	53,150	75,274	39,881	54,493	14,612
P	226,542	270,381	267,569	311,398	198,062	268,193	70,131
Outputs:							
MDC5	100	75	89	105	84	70	–14
MDC4	66	45	60	54	55	34	–21
MDC6	54	42	53	63	46	42	– 4
MDC8	53	59	60	62	46	46	0
O	185	145	184	193	156	156	0

N = Nursing Services (Hours)
A = Ancillary Services (Hours)
S = Support (Hours)
T = Tempory/Purchased Services ($s)
P = Patient Supplies ($s)
MDC5 = Circulatory System Diseases and Disorders
MDC4 = Respiratory System Diseases and Disorders
MDC6 = Digestive System Diseases and Disorders
MDC8 = Musculoskeletal System and Connective Tissue Diseases and Disorders
O = All Other MDCs

control over their cost of operations and other inputs than over the number of patients they treat (e.g., a hospital cannot cure more patients in a particular category if they do not exist).

The input item with the greatest percentage of excess occurred during Month 11. A comparison of Month 11's "temporary services" cost of $54,493 with its ERS composite of $39,881 indicates an excess of $14,612 (36.6% above the ERS composite). Part of this excess is explained above in the discussion of the incentive plan. A closer analysis of the temporary service costs reveals that they are comprised of various types of services with differing costs per hour. Over 72% of the temporary service costs in Month 11 were from the intensive care unit (ICU) and telemetry. Additionally, Month 11 had the highest ICU-temporary service use of any month under examination. The average hourly cost for the ICU and telemetry temporary services during Month 11 was $36.62. This is 27.8% above the overall average temporary service cost of $28.66 per hour. Thus, when considering the cost of temporary services, a large amount of inefficiency is indicated, but when considering the hours of temporary services the amount of inefficiency is reduced. This indicates to the hospital management that a shift in the type of temporary nursing services purchased may be cost efficient (i.e., more permanent nursing staff should be used in ICU and telemetry and more of the temporary nursing staff should be used in the other areas). Further analysis is considered necessary.

The only other major input excess noted in the inefficient months (Months 9 and 11) was for patient supplies. This excess amounted to $39,822 in Month 9 and $70,131 in Month 11. Accurate accounting records are kept as to the supplies purchased and their ultimate disposition to patients. Hospital management examined the records, but no errors or irregularities were found. It appears that just a larger than normal amount of supplies were needed relative to the level of the other inputs and outputs during these months.

IMPLICATIONS FOR MANAGEMENT

Data envelopment analysis (DEA) was applied to a single hospital situation. The most recent twenty-two months of available data were examined in an attempt to determine which months, if any, where inefficient.

The following implications can be derived from this study: Although DEA cannot determine the optimal path to follow for improving a hospital's efficiency, it was shown to be useful in assisting management in identifying the existing inefficiencies. Additionally, the hospital management indicated that they were able to easily understand and interpret the DEA results. Included in these results are the overall levels of inefficiency, the specific inputs and outputs that caused a month to be considered inefficient, and the magnitude of the input excess or output insufficiency. Thus, DEA is able to assist management's decision as to which time periods and areas require their attention. After management knows the specific inputs and outputs that cause inefficiencies to exist within certain time periods, they can begin their investigation into the underlying causes. In this particular DEA application, subsequent investigation by hospital management was able to reveal most of the underlying causes of the inefficiencies.

Thus, DEA has been shown to be an effective and efficient tool for identifying and measuring existing inefficiencies within a hospital and as a tool for assisting management's efforts in increasing efficiency and reducing hospital costs. IT managers are responsible for coordinating the development of data bases and the software to provide the information that is needed by organizational managers. Within these roles, IT managers have a responsibility to make such tools as DEA available in situations that are deemed appropriate. IT managers may also use DEA themselves as a tool to evaluate the productivity of information systems.

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APPENDIX A

Simplified DEA Illustration

Assume the following occurred in a hospital over a period of four months:

	Nursing Hours	Support Hours	Patients Serviced
January (J)	10	60	10
February (F)	20	40	10
March (M)	60	10	10
April (A)	50	30	10

The problem for management is to determine which months are inefficient, if any. Annpying the DEA formulas 1 through 3 of this paper will result in the following:

Month	Efficiency Rating Rating	Efficiency Reference Set (ERS) and Weightings
January	100%	NA
February	100%	NA
March	100%	NA
April	81.5%	(.4815 Feb. + .5185 Mar.)

This information suggests that April is inefficient relative to a hypothetical month that is a linear combination of the inputs and putput of February and March. April should be able to produce the same output with only 81.5% of the inputs. A hypothetical composite comparison month could be calculated as follows:

	.4815 Feb.	+	.5185 Mar.	=	ERS Composite
Outputs					
Patients	(.4815 X 10)	+	(.5185 X 10)	=	10.0
Inputs:					
Nursing Hours	(.4815 X 20)	+	(.5185 X 60)	=	40.7
Support Hours	(.4815 X 40)	+	(.5185 X 10)	=	24.4

A geometric illustration of the relative efficiencies of the four observations and the ERS Composite month is as follows:

A Geometric Illustration of the Relative Efficiencies