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Effectiveness Analysis with Data Envelopment Technique in Healthcare Organizations: An Application

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Abstract:
Efficiency concept is important for every sector including service sector. The development of service sector relates other sub sectors as health. The development of health sector depends on high efficiency level. The aim of this study is to compare efficiency level of two state hospitals with DEA. Required data gathered by questionnaire method and analyzed, as a result of the study, efficient and inefficient departments determined and necessary improvement rates calculated.

Keywords: *DEA Method, Efficiency, Health Sector*

1. Introduction

The concepts of change and development have become highly important in our world that became a great market as a result of the globalization. In such an environment, businesses can provide sustainability and competitive edge only if they can accommodate themselves to the constantly changing setting. In this sense, flexibility and customer orientation will provide success to the businesses [xii]. Similar to that the major goals of Turkish healthcare system are to improve the health status, to increase efficiency, to ensure the sustainability of health services by improving service quality and patient satisfaction [xv].Today resource scarcity is the biggest problem of the production of health services which is regarded as an indicator of developmentfor countries, as in all other sectors. The optimal use of resources will reduce costs in the service sector as in other sectors. The improvement of the inefficient units is required by performing efficiency measurement to provide reduction of the costs. Efficiency can be defined as obtaining the maximum output with minimal effort and expense or as the ratio of performing the objectives of the business. The method of efficiency measurement is the DEA technique. This technique enables to compare the activities of businesses that have the same structure with each other and it also allows you to use numerous input and output.

In this study, efficiency measurement has done in health sector. The study includes five parts. In the second part after the introduction, the general information is given about the health sector which is a service sector, in the third part the DEA method is explained and in the fourth part, the application part is initiated. Questionnaire method has been used and the conclusion part is formed by analyzing the data obtained via DEA technique.

2. Health Sector

The production is the human activities that come out as a result when human needs are not fully met in their natural state in the nature. While this concept for engineers means to make a change on physical entity that will increaseits value, it does not include the production of the services. However, the science of business has a definition that includes the production of services [vii]. The services are different from the products. The main reason of this difference is that the services have diverse features. The service sector has many departments. One of these departments is the health sector. The health services can be defined as services that are given personally or institutionally by public or private parties to protect the current health of the individuals, and to enable diagnosis and treatment of diseases.

The key features of this definition are listed as follows:

- Health services are divided into two categories according to their activities as “the protection of individuals’ health” and “diagnosis, treatment and care”.
- Health services are services that are provided by public or private parties [xxi].

Health services have some specific features that distinguish them from other goods and services.The basic properties of health services in Turkey can be counted in the following way [ix]:

- Health services are a need that come out as a result of the demand related to health and a need that must be resolved. Therefore, they cannot be substituted and postponed.

- There is a disparity between the demand and supply of health services. The costs that patient would make depending on the risk of disease, are unclear. This case causes the health service demand to be uncertain.
- The determinants of demand are physicians because diagnosis and treatment of the need for health care services are determined by physicians.

The hospitals that are among the institutions that provide health services, have differences in terms of management, production, finance and investment because of the reason that the production of services are different from the production and sale of goods. Although the main point is not to make profit, especially the private hospitals will be out of this concept. Making profit in healthcare market depends on providing the healthcare in the requested style and kind and in the expected quality in the right place and for the right purpose [xiv]. Determination of the inefficient units by doing efficiency measurement is required to control this situation.

3. The Concepts of Efficiency and Productivity- Data Envelopment Analysis (DEA) Technique

The concepts of efficiency and productivity have difference in the meaning even if they are sometimes used in each others' place. Technically, efficiency is expressed as the ratio between "the number of goods and services that are produced and the amount of inputs used in the production of these goods and services, and generally this criterion is formulated as the ratio of output to input [xviii]. According to famous management scientist Peter Drucker; productivity is the alignment among the all production resources that can provide to get the most output with the least effort [ii]. Efficiency is an evaluation criterion that indicates how effectively or sufficiently the entry is used in line with the business objectives. Efficiency demonstrates in which rate a business has been realized the program that is previously identified for their production and production factors. In other words, efficiency shows to what extent the achieved performance gets close to the standard one when the achieved performance is compared to the previously identified standard performance [xxvi]. When these definitions are considered, it can be stated that efficiency is the degree of achieving the objective. Three types of efficiency are referred in the business world in terms of engineering, technic and economic. In terms of engineering, efficiency expresses the physical quantity of input that is used in production [xvi]. In terms of economy, efficiency is based on the efficiency of Pareto. The efficiency of Pareto determines that it is not possible to increase the production of a good without decrease the production of another one [xxii]. The efficiency measurement is required to calculate efficiency. The concept of efficiency measurement was introduced first by Farrell (1957). Farrell (1957) suggested that efficiency of the business should be examined as technical efficiency and cost efficiency. While technic efficiency is defined as the production of possible maximum output by using the input at hand in an optimal way, on the other hand allocative efficiency can be expressed as the success of a business in choosing the most appropriate input composition that will provide the lowest production costs, by taking into consideration the input prices [xiii].Data Envelopment Analysis (DEA), is the most used method in efficiency measurement. It is a non-parametric method, and it is used in performance efficiency measurement of businesses that are named as decision-making unit (DMU) [viii].DEA was introduced by Charnes, Cooper and Rhodes in 1987 based on the study done by Farrell in 1957. Farrell analyzed efficiency of units that had inputs more than one and had only one output. Rhodes tried firstly regression and correlation analysis techniques in one of the studies he carried on, but he searched different techniques when he found the results unsatisfying. While he was looking for different methods, Rhodes analyzed Farrell's article and he adapted the fractional programming model that was studied on the article to the linear programming model which is called as DEA. He defended that Farrell's approach is not competent in the cases when outputs and inputs are more than one. Therefore, they suggested DEA method that provides to measure the efficiency of units that have inputs and outputs in large quantities [v]. DEA is a linear programming-based method that aims to measure the relative performance of decision making units in the cases when there are inputs-outputs more than one and different measurement units of inputs-outputs. The basic assumption in DEA is that all businesses have the similar objectives and they use same kind of inputs and they produce same kind of outputs [xi]. The main objective of the method is not to choose one of the appropriate numbers of decision-making units according to various criteria, but to determine the efficiency of the outputs and the amount of ineffectiveness based on the ratio of the outputs weighted sum to the weighted sum of the inputs. Additionally, the method gives opportunity of providing to obtain an estimated production function, and benchmarking this function with the decision-making units in the observation set. Thus, it allows you to arrange decision making units, sorted by their activities [xxiii]. Strengths and weaknesses of data envelopment analysis can be expressed in the following way:

DEA's Strength

- Allows to use input-outputs in large quantities.
- There is the need to make assumptions about input and output.
- Allows you to compare firms with similar production structure with each other.
- Inputs-outputs may have different units.
- Allows decision-makers to get to know manufacturing process better.
- Can create a detailed database in accordance with information obtained as the results of the data and the analysis.
- Efficiency measurement isn't done by comparing the units that have average efficiency but it is done by comparing the most efficient decision making units.

DEA's Weaknesses

- It is sufficient to measure the efficiency of decision making units, but it does not give a clue about the interpretation of this evaluation based on the absolute activity.
- Because it is a nonparametric method, the implementation of statistical hypothesis testing to the results is difficult.
- The solution of large-dimensional problems with the DEA is computationally time-consuming because solution of separate linear programming model is required for each decision making unit.

- Only allows to measure the relative efficiency of analyzed decision making units.
- It is highly sensitive to measurement errors.
- The difference between the observed efficiency and the best efficiency is only attributed to unproductiveness and top observation points and the measurement errors are ignored.
- The superiority of decision making units in the set reference compared to the others is relative and therefore it can be hard to make an interpretation whether these units are also really effective when evaluated on their own.For this reason, the efficiency results obtained by DEA should be evaluated within the framework of relativity. (Oruç, 2008).
- As a result of transactions, one should be careful to pick the correct data during the data collection because DEA does not warn the decision-makers about data errors. Also these packet programs do not make a warning to the decision makers whether or not a wrong model is used so the decision makers should be careful in such cases [i].

A. Stages of Data Envelopment Analysis

1. Stage: Determination of which decision making units (DMU) will be in the analysis: The first step in the process of implementation of the DEA analysis covers DMU. In this stage, the DMUs that will be part of the analysis, are determined. This stage is the most important one. Golany and Roll (1989) are attributed the success of DEA to the need of the determination of DMU as a homogenous group. The inclusion of wrong decision making units to the analysis will influence all analysis results because DEA is a comparative analysis. Therefore, the decision making units that will be included to the analysis, should be selected carefully [x].
2. Stage: Determination of appropriate input and output variables for evaluating the effectiveness of selected DMU: The term input, in general, refers to resources that are used by DMU or the conditions that affect DMU's performance. The term output refers to the benefits achieved as a result of the activities of DMU. One of the main challenges in the implementation of DEA is the case of determination of inputs and outputs. According to a generally accepted view, the number of DMU must be at least two or three times multiple of the total number of input and output [xix].
3. Stage: Implementation of Data Envelopment Analysis Model and Evaluation of Efficiency Results of DMU: The efficiency results of the all DMUs and the values of input and output variables should be taken into consideration while the efficiency results that are obtained as a result of DEA implementation, are being evaluated. Additionally, the common results for all DMU which are efficient and are inefficient according to DEA, should be evaluated and these evaluations should be interpreted according to the situation of DMU within the industry [xxv].

B. Basic Data Envelopment Analysis Models

Several studies have been done to improve the method since DEA' s establishment within literature. As a result of these studies, several models have been developed within the framework of the basic concepts and principles of the method [iii]. These models:

1.CCR (Charnes-Cooper- Rhodes) Models: CCR model that was developed by Charnes, Cooper and Rhodes in 1978, is separated into two parts as input-oriented and output-oriented.

1.1. Input-oriented CCR Model

This model is the basis of data envelopment analysis. Weighted and envelopment models are improved models by basing on this model to complete the missing aspects of the model. The mathematical expression of the model is as follows: [xx].

E_k =Max ($\sum_{r=1}^{p} u_r\ Y_{rk}$) / ($\sum_{i=1}^{m} v_i\ X_{ik}$)(1)

The results, obtained by solving the model above, are relative efficiency criteria. If this result is to be 1, it shows that the efficiency analysis implemented decision-making unit is efficient; if the results is less than 1, it implies that it is not effective. However, the ratio in the objective function of this model reflects the concept of relative efficiency, although, some problems in terms of the solution technique come out due to the fact that this program is not a linear program.

1.2.Out-put oriented CCR Model

Output-oriented models examine the rate of the necessity of enhancing output, by holding inputs constant and by not using more inputs, and they are intended to maximize outcomes.The output oriented proportional model is like the opposite of the input oriented proportional model, and in this model the input/output ratio is based on minimization. When the inverse of the objective function of input oriented proportional is considered, the following objective function is obtained. In this direction, the mathematical expression of the output oriented proportional DEA model is as follows [xx].

E_k =Min ($\sum_{i=1}^{m} v_i\ X_{ik}$) / ($\sum_{r=1}^{p} u_r\ Y_{rk}$)(2)

The minimum value of $E_k$is 1 in the objective function of this program.If E_k is equal to 1, it means that decision making unit is efficient, if it is bigger than 1, it shows that DMU is not efficient.

2.BCC (Banker- Charnes-Cooper) Models: It was developed to evaluate the effectiveness on the basis of the CCR model, under the name of the profit assumption, according to the scale developed by Banker, Charles, and Cooper in 198[vi].

2.1. Input oriented BCC Model

Input-oriented BCC model aims to the maximum movement in the direction of the border during the proportional reduction of inputs. The mathematical expression of input oriented BCC fractional programming model is as follows: [iv]

E_k =Max ($\sum_{r=1}^{p} u_r\ Y_{rk}$) -$\mu_o$(3)

For the effective decision making units after the solution of this model, the value of E_k is equal to 1. However, this efficiency value is less than 1 for the ineffective decision making units[xx].

2.2. Output Oriented BCC Model

The output oriented BCC models aim to get the maximum movement in the direction of border with the proportional increase of outputs. The mathematical expression of output oriented fractional BCC programming model is as follows [xxiv]:

E_k =Min ($\sum_{i=1}^{m} v_i\ X_{ik}$) -$P_o$(4)

4. Methodology and Practice

4.1. Purpose, Scope and Constraints of the Research

The objective of the research is to perform effectiveness analysis in health institutions with data envelopment analysis method. This research is intended to determine efficient and inefficient units in health institutions by measuring unit-based efficiency and aims to make the identification of the amount of necessary improvement in order to make inefficient units efficient, and also aims to enable efficiency based comparison.

The study carried out in one state, one private hospital and in their 10 units. The study includes the data of 2015. In the light of these data, the efficiency comparison of two hospitals will be done. Our constraint is that the research covers only two hospitals.

4.2. The Method of the Research

"Input-Oriented data envelopment analysis Model" was used as efficiency measurement method in the research. This technique was chosen because the control mechanism is easier on the inputs of hospitals and hospital units rather than their outputs.

4.3. The Research Data Set

While determining the set of research data, firstly the decision making units were selected. 10 decision making units (DMU) have been established based on the common units of the 2 hospitals of Erzurum province. These DMUs are seen in following table.

Dermatology
Internal Medicine
Physical Therapy
General Surgery
Opthalmology
Cardiology
Ear Nose Throat
Neurology
Orthopedy
Urology

Table 1: Decision-making units (DMU)

Secondly, related literature and previous studies were examined and what the input and output will be was decided. The research inputs are the number of beds and expert doctor and outputs are polyclinic service number, hospitalized patient number and all these four are the variables of the research. Based on this information, the research model is shown in Table 2.

Inputs	**Outputs**
Bed Number	Polyclinic Service Number
Expert Doctor Number	The hospitalized patient number

Table 2: The model of the research

Decision-making Units Number: 10
Analysis technique: Input oriented CCR Model

4.4. Analysis and Findings of the Research

The information related to their inputs and outputs were taken from studied hospitals in accordance with determined DMU. This information is shown in Table 3.

	Input	Input	Output	Output
DMU (State Hospital)	Bed Number	Expert Doc. Number	Polyclinic service Number	Hospitalized Patient Number
Dermatology	10	2	45003	324
Internal Medicine	98	5	89041	1464
Physical Therapy	15	2	15600	560
General Surgery	25	2	20350	792
Opthalmology	22	3	44970	1788
Cardiology	6	2	27580	276
Ear Nose Throat	28	6	74263	924
Neurology	17	3	38970	420
Orthopedy	24	3	47564	900
Urology	23	3	36000	612
DMU (Private Hospital)				
Dermology	0	1	20020	20
Internal Medicine	30	2	40230	1112
Physical Therapy	4	2	13700	300
General Surgery	12	1	15036	652
Opthalmology	10	1	35657	986
Cardiology	5	1	24657	115
Ear Nose Throat	15	1	14000	520
Neurology	5	1	21230	784
Orthopedy	10	1	36230	300
Urology	9	1	12250	365

Table 3: DMU, Input, Output Values

In accordance with the information in Table 3, the necessary analyses were done with "the Method of Input Oriented Data Envelopment Analyses" and the unit based efficiency values of the hospitals were found. The values are shown in Table 4.

DMU	Efficiency Score % (State Hospital)	Efficiency Score %(Private Hospital)
Dermatology	100	100
Internal Medicine	90.40	56.41
Physical Therapy	49.97	46.07
General Surgery	67.29	66.13
Opthalmology	100	100
Cardiology	100	87.70
Ear Nose Throat	68.32	52.74
Neurology	60.91	100
Orthopedy	83.17	100
Urology	61.37	38.60

Table 4: Unit based efficiency values of hospitals

As it is observed in Table 4, According to the result of input oriented CCR model, the dermatology, opthalmology and cardiology units of State Hospital and the dermatology, opthalmology, neurology and orthopedy units of Private Hospital are found as efficient units that have 100 percent efficiency. Such an interpretation can be done that these units carry on their activities efficiently on the basis of the inputs they have and the outputs they revealed. When two hospitals are compared in unit based, it can be interpreted as the efficiency ratio of internal medicine, physicaltherapy, general surgery, cardiology, ear, nose, throat and urology units of State Hospital is higher than the ones of the Private Hospital, on the other hand, the efficiency ratio of neurology and orthopedy units of Private Hospital is higher than the State Hospital.

In accordance with the information in Table 4 the inefficient units were determined and they are shown in Table 5. Input values of the inefficient units and target input values required to be effective are also shown in Table 5.

DMU	State H.		State H.		Private H.		Private H.	
	Bed Number		Expert Doc. Number		Bed Number		Expert Doc. Number	
	GD	HD	GD	HD	GD	HD	GD	HD
Dermatology	10	10.00	2	2.00	0	0.00	1	1.00
Internal Medicine	98	26.53	5	4.52	30	11.28	2	1.13
Physical Therapy	15	7.14	2	1.00	4	1.84	2	0.92
General Surgery	25	9.82	2	1.35	12	6.61	1	0.66
opthalmology	22	22.00	3	3.00	10	10.00	1	1.00
Cardiology	6	6.00	2	2.00	5	4.38	1	0.88
Ear Nose Throat	28	19.13	6	4.10	15	5.27	1	0.53
Neurology	17	9.80	3	1.83	5	5.00	1	1.00
Orthopedy	24	15.14	3	2.50	10	10.00	1	1.00
Urology	23	10.90	3	1.84	9	3.47	1	0.39

Table 5: Real values (RV) for input factors and target values(TV) for input factors)

The hospital units that are written with bold characters in the table, are the efficient units which are not in need of any change in their input value. The units that are not written with bold characters are the values that need to be reduced to make the actual values of the respective units effective. The input values must be reduced because better performance means more output with less input. Therefore, when the target values are examined, it is seen that the all of them are lower than the actual value. The rates of improvement were calculated for each unit in accordance with this information. The improvement ratios calculated for the units of State Hospital, is illustrated in Table 6.

DMU	State H.			State H.		
	Bed Number		Improvement Ratio %	Expert Doc Number		Improvement Ratio %
	GD	HD		GD	HD	
Dermatology	10	10.00	0	2	2.00	0
Internal Medicine	98	26.53	-73	5	4.52	-11
Physical Therapy	15	7.14	-52	2	1.00	-50
General Surgery	25	9.82	-61	2	1.35	-33
opthalmology	22	22.00	0	3	3.00	0
Cardiology	6	6.00	0	2	2.00	0
Ear Nose Throat	28	19.13	-32	6	4.10	-32
Neurology	17	9.80	-42	3	1.83	-39
Orthopedy	24	15.14	-37	3	2.50	-17
Urology	23	10.90	-53	3	1.84	-39

Table 6: State hospital improvement ratios

As it is seen in Table 6, when the units that belong to the State Hospital, are analyzed, it seems necessary that the most important improvement in terms of inputs should be done over the amount of bed number in the general surgery and internal medicine units. Evidences about the improvement on the number of beds for the specified units can be also interpreted in the direction that physical facilities are not being used efficiently in these units. When the same situation is calculated for Private hospital units, the rates of improvement are as it is shown in Table 7.

DMU	Private H.			Private H.		
	Bed Number		Improvement Ratio %	Expert Doc Number		Improvement Ratio %
	GD	HD		GD	HD	
Dermatology	0	0.00	0	1	1.00	0
Internal Medicine	30	11.28	-62	2	1.13	-44
Physical Therapy	4	1.84	-54	2	0.92	-54
General Surgery	12	6.61	-45	1	0.66	-34
opthalmology	10	10.00	0	1	1.00	0
Cardiology	5	4.38	-12	1	0.88	-12
Ear Nose Throat	15	5.27	-65	1	0.53	-47
Neurology	5	5.00	0	1	1.00	0
Orthopedy	10	10.00	0	1	1.00	0
Urology	9	3.47	-61	1	0.39	-61

Table 7: Private hospital improvement ratios

As it is seen in Table 7, when the units that belong to the Private Hospital are analyzed, it seems necessary that the most important improvement in terms of inputs should be done over the amount of bed number in internal medicine, ear, nose, throat and urology units. Evidences about the improvement on the number of beds for the specified units can be also interpreted in the direction that physical facilities are not being used efficiently in these units. When the other input, the expert doctor number, is analyzed, it can be interpreted as there should be done a reduction in the doctor number if it is possible.

5. Result and Evaluations

In today's rapidly changing technological, political, and economic enviroment, businesses could only survive if they have the power to adapt themselves to these changes. What this means is that businesses can enable efficiency in their operations. Several methods have been developed to measure the effectiveness in business. One of these methods is DEA method. This study aims to measure efficiency of health institutes via DEA method. Health care institutions are the institutions in charge of improving the health level of the society, improving the living standards and also the providing treatment for diseases. Evaluating the effectiveness of these institutions and identifying the ineffective units, will allow to increase the effectiveness and quality of this sector.

The objective of the research is to determine the improvement ratio of two hospitals by measuring efficiency of their various units and by providing the comparison. For this reason, there are formed two input values named as bed number and expert doctor number; two output values namedas polyclinic service number and hospitalized patient number. In parallel with input and output values Dermatology, Internal Medicine, physical therapy, general surgery, Ophthalmology, Cardiology, ENT, Neurology, Orthopedics, and Urology departments of the hospitals that have 10 the decision-making units, were selected. The required data was received through face to face interviews with managers, and the data were analyzed with DEA method that has input-oriented CCR model.

Dermatology, Ophthalmology and Cardiology departments of the State Hospital and Dermatology, Ophthalmology, Neurology, Orthopedics department of the private hospital were found as “efficient” units whose efficiency percentage was 100 according to the results of input oriented CCR model. The units that have the lowest efficiency ratio, are physical therapy departmentof State Hospital, the urology department of Private Hospital.

When two hospitals are compared in unit based, it can be interpreted as the efficiency ratio of internal medicine, physical therapy, general surgery, cardiology, ENT and urology units of State Hospital is higher than the ones of the Private Hospital, on the other hand, the efficiency ratio of neurology and orthopedy units of Private Hospital is higher than the State Hospital. It can be interpreted in such way that the units with high efficiency ratio are using their resources more efficiently than the other units.

Bed and expert doctor numbers that are our input variables whose control are easier than the outputs, can be accepted as our resources in this study. In this direction, the target values are found to make the inefficient units efficient. The target values are same with the real values in Dermatology, Ophthalmology and Cardiology departments of the State Hospital, and in Dermatology, Ophthalmology, Neurology, Orthopedics department of the private hospital because they are totally efficient. When the other units are examined, it is observed that the real values are too high and they should be reduced. Unit based improvement ratio is determined in accordance with these reductions. Firstly, the bed number in internal medicine and general surgery and the expert doctor number in the physical therapy unit of the State Hospital are required to be reduced. On the other hand, bed number in internal medicine, ENT, and urology units and also expert doctor number in the urology unit of the Private Hospital is required to be reduced. However, the efficiency can be enhanced by increasing the polyclinic service and hospitalized patient numbers in the cases that the reduction of resource ratio is not possible as it is in this study in which there is only one expert doctor in the urology department.

As a result, DEA is a widely used method in efficiency measurement. The improvement of the inefficient units by measuring the efficiency of the Health institutes, will also increase the quality in health sector. Ideas for improvement are offered to the hospitals by making due diligence and by determining the efficient and inefficient units via efficiency measurement. The deficiency of this method may be the interpretation of results as the unit but not as the number. This method can be applied to other service sector units, not only to health sector which is an arm of the service sector.

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