

# **AN ANALYTIC NETWORK PROCESS COMBINED DATA ENVELOPMENT ANALYSIS METHODOLOGY TO EVALUATE THE PERFORMANCE OF AIRPORTS IN TURKEY**

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## **ABSTRACT**

Data Envelopment Analysis (DEA) is a known method to determine the efficient and inefficient units in concern. Selection of the proper input and output factors lead to successful and meaningful results. But these depend to the problem type and there is no specific methodology proposed for defining the factors. While inadequate number of factors can lead to incorrect results, redundant factors may cause unnecessary calculations. Therefore this study introduces an Analytical Network Process (ANP) model to select the most important factors among others. The methodology is demonstrated by use of a performance evaluation problem of airports. The characteristics of major airports in Turkey that impact the operations are defined by ANP, and results that will aid operations managers and communities in improving their efficiency are obtained by DEA.

Keywords: Airports, Analytical Network Process, Data envelopment analysis, Input/output factors

## **1. Introduction**

Several input and output criteria can be defined for performance evaluation in profit and non-profit organizations by means of DEA. Certain factors that can be grouped as physical and technical are considered in literature. In many studies data for number of employees, expenditures, et all. are used. But the determination of the factors depends on the problem type and also the experience of the researcher. There is no certain input or output factors defined for any problem.

Main contribution of this study is the novel approach which is proposed to define the inputs and outputs for a problem where airports are being evaluated. ANP provides to reflect the personal judgments to the problem. Also one can consider the relationships between the input/output factor alternatives.

Various airport characteristics can be evaluated to determine an airport's efficiency. After a literature survey about DEA applications for airports, possible inputs and outputs are clarified. Then by using ANP, input factor alternatives are ranked. This methodology helps decision makers to identify the important factors from others by pair wise comparisons.

The study concentrates on the airports in Turkey which are non profit organizations. As they are managed by government the importance on performance evaluation is not highlighted.

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Evaluating airport operational efficiency is important for a number of reasons. Communities rely on airports for economic well-being, deregulation allows air carriers to choose among competing airports, and federal funding for airport improvements is based on performance measures.

After the determination of the appropriate criteria for the problem, an application is held to evaluate the performance measures of totally 31 major airports and aerodromes in Turkey. Data are gathered from the State Airports Authority Directorate General (Devlet Hava Meydanları İşletmesi, DHMI) and are input to a series of models that evaluate the relative efficiency of sets of airports.

DEA, which is based on a set of mathematical programming formulations, is briefly described in the with a general literature survey in Section 2. Main concern is explained in Section 3. The computational results are provided in Section 4 that is followed with conclusions and potential further research areas.

## **2.Data Envelopment Analysis**

DEA has become a popular methodology for evaluating the relative efficiencies of decision-making units within a relatively homogenous set. Productivity models have traditionally been used to measure the efficiency of systems. Typically, DEA productivity models for a given decision-making unit use ratios based on the amount of outputs per given set of inputs; here a decision-making unit is an airport (Sarkis, 2000). The use of the CCR and BCC of DEA models together helps determine the overall technical and scale efficiencies of the airport respondents and whether the data exhibits varying returns to scale.

Seiford (1997) proposes a DEA literature bibliography for the years 1978-1996 concerning for about 800 papers. Also, Tavares (2002) investigated 3203 studies for 1978-2001. Gattoufi et al., (2001) claim that there had been a 150% increase in since Seiford (1997), and formed a DEA paper list from 1978 to 2001. These bibliography studies demonstrate that DEA is applied in many organizations, especially in health, education, and banking. The application of the method in wide range of areas is increasing too. On the other hand considering both ANP and DEA is a new area of research.

Sarkis (1999) involve the synthesis of ANP and DEA for environmentally conscious manufacturing programs. Hasan et al.(2008) integrate ANP and DEA in a multi phased supplier selection approach.

This paper magnifies on studies in literature related to airports. A brief literature survey for airports is given in the following section.

## **3.Performance Evaluation for the Airports by DEA**

Despite its importance, few studies have focused on airport productivity or operational efficiency (Sarkis, 2000). The evaluation of performance to increase the efficiency in airports has attracted the attention of some researchers, and this section explains the use of DEA for the problem.

Martin and Roman (2001) apply data envelopment analysis to analyze the technical efficiency and performance of each individual Spanish airport. Based on the data of 1997, 37 airports are evaluated. They measured output with three variables: air traffic movements, number of passengers and number of tons of cargo transported in each airport. Input variables were introduced as expenditures and were classified according to: labor, capital and materials. Number of runways, Gates and terminal area, also number of employees are not considered in this study due to the lack of data. Results are used to extract some policy considerations before the process of privatization of the Spanish airport system.

Yu (2004) evaluates the data collected for 14 domestic airports for the period 1994–2000. Four variables make up the inputs: runway area (in square meters), apron area (in square meters), terminal area (in square meters), and each airport's number of air routes connecting with the other domestic

airports. Desirable output variables are the number of aircraft traffic movements and number of passengers with an undesirable output: aircraft noise.

Sarkis (2000) used data from 44 major US airports to evaluate efficiency using the DEA model with output variables of revenue, passengers, aviation movements, and total cargo transportation. Input variables in this case were airport operation costs, number of airport employees, gates, and runways. Sarkis and Talluri (2004) evaluates the operational efficiencies of 44 major US airports across 5 years using multi-criteria non-parametric models. These efficiency scores are treated by a clustering method in identifying benchmarks for improving poorly performing airports. Efficiency measures are based on four resource input measures including airport operational costs, number of airport employees, gates and runways, and five output measures including operational revenue, passenger flow, commercial and general aviation movement, and total cargo transportation.

Gillen and Lall (1997) considers data of 1989-1992 for 21 USA airports. Six input is defined as number of runways, gates, employees, baggage belts and also terminal area and passenger park area. The two outputs are defined as number of passengers and number of tons of cargo.

Bazargan and Vasigh (2003) selected four input measures as, operating expenses, non-operating expenses, number of runways, number of gates, and 6 output measures as, numbers of passengers, number of air carrier operations, number of other operations, aeronautical revenue, non-aeronautical revenue, percentage of on time operations.

Fernandes and Pacheco (2002) present a capacity efficiency analysis of 35 Brazilian domestic airports using DEA. Airport capacity data, such as area of apron, departure lounge, number of check-in counters, curb frontage, number of vehicle parking spaces, and baggage claim area, are used as inputs. Domestic passengers are the only output considered. In later work, Pacheco and Fernandes (2003) analyze outputs as domestic passengers, embarked plus disembarked, in thousands, cargo plus mail, embarked plus disembarked, in tones, operating revenue, commercial revenue, other revenues, such as financial and miscellaneous revenues. Inputs are defined as average number of employees, payroll, including direct and indirect benefits, operating expenses.

Yoshida and Fujimoto (2004) collected the data for 67 airports in Japan in the year 2000. The data set contains three kinds of outputs in airport activity, namely, passenger loading, cargo handling, and aircraft movement. International and domestic volumes are aggregated. For the input side, there are four factors that are: runway length, terminal size, and access cost, and labor.

A sole study for Turkish airports is given in Duzakin ve Gucray (2001) which defines the input and output factors as in Sarkis (2000).

Based on the accessible literature it can be seen that no study had focused on defining the input and output factors for DEA. The ANP model proposed in the following section aims to find appropriate efficiency factors for the problem.

### **3.1. Definition of Inputs and Outputs for Airport Efficiency Problems**

An airport comprises runways, aprons, a terminal building, and a control tower, that not only process passengers and freight through the terminal building, but also serves aircrafts. Aircrafts require airspace, runways, and other terminal capacity such as apron stands. Aircraft traffic movements represent landings and take-offs of airplanes. Passenger movements are defined as the passengers arriving or departing on a commercial flight.

In any DEA problem appropriate factors should be defined. Lack of some important inputs and outputs may cause unrealistic results. According to Cooper et al. (2000), a good rule of thumb for the number of DMUs in applying DEA is given in Equation(1) as,

$$n \geq \max\{m^* s, 3(m + s)\} \quad (1)$$

where  $n$  is the number of DMUs,  $m$  is the number of inputs and  $s$  is the number of outputs.

The data for DEA models include both input and output factors from which relative technical, scale, and cross-efficiency measures are determined each of these types of efficiencies is defined below based on the literature.

Input data, composed of resources that are common to all airports, include financial costs measured in operating costs, labor measured in the number of full-time equivalent employees directly employed by the airport. People want to reach to airports in the easiest and cheapest way. Therefore access cost to airports can be considered. The number of gates, check-in counters, and runways are standard resources that are available to all airports and airport operations managers to help generate the necessary outputs. On the other hand terminal, runway, apron, departure lounge, baggage claim and passenger park area can also be considered for improving the quality and efficiency of terminal and aviation services.

Output data are comprised of operating revenue generated which can be derived from a number of sources including concessions, parking fees, landing fees, user charges, and commercial development revenue. While one airport reports that due to nonprofit and federal regulations, it has equal revenues and costs, the vast majority of revenues and costs are not equal. Also number of aircraft movements, general and commercial aviation movements, passenger movements, and amount of cargo shipped can be considered.

The determination of input and output factors problem for DEA requires a model that evaluates several criteria on different dimensions. When the number of input and output factors is excessive, some of them need to be eliminated. The decision maker needs to trust on his experience on the problem. But the use of ANP also enables to emerge the relationships of the factors and provides scientific way for the decision process.

In this study 31 airports are selected as the decision units. Five common output measures are chosen from literature for evaluation. But a number of input factors are defined in literature. Based on the Equation(1) there must be at most 5 input factors for this problem. Therefore an ANP model is constructed to consider the most important input factors. The following section explains how the appropriate input set is formed.

### **3.2. ANP model for determination of input factors**

ANP allows interactions and feedback within clusters and between clusters. Feedback can better capture the complex effects of interplay in human society. ANP provides a thorough framework that includes clusters of elements connected in any desired way to investigate the process of deriving ratio scales priorities from the distribution of influence among elements and among clusters (Saaty, 2001-a, 2001-b).

The selected dimensions are benefits, costs, and risks will be required for ranking them according to their appropriateness for the problem in concern. The favorable concerns are called benefits while the unfavorable ones are called costs. Each of these concerns utilizes a separate structure for the decision (Saaty, 2001-a).

The next step in an ANP problem is to form the networks. Then, for each network corresponding to one of the several control criteria under benefits, the priorities from paired comparison matrices are derived, and are used in super matrix. The control criteria and decision networks for input alternatives are formed. This study utilizes Super Decisions, the software that implements the ANP for the PC. Clusters and the elements in each cluster for input alternatives are illustrated in Figure 1.

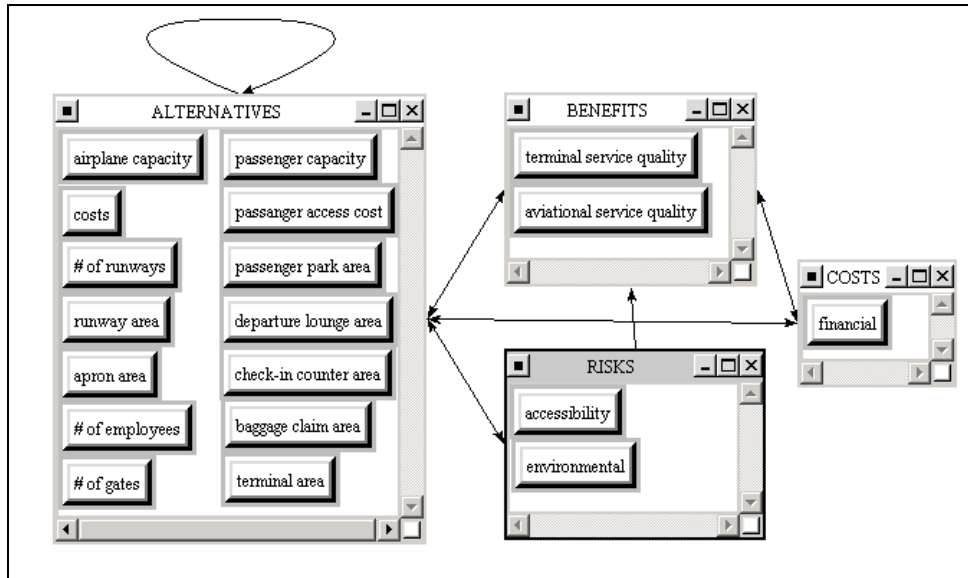


Figure 1. ANP model representation for input alternatives

Sarkis (2000) defines six performance measurement areas have been defined for airport development systems: infrastructure, environment, accessibility, capacity, and investment. Based on these, the nodes in clusters are formed. Benefits include terminal and aviation service quality, costs include financial dimension, and the risks node contain environmental and accessibility issues. The alternatives and the nodes in BCR (Benefits, Costs, Risks) clusters are connected if they have any effect to each other. The Alternatives cluster is inner dependent; it is connected to itself, so it is one of the four clusters being pairwise compared with respect to Alternatives. Pair wise comparisons for the nodes in each cluster—that belong to a parent node—are carried out for all the parent nodes in the model. The comparisons are made depending on the fundamental scale introduced by Saaty (2001-a) given as in Table 1.

Table 1. The fundamental scale

Intensity of importance	Definition	Explanation
1	Equal importance	Two activities contribute equally to the objective
3	Moderate importance	Experience and judgment slightly favor one activity over another
5	Strong importance	Experience and judgment strongly favor one activity over another
7	Very strong importance	An activity is favored very strongly over another; its dominance demonstrated in practice
9	Extreme importance	The evidence favoring one activity over another is of the highest possible order of affirmation
2, 4, 6, 8	For compromise between the above values	Sometimes one needs to interpolate a compromise judgment numerically because there is no good word to describe it

These clusters and elements are then introduced to the software, and the evaluation is held by pair wise comparisons as shown in Figure 2. The number of comparisons is related to the connected nodes in each cluster.

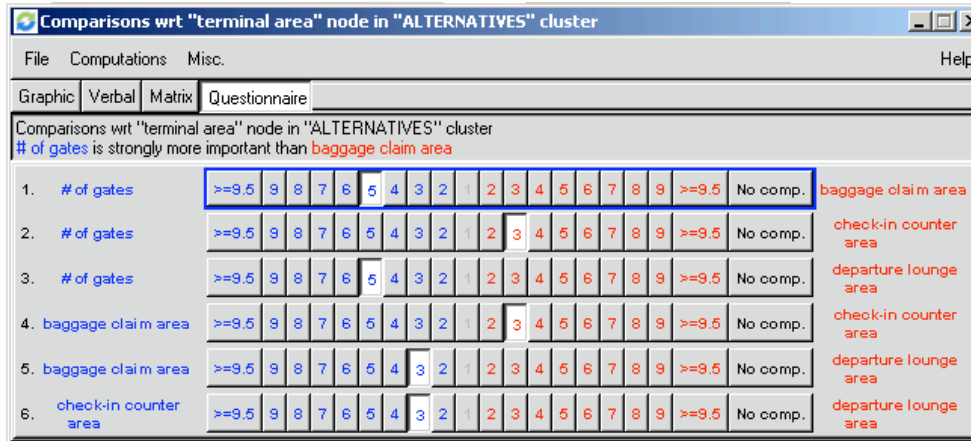


Figure 2. An example pairwise comparison

The multiplicative method of synthesizing results is, and the final result of the analysis is given in Figure 3. The high ideal states the most favorable alternatives in concern.

Name	Graphic	Ideals	Normals	Raw
# of employees		0.992708	0.242547	0.144433
# of gates		0.195513	0.047769	0.028446
# of runways		0.016568	0.004048	0.002411
airplane capacity		0.331157	0.080911	0.048181
apron area		0.062102	0.015173	0.009035
baggage claim area		0.089248	0.021806	0.012985
check-in counter area		0.254504	0.062183	0.037029
costs		1.000000	0.244329	0.145494
departure lounge area		0.063162	0.015432	0.009190
passanger access cost		0.093500	0.022845	0.013604
passenger capacity		0.331206	0.080923	0.048188
passenger park area		0.122780	0.029999	0.017864
runway area		0.033676	0.008228	0.004900
terminal area		0.506719	0.123806	0.073724

Figure 3. ANP model results for alternative inputs

Based on these a list of inputs is formed. For example costs are the most important factor to be considered for inputs. And the number of employees follows it. First five input alternatives are selected due to the constraint for decision making units in data envelopment analysis.

#### 4. Computational Experience

CCR input model is applied to evaluate the performance of airports. The inputs used here are selected by ANP model, and the outputs are considered as the ones that are common in literature. Provided input and outputs factors are given in Table 2.

Table 2. Inputs and outputs for the problem

Inputs	Outputs
I1. Costs	O1. Revenue
I2. Number of employees	O2. Passenger movements
I3. Terminal area	O3. General aviation movements
I4. Passenger capacity	O4. Commercial aviation movements
I5. Airplane capacity	O5. Amount of cargo shipped

#### 4.1. The airports in concern

The aeronautical platforms under the authority of the provincial organization are subdivided into airports and aerodromes. DHMI operates airports and aerodromes in Turkey. Ataturk, Esenboga, Adnan Menderes, Antalya, Adana, Trabzon, Milas–Bodrum, Suleyman Demirel and Nevsehir–Kapadokya Airports are open for international and domestic flights, both regular and charter. Agri, Ferit Melen, Gaziantep, Kars, Korfez, Mardin, Samsun–Carsamba, and Sanliurfa aerodromes are open only for domestic flights. In addition to these; there are also some aerodromes operating together with military authorities such as Dalaman, Bursa–Yenisehir, Canakkale, Cardak, Corlu, Diyarbakir, Elazig, Erzincan, Erzurum, Kayseri, Konya, Malatya, Mus, and Sivas. The mentioned 31 airports are selected for performance evaluation.

#### 4.2. Data collection

All data are self-reported by the airports and published as a statistical year book by DHMI. The data for 2004 and 2005 are considered in this study. Included input and output variables have a clear interpretation. There are no problems regarding data comparability, since DHMI is the only source of information.

#### 4.3. Computational results

The data related to input and output factors are evaluated by using DEA Solver software for the considered airports. This study mainly focuses on the input factors therefore CCR input model is utilized. The efficiency scores of airports for the years 2004-2005 are given in Figure 4a-b respectively. Max value 1 indicates the most efficient airports, while lower scores illustrate the inefficient ones.

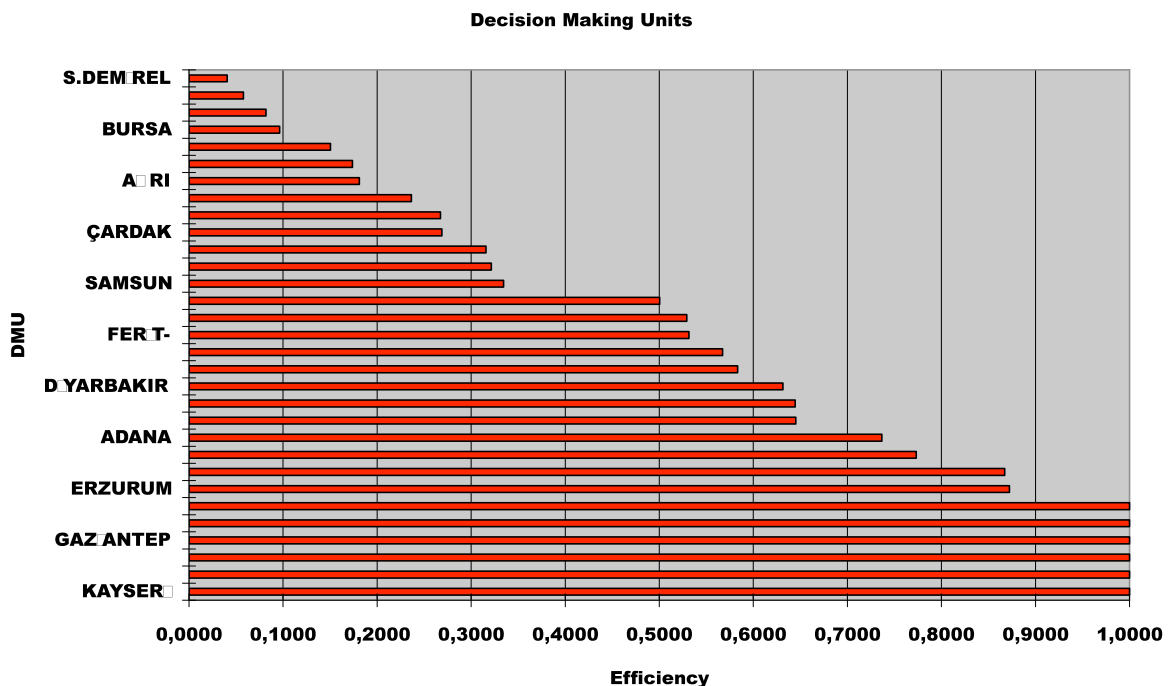


Figure 4-a. Efficiency scores for DMUs (2004)

Decision Making Units

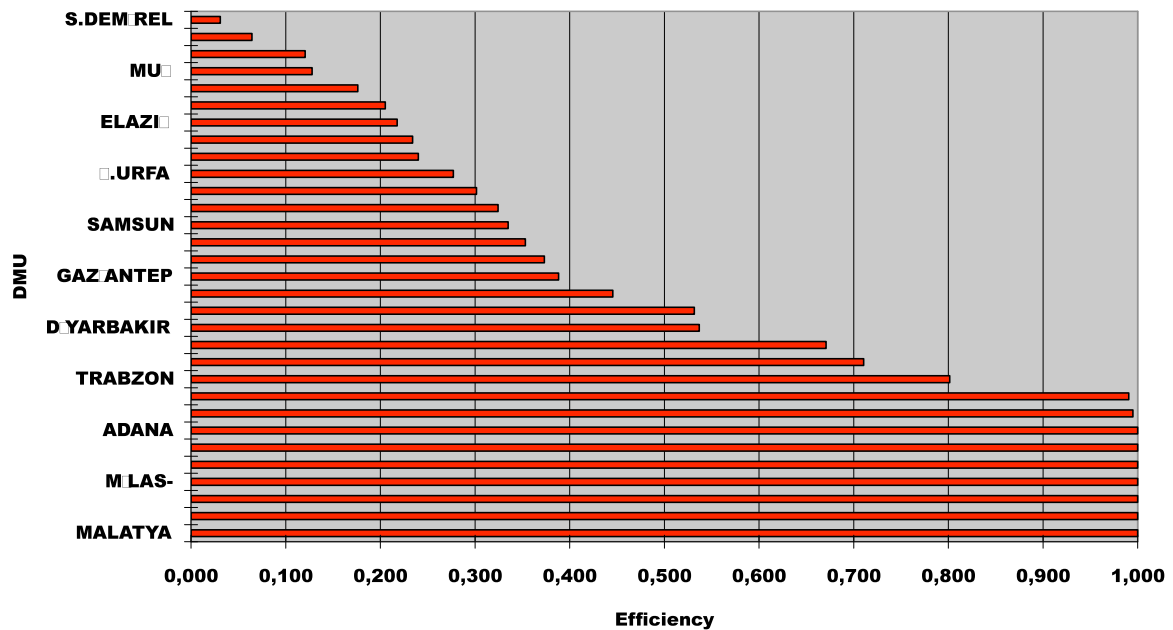


Figure 4-b. Efficiency scores for DMUs (2005)

Target values for two airports for each year are stated in Table 3 as an example. Based on these data, the inefficient airports can increase their output values and decrease input values as stated percents in order to become more efficient.

Table 3. Target values for CCR-I model 2004-2005

DMU I/O	2004				2005			
	Score Data	Projection	Difference	%	Score Data	Projection	Difference	%
S.DEMREL	0,0406				0,0309			
costs	1858	75,4259899	-1782,57401	-95,94%	2132	65,83935329	-2066,160647	-96,91%
number of employees	43	1,67053115	-41,3294688	-96,12%	48	1,247452435	-46,75254756	-97,40%
terminal area	5400	219,214395	-5180,78561	-95,94%	5400	166,7600881	-5233,239912	-96,91%
passenger capacity	600000	24357,155	-575642,845	-95,94%	600000	18528,89868	-581471,1013	-96,91%
airplane capacity	43800	857,645381	-42942,3546	-98,04%	43800	478,7644128	-43321,23559	-98,91%
revenue	202	659,665207	457,665207	226,57%	205	228,1018352	23,10183516	11,27%
passenger movements	3861	38662,5647	34801,5647	901,36%	4048	18052,20504	14004,20504	345,95%
general aviation movements	254	254	0	0,00%	160	160	0	0,00%
commercial aviation movements	43	242,216958	199,216958	463,30%	45	153,1491698	108,1491698	240,33%
amount of cargo shipped	42	772,961597	730,961597	999,90%	108	393,1634474	285,1634474	264,04%
GAZ ANTEP	1				0,38822956			
costs	4809	4809	0	0,00%	6565	1676,873016	-4888,126984	-74,46%
number of employees	131	131	0	0,00%	138	34,38880358	-103,6111964	-75,08%
terminal area	2792	2792	0	0,00%	2792	1083,936944	-1708,063056	-61,18%
passenger capacity	620000	620000	0	0,00%	620000	223385,1395	-396614,8605	-63,97%
airplane capacity	17520	17520	0	0,00%	17520	6801,781968	-10718,21803	-61,18%
revenue	3100	3100	0	0,00%	1967	3081,056127	1114,056127	56,64%
passenger movements	411213	411213	0	0,00%	210539	234824,9949	24285,99487	11,54%
general aviation movements	4369	4369	0	0,00%	2213	2287,426524	74,42652376	3,36%
commercial aviation movements	3879	3879	0	0,00%	1893	1893	0	0,00%
amount of cargo shipped	6538	6538	0	0,00%	2860	4694,770809	1834,770809	64,15%



A number of airports in Turkey are unfortunately set up without detailed feasibility studies. Because of politic policies some airports are built before comprehensive location selection and demand analysis. An example is the S.Demirel airport. This airport is very closely sited near an efficiently working airport named Antalya. Although the physical facilities are fully equipped, people usually prefer Antalya airport. Table 4 states that the outputs related to S.Demirel airport need to be increased in high percents in order to make this airport efficient. Another solution for the problem may be solved by closing this inefficient service unit, and direct the demand to the close airports. On the other hand there are some peak-months for some airports; especially the ones that are near to touristic areas. When the total data for a year considered, some airports such as Nevsehir might seem inefficient.

While G.Antep was an efficient airport in 2004, the calculated efficiency values states that it was not efficient the next year. The possible improvements for the airport G.Antep can be obtained based on the projection values. Similar comments can be made for other inefficient units.

A comparison for CCR-input model results for the two years is illustrated in Table 4.

Table 4. CCR-I model for 2004-2005

2004			2005		
Rank	DMU	Score	Rank	DMU	Score
1	KAYSERİ	1,0000	1	MALATYA	1,000
1	ATATÜRK	1,0000	1	ATATÜRK	1,000
1	ESENBOĞA	1,0000	1	ESENBOĞA	1,000
1	GAZİANTEP	1,0000	1	MYLA-BODRUM	1,000
1	ANTALYA	1,0000	1	ANTALYA	1,000
1	DALAMAN	1,0000	1	DALAMAN	1,000
7	ERZURUM	0,8724	1	ADANA	1,000
8	MYLA-BODRUM	0,8673	8	A.MENDERES	0,995
9	KONYA	0,7733	9	KAYSERİ	0,991
10	ADANA	0,7367	10	TRABZON	0,801
11	ÇANAKKALE	0,6452	11	ÇANAKKALE	0,711
12	A.MENDERES	0,6444	12	FERİT-MELEN	0,671
13	DİYARBAKIR	0,6314	13	DİYARBAKIR	0,537
14	MALATYA	0,5833	14	KÖRFEZ	0,532
15	TRABZON	0,5673	15	KONYA	0,446
16	FERİT-MELEN	0,5315	16	GAZİANTEP	0,388
17	ERZİNCAN	0,5292	17	ERZİNCAN	0,373
18	KÖRFEZ	0,5004	18	ERZURUM	0,353
19	SAMSUN	0,3345	19	SAMSUN	0,335
20	KARS	0,3213	20	KARS	0,324
21	ŞURFA	0,3157	21	ÇORLU	0,302
22	ÇARDAK	0,2687	22	ŞURFA	0,277
23	MUŞ	0,2674	23	MARDİN	0,240
24	ELAZIĞ	0,2364	24	ÇARDAK	0,234
25	AĞRI	0,1812	25	ELAZIĞ	0,218
26	MARDİN	0,1738	26	ŞİVAN	0,205
27	ÇORLU	0,1504	27	AĞRI	0,176
28	BURSA	0,0964	28	MUŞ	0,128
29	ŞİVAN	0,0819	29	BURSA	0,121
30	NEVŞEHİR	0,0578	30	NEVŞEHİR	0,064
31	S.DEMİREL	0,0406	31	S.DEMİREL	0,031

Ataturk, Esenboga, Antalya, and Dalaman airports are found as efficient in each year. But although was efficient in 2004, Kayseri and G.Antep has become inefficient in the next year. On the other hand

Malatya, Bodrum and Adana airports have become efficient airports in 2005 as they were not in the previous year.

The data are also used to solve the CCR-I, CCR-O, BCC-I and BCC-O models. But the outcomes for CCR-I and CCR-O did not have a significant difference. Therefore the complete results are not stated here. It can be stated that the differences in average CCR and BCC efficiency scores point to some varying returns to scale in the data set. That is, relationships among the input and output values depend on the magnitude of the data set.

## **5. Conclusion and Directions for Future Studies**

When solving a problem with DEA, determination of input and output factors is one of the most important issues. Therefore this study introduced a new methodology to overcome this problem. ANP which is a decision making method is used to support the selection of appropriate input alternatives for the problem. The study concentrated on terminal and aviation service quality, also costs, accessibility and environmental issues. During comparisons passengers are considered as a base matter that is why more importance is assigned to terminal service quality. In the following studies several other Benefit, Opportunity, Cost and Risk criteria can be proposed for the problem. The analysis and evaluation of airport operational efficiency have implications for a number of airport customers. Air carriers want to schedule and locate at airports that are more efficient. Municipalities want airports to be as efficient, and, thus, as competitive as possible to attract business and passengers, and to show local governments that they provide good service. The federal government, in funding airport improvement projects, could use airport efficiency evaluation to help determine the effectiveness of these programs and whether various airport improvement projects that focus on reengineering or capital improvements impact relative airport efficiency. Therefore these decision makers may probably define different criteria, and also offer different weights for these criteria. A survey that gathers information from diverse communities would be helpful for realistic evaluation.

This study was applied based on data for two years. The trend for efficiency can be obtained by using several years' data. The estimate values for each airport can also be gained with methods like forecasting in statistics.

Even though almost all airports in Turkey are publicly owned and operated, a significant portion of their operations are run by private commercial organizations. Airport operations privatization and its effect on airport efficiency is a potentially interesting area of research. When an airport is not effectively operated, the issues like to sell it to private organizations or closing it for flights may come into questions. At this point ANP can also be helpful for decision makers to support their judgments.

## REFERENCES

- Bazargan M., & Vasigh B. (2003). Size versus efficiency: a case study of US commercial airports. *Journal of Air Transport Management*, 9(3), 187-193.
- Cooper, W., Sieford, L., & Tone, K. (2000). *Data Envelopment Analysis. A Comprehensive Text with Models, Applications, Reference and DEA–Solver software*. Kluwer Academic Publishers, Norwell.
- Web site of Devlet Hava Meydanları İşletmesi, available at January 2006 <http://www.dhmi.gov.tr>.
- Düzakın E, & Gücray A. (2001). An analysis of the efficiency of airports in Turkey. (*OR 43*) *43th Annual Conference of the Operational Research Society Abstracts*, Bath, United Kingdom, 9/4 to 9/6.
- Fernandes E., & Pacheco R.R. (2002). Efficient use of airport capacity. *Transportation Research Part A: Policy and Practice*, 36(3), 225-238.
- Gattoufi S., Oral M., & Reisman A. (2002). Data Envelopment Analysis Literature: A Bibliography Update (1951 - 2001). [http://bilmer.sabanciuniv.edu/elit/gsm/sugsm02\\_08.pdf](http://bilmer.sabanciuniv.edu/elit/gsm/sugsm02_08.pdf).
- Gillen D., & Lall A. (1997). Developing measures of airport productivity and performance: an application of data envelopment analysis. *Transportation Research Part E: Logistics and Transportation Review*, 33(4), 261-273.
- Hasan M.A., Shankar R., & Sarkis J. (2008), Supplier selection in an agile manufacturing environment using Data Envelopment analysis and Analytical Network Process, *International journal of Systems and Management*, 4(5), 523-547.
- Martín C.J., & Román C. (2001). An application of DEA to measure the efficiency of Spanish airports prior to privatization. *Journal of Air Transport Management*, 7(3), 149-157.
- Pacheco R. R., & Fernandes E. (2003). Managerial efficiency of Brazilian airports. *Transportation Research Part A: Policy and Practice*, 37(8), 667-680.
- Saaty T., (2001-a). *The analytic network process*. Pittsburgh: RWS.
- Saaty T., (2001-b). *Creative thinking, problem solving and decision making*. Pittsburgh: RWS.
- Sarkis J., & Talluri S. (2004). Performance based clustering for benchmarking of US airports. *Transportation Research Part A: Policy and Practice*, 38(5),329-346.
- Sarkis J. (2000). An analysis of the operational efficiency of major airports in the United States, *Journal of Operations Management*, 18(3), 335-351.
- Sarkis J. (1999). A methodological framework for evaluating environmentally conscious manufacturing programs, *Computers & Industrial Engineering* 36, 793-810.
- Seiford LM. (1997). A bibliography for data envelopment analysis (1978 -1996). *Annals of Operations Research*, 73, 393-438.
- Tavares G. (2002). *A Bibliography of Data Envelopment Analysis, Rutgers Reserach Report (RRR 01-02)*, Rutgers Center for Operations Research Rutgers University, pp 189.

Yoshida Y., & Fujimoto H. (2004). Japanese-airport benchmarking with the DEA and endogenous-weight TFP methods: testing the criticism of overinvestment in Japanese regional airports. *Transportation Research Part E: Logistics and Transportation Review*, 40(6), 533-546.

Yu M.M. (2004). Measuring physical efficiency of domestic airports in Taiwan with undesirable outputs and environmental factors. *Journal of Air Transport Management*, 10(5), 295-303.