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EVALUATING AIRPORT EFFICIENCY USING DATA ENVELOPMENT ANALYSIS[1]

Heri Bezić

University of Rijeka, Faculty of Economics, I. Filipovića 4, 51 000 Rijeka

Croatia

bezic@efri.hr

Alemka Šegota

University of Rijeka, Faculty of Economics, I. Filipovića 4, 51 000 Rijeka

Croatia

alemka.segota@efri.hr

Katija Vojvodić

University of Dubrovnik, Department of Economics, Lapadska obala 7, 20 000 Dubrovnik

Croatia

katija.vojvodic@unidu.hr

Abstract

Performance measurements have become an issue of the utmost importance in the airport business, as airports become more competitive and face the challenging market environment. Thus, the analysis of airport efficiency might help to increase competitiveness. The paper aims to assess the efficiency of Croatian airports over the five-year period 2004-2008 using Data Envelopment Analysis (DEA). DEA has been proven as a valuable performance evaluation methodology when homogeneous decision-making units (DMUs) have multiple inputs and outputs and operate in similar conditions. Initially, DEA has been deployed to analyse the efficiency of Croatian airports in 2008. The analysis has revealed that only Split Airport and Dubrovnik Airport are relative efficient performers. DEA provides estimates of the potential improvement that can be made by inefficient airports. The analysis has then been extended by utilising window analysis, which is useful for detecting efficiency trends of DMUs over time. It has shown significant disparities in efficiencies among the airports over the period examined.

Key Words: Data Envelopment Analysis, efficiency, competitiveness, Croatian airports

Topic Groups: Industry, area or region specific studies, International business

INTRODUCTION

The efficiency of an airport is one of the most significant determinants of the success and progress in the airport business. With the processes of deregulation and liberalization within the air transport industry, airports began to contend with each other and to improve their

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efficiency in order to have a competitive edge. In that sense, it is essential to realize which airports are performing well and which are underperforming, as well as to indicate relative inefficiencies in order to improve their performance.

Data Envelopment Analysis (DEA) is a non-parametric multiple input-output methodology that assesses the relative efficiency of decision-making units (DMUs) using a linear programming based model. In that context, airports operate in similar conditions and can be regarded as decision-making entities and uniform decision-making units, with regard to both input and output components.

The main objective of the paper is to apply Data Envelopment Analysis to analyse the efficiency and overall performance of Croatian airports. The DEA model is also very useful in indicating relative inefficiencies in order to improve the performance. The paper attempts to investigate the efficiency of Croatian airports during the year 2008 and the period 2004-2008.

The paper is structured as follows: Section 2 provides the results of previous studies on airport efficiency applying Data Envelopment Analysis. This is followed by introducing the DEA method and describing its main characteristics. Then, in Section 4, data and methodology are presented. The following section presents the results of the DEA analysis and its discussion. Finally, certain conclusions emerging from the previous sections are outlined and some proposals for the improvement of future research are indicated.

LITERATURE REVIEW

Assessing the efficiency of airports by applying Data Envelopment Analysis has been the subject of much research in the recent past (Martin and Roman, 2001, 2006, 2008; Abbott and Wu, 2002; Yoshida and Fujimoto, 2004; Yu, 2004; Malighetti et al., 2007; Barros and Dieke, 2007, 2008; Fung et al., 2008; Tapiador et al., 2008; Chi-Lok and Zhang, 2009).

Previous research on the assessment of airport efficiency through the use of DEA methods reveals the following results:

- significant differences in efficiencies among airports depending on their geographical location (Sarkis, 2000; Yu, 2004; Yoshida and Fujimoto, 2004; Lin and Hong, 2006; Tapiador et al., 2008; Fung et al., 2008)
- airports with more competition are more efficient than their counterparts (Yu, 2004; Chi-Lok and Zhang, 2009)
- partially and fully privatised airports are more efficient than publicly owned ones (Vogel, 2005)
- fully private airports tend to have higher efficiency scores than partially private airport authorities (Barros and Dieke, 2007)
- airports with higher WLU (work load unit) tend to be more efficient than those with lower WLU (Barros and Dieke, 2007), which can be explained by the economies of scale (Graham, 2005)
- efficiency is related to airports` size i.e. large airports (with more than 5 million passengers) are more efficient than domestic and regional ones (Malighetti et al., 2007; Barros and Dieke, 2007; Yoshida and Fujimoto, 2004; Martin and Roman, 2008)
- the status of public-owned management company has a positive impact on the efficiency (Curi et al., 2010)

- the changes in managerial style influence airport performance (Pacheco and Fernandes, 2003; Pacheco et al., 2006)

Numerous studies evidently confirm that Data Envelopment Analysis has been a widely utilized method in the literature on airport efficiency and productivity.

DATA ENVELOPMENT ANALYSIS

In order to measure the efficiency of the airports, we apply the widely utilised and useful methodology - Data Envelopment Analysis. It is a methodology which enables comparative efficiency analysis of the decision-making units (DMUs). It uses a specific set of resource inputs in order to produce a specific set of outputs without knowing the form specification of the relation between inputs and outputs. The DEA is a nonparametric efficiency measurement that uses linear programming methods to construct a piecewise linear surface or frontier over the data. Through the reference to this frontier, we can determine the position of inefficient units and identify the sources and the amounts of inefficiency.

Graham (2005) notes that the key advantage of DEA is that the weights for the inputs and outputs are not pre-determined but instead are the results of the linear programming procedure. She also outlines that DEA is often a more attractive technique than other methods because it has less demanding data requirements and, therefore, has been used more extensively to measure airport performance.

Let us suppose there are n DMUs: DMU_1, DMU_2, ... , DMU_n. Some common input and output items for each of these j = 1, ... , n DMUs are selected as follows (Cooper et al., 2006):

1. Numerical data are available for each input and output, with the data assumed to be positive for all DMUs;
2. The items (inputs, outputs and choice of DMUs) should reflect an analyst`s or a manager`s interest in the components that will enter into the relative efficiency evaluations of the DMUs;
3. In principle, smaller input amounts are preferable and larger output amounts are preferable so the efficiency scores should reflect these principles;
4. The measurement units of the different inputs and outputs need not be congruent.

The determination of the efficiency score of the ith airport in a sample of N airports in the constant returns to scale will be based on one of the fundamental models of DEA: CCR model. Efficiency is defined as the ratio of weighted sum of outputs to weighted sum of inputs. The fundamental idea of the model is to determine the weight that maximises the goal function: ratio of virtual inputs and outputs, after their establishment through the relevant weights. More precisely: let us suppose to have available data on some n decision-making units that utilise the m of the same inputs and realise the s of the same outputs. In order to determine the values for the inputs' "weights" (v_i) (i = 1,..., m) and the outputs' "weights" (u_r) (r = 1,...,s) which represent the variables, we are solving the following problem of the fraction programming (Cooper et al., 2000):

$$\max \quad \theta = \frac{u_1 y_{10} + u_2 y_{20} + ... + u_s y_{s0}}{v_1 x_{10} + v_2 x_{20} + ... + v_m x_{m0}}$$

s.t.

$$\frac{u_1 y_{1j} + ... + u_s y_{sj}}{v_1 x_{1j} + ... + v_m x_{mj}} \leq 1 \text{ (j = 1,..., } n)$$

$$v_1 \ , \ v_2 ,..., v_m \geq 0$$

$$v_1 \quad u_1 , \ u_2 ,..., u_s \geq 0$$

The variables (u_r) (r = 1,...,s) and (v_i) (i = 1,...,m) are determined through the CCR model for each DMU, they are not previously given. Consequently, the data on inputs and outputs enters the goal function. The restrictions mean that the ratio of "virtual outputs" and "virtual inputs" cannot cross the value of 1, for each DMU. If the optimal value is θ^* = max θ = 1, the efficiency for the relevant DMU has been reached.

DATA AND METHODOLOGY

There are seven airports handling international air traffic in the Republic of Croatia – Zagreb, Split, Dubrovnik, Zadar, Rijeka, Pula and Osijek. A 55% stake in each is owned by the state, with the remaining 45% divided between different levels of regional and local authorities. In terms of total passenger volume, Croatia airports recorded 4,897.975 passengers in 2009 (http:// www.mmpi.hr). The airports of Zagreb, Split and Dubrovnik amount to approximately 85% of the total passenger traffic in Croatia.

The goal of the analysis is to make the cross-airports comparison of performance. For this purpose, CCR input-oriented model (constant returns to scale) and the DEA-SolverPro6.0 software program have been utilised. Adequate choice of inputs and outputs represents an important step in the DEA utilisation. Two variables make up the inputs: operating costs and the number of employees. The output is measured by one variable: total revenues. All input and output data were taken from the annual reports of the airports, which provide information on the airports` physical and financial parameters. The combination of input and output variables meets the DEA convention that the minimum number of DMU observations should be greater than two times the number of inputs plus outputs.

As Mantri (2008) notes, conventional DEA is static, i.e. the analysis does not consider the time frame to which the input consumption and output production refers. However, multi-period efficiency measurement is possible through window analysis. Initiated by Charnes et al. (1985), window analysis is a time-dependent version of DEA with various applications. The input/output data of the DMUs for a number of consecutive periods (i.e. a window) are used to assess the efficiency of each DMU in each period.

After selecting input and output variables in the first stage, the efficiency scores of Croatian airports in 2008 are analysed. This is followed by identifying sources and amounts of relative inefficiency. In the second stage we proceed with window analysis, which is applied to provide trend information on the relative efficiency scores of Croatian airports over the five-year period 2004-2008.

DEA RESULTS AND DISCUSSION

The correlation analysis for seven Croatian airports shows that there is a strong relationship between inputs and output: between operating costs and revenues 0.96453257, and between the number of employees and revenues 0.85041342 (Table 1).

Table 1: Correlation matrix

	OPER. COSTS	EMPLOYEES	REVENUES
OPER. COSTS	1	0.937752	0.96453257
EMPLOYEES	0.9377518	1	0.85041342
REVENUES	0.9645326	0.850413	1

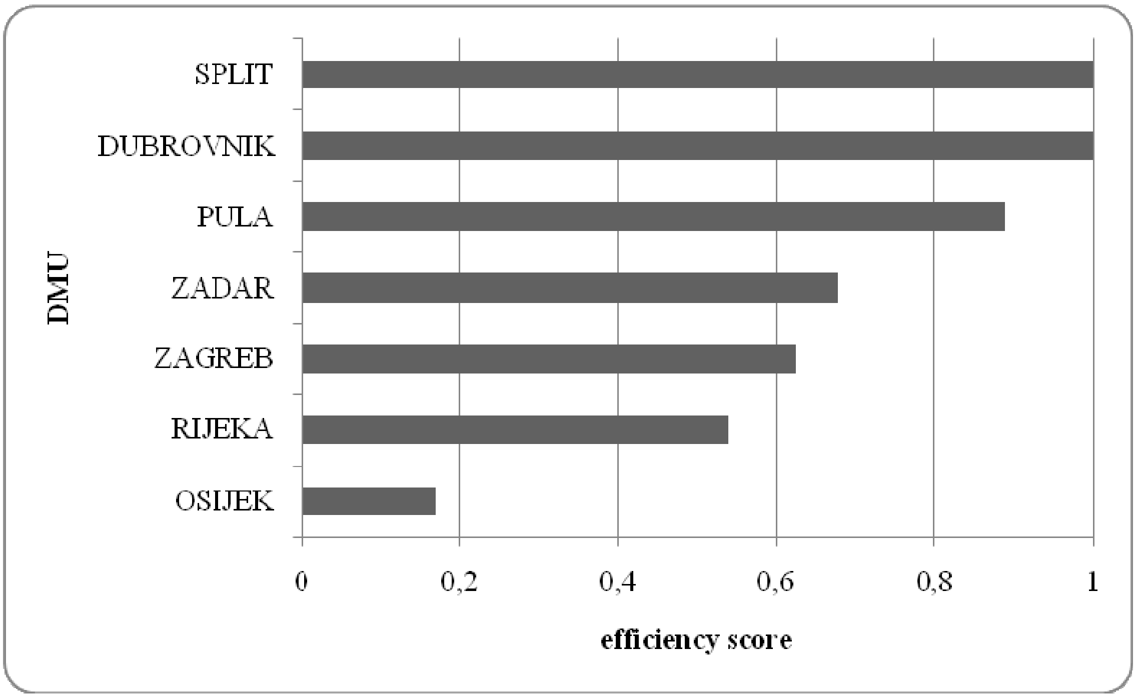
The results of relative efficiency for seven Croatian airports are presented in Table 2. The position in the ranking based on these scores is displayed in the third column.

Table 2: Efficiency scores, 2008

DMU	Score	Rank
DUBROVNIK	1	1
OSIJEK	0.168968	7
PULA	0.887644	3
RIJEKA	0.539099	6
SPLIT	1	1
ZADAR	0.677358	4
ZAGREB	0.624301	5

The efficiency indices diverge from 0.168968 to 1. These efficiency scores show that only Dubrovnik Airport and Split Airport are relative efficient airports having a max-efficiency value of 1.0.

Figure 1: Relative efficiency scores, 2008



That would mean that they could not increase the outputs without increasing the inputs, nor reduce the inputs without reducing the outputs. Osijek's efficiency is 0.168968, i.e. Osijek Airport achieved only approximately 16% of Dubrovnik's and Split`s efficiency. Pula Airport is approximately 89% efficient compared to Dubrovnik and Split while Rijeka achieved 54% efficiency. Zadar achieved 68% efficiency and Zagreb approximately 62% of Dubrovnik´s and Split`s efficiency. Relative efficiency scores are also shown in Figure 1.

Table 3 contains the improvements required in order to make inefficient airports efficient. As seen in Table 3, results suggest that all inefficient airports could improve their efficiency on both input variables, i.e. these airports might reduce some of the inputs. Having this information, airport managers should concentrate their efforts in enhancing the performance.

Table 3: Projections values

No.	DMU I/O	Score Data	Projection	Difference	%
1	DUBROVNIK	1			
	OPER. COSTS	40012470	40012470	0	0.00%
	EMPLOYEES	350	350	0	0.00%
	REVENUES	152301507	152301507	0	0.00%
2	OSIJEK	0.16896829			
	OPER. COSTS	4320385	730008.075	-3590376.9	-83.10%
	EMPLOYEES	42	6.38557995	-35.61442	-84.80%
	REVENUES	2778667	2778667	0	0.00%
3	PULA	0.88764376			
	OPER. COSTS	17624641	15644402.6	-1980238.4	-11.24%
	EMPLOYEES	171	136.845861	-34.154139	-19.97%
	REVENUES	59548088	59548088	0	0.00%
4	RIJEKA	0.53909907			
	OPER. COSTS	4369012	2355330.31	-2013681.7	-46.09%
	EMPLOYEES	76	20.6027173	-55.397283	-72.89%
	REVENUES	8965214	8965214	0	0.00%
5	SPLIT	1			
	OPER. COSTS	62267000	62267000	0	0.00%
	EMPLOYEES	380	380	0	0.00%
	REVENUES	184865000	184865000	0	0.00%
6	ZADAR	0.6773584			
	OPER. COSTS	7886054	5341684.93	-2544369.1	-32.26%
	EMPLOYEES	99	46.7251765	-52.274823	-52.80%
	REVENUES	20332328	20332328	0	0.00%
7	ZAGREB	0.62430105			
	OPER. COSTS	78889943	49251074.5	-29638868	-37.57%
	EMPLOYEES	875	430.812596	-444.1874	-50.76%
	REVENUES	187466879	187466879	0	0.00%

Since the model is input-orientated, output is considered as a constant. That is why projections suggest decreasing the inputs for all inefficient airports in order to become relative efficient. The total number of employees should decrease as follows: Osijek Airport by about 85%, Pula Airport 20%, Rijeka Airport 73%, Zadar Airport 53% and Zagreb 51%. With regard to expenditures, Osijek Airport should decrease expenditures by about 83%, Zadar Airport should decrease expenditures by 32%, Rijeka Airport by 46%, Pula Airport by

11%, while Zagreb Airport should decrease expenditures by 37%. These percentages suggest significant surplus of both employees and expenditures for all inefficient airports.

One of the advantages of DEA lies in its ability to identify the area of excess. In that context, the basic DEA efficiency results are extended by decomposing the efficiency scores. This decomposition indicates the sources of inefficiency. It is interesting to examine an excess in an input (or a shortage in an output) from the optimal solution of the model. DEA is able to identify the exact amount of excess or slack. In that way, it helps allocate resources between airports more efficiently.

Table 4: Decomposition of efficiency score

DMU	Score	Excess OPER.COSTS S-(1)	Excess EMPLOYEES S-(2)	Shortage REVENUES S+(1)
DUBROVNIK	1	0	0	0
OSIJEK	0.168968	0	0.711088	0
PULA	0.887644	0	14.94122	0
RIJEKA	0.539099	0	20.36881	0
SPLIT	1	0	0	0
ZADAR	0.677358	0	20.33331	0
ZAGREB	0.624301	0	115.4508	0

The Table 4 decomposes inefficiency into each input/output factor. It indicates that the excess of employees dominates the other input in inefficiency. These pieces of information further increase the usefulness of DEA as a means of assessing airports` performances.

Until now we have dealt with DEA under static conditions. When the time is not considered, the efficiency results can be biased. In order to deal with this, further analysis is extended by adopting DEA window analysis approach. The basic idea of window analysis is to regard each DMU as if it were different DMU in each of the reporting dates: a DMU is compared to itself over time. It is useful for detecting efficiency trends of DMU over time. The efficiency of Croatian airports for the period 2004-2008 is displayed in Table 5 and the efficiency of these airports is analysed over time. As it can be noted in the last row in Table 5, results indicate that the overall average efficiencies of Croatian airports haven`t shown considerable fluctuations over the five-year period analysed.

Table 6 contains the averages through a window. The first window incorporates years 2004, 2005 and 2006. Generally, when a new period is introduced into a window, the earliest period is dropped. In the next window the year 2004 will be dropped and year the 2007 will be added to the window. The analysis is over when the window analyses years 2006, 2007 and 2008.

Table 5: DEA-CCR window analysis for airport efficiency

	2004	2005	2006	2007	2008	Average	C-Average
DBV	0.947094	1	1			0.982365	
		1	1	0.938243		0.979414	
			1	0.88464	1	0.961547	0.974442
OSI	0.182574	0.390865	0.189535			0.254325	
		0.390865	0.189535	0.131413		0.237271	
			0.189535	0.131413	0.160851	0.1606	0.217398
PUL	0.732631	0.863112	0.910461			0.835401	
		0.863112	0.910461	0.861166		0.878246	
			0.910461	0.843008	0.845797	0.866422	0.860023
RIJ	0.449493	0.636746	0.416383			0.500874	
		0.636746	0.416383	0.467134		0.506754	
			0.416383	0.467134	0.451373	0.444963	0.484197
SPL	0.717182	0.84154	1			0.852907	
		0.806261	0.941383	1		0.915882	
			0.876742	0.931606	1	0.936116	0.901635
ZAD	0.409132	0.486762	0.425828			0.440574	
		0.486762	0.425828	0.496994		0.469861	
			0.425828	0.5001	0.567134	0.497687	0.469374
ZAG	0.741541	0.7237	0.485737			0.650326	
		0.720313	0.484632	0.527461		0.577469	
			0.486466	0.524822	0.556698	0.522662	0.583485
Average	0.597092	0.703342	0.623885	0.621795	0.654551		

Table 6: Average through window

	2004-2005-2006	2005-2006-2007	2006-2007-2008
DUBROVNIK	0.982365	0.979414	0.961547
OSIJEK	0.254325	0.237271	0.1606
PULA	0.835401	0.878246	0.866422
RIJEKA	0.500874	0.506754	0.444963
SPLIT	0.852907	0.915882	0.936116
ZADAR	0.440574	0.469861	0.497687
ZAGREB	0.650326	0.577469	0.522662

Figure 2 shows relative efficiency trend for all analysed airports. It can be observed that Dubrovnik Airport achieved the best average scores for all three windows.

Consequently, the final average score for Dubrovnik Airport is the best one equals 0.974442 (column C-Average). Split Airport is estimated as the second with score 0.901635 and so on.

Figure 2: Relative efficiency variation through window

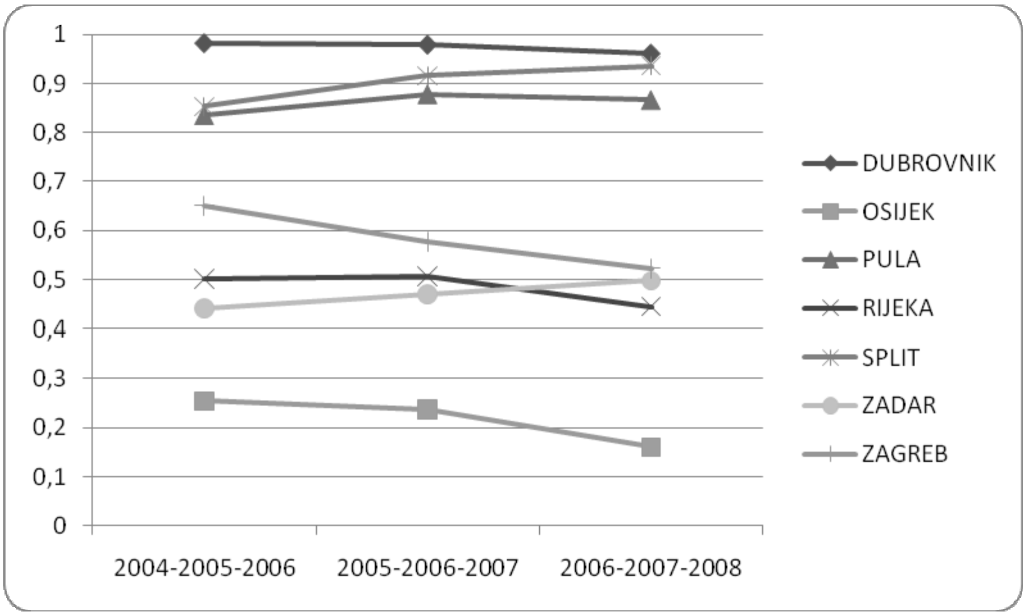


Figure 3: Relative efficiency variation by term

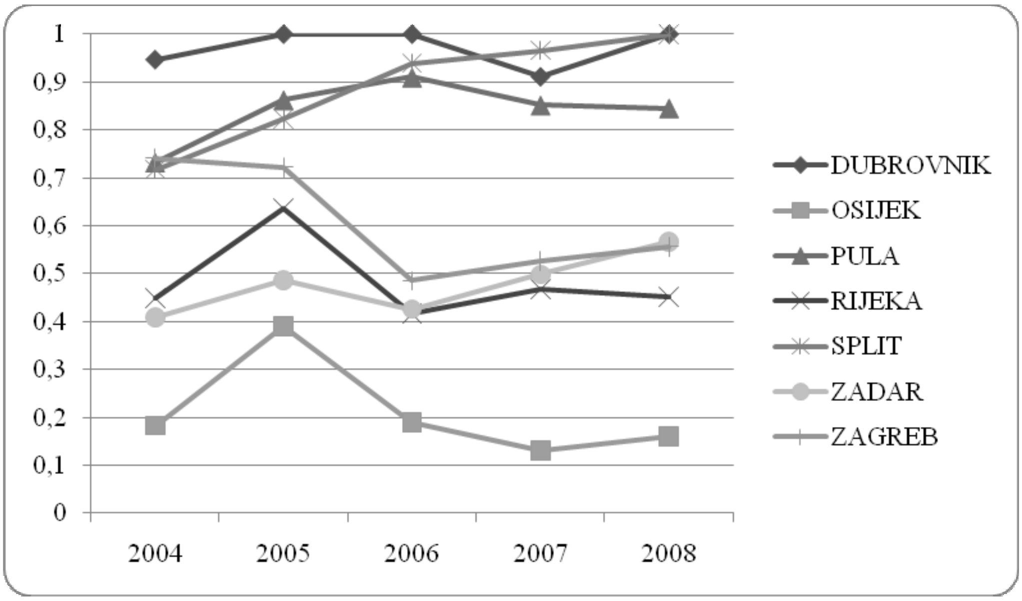


Figure 3 presents relative efficiency variation by term. When considering each year of the period 2004-2008, the results indicate no regular trend in average airport efficiency variation. Furthermore, a significant difference in relative efficiency among Croatian airports is obvious. Figure 3 shows that Dubrovnik Airport, as well as Split Airport, were the most efficient on average, followed by Pula Airport and Zadar Airport which reveal relatively steady efficiency trends. In contrast, Zagreb Airport and Rijeka Airport recorded some considerable drops in efficiency scores in the last 3 consecutive years (2006-2008), whereas Osijek Airport was the least efficient and, at the same time, it is the airport with fewest passengers per year in Croatia.

CONCLUSIONS AND IMPLICATIONS

This paper uses the well established Data Envelopment Analysis method to compare the relative efficiencies of Croatian airports. The method is very useful since it also provides estimates of the potential improvement that can be made by inefficient DMUs. In this case, an input-oriented CCR model has been utilised to assess the overall efficiency of seven Croatian airports in the year 2008 and over the five-year period 2004-2008.

This paper provides new empirical evidence on the trends in efficiency of Croatian airports and, consequently, it contributes to the existing airport efficiency literature by presenting an assessment of the efficiency of Croatian airports by applying the Data Envelopment Analysis methodology. To the best extent of authors` knowledge, this is the first time that this data set, i.e. input and output variables, have been applied to compute the efficiency of the airports in Croatia through the use of DEA methods.

Input data include operating costs and the number of employees while output data is comprised of total revenues. In that sense, the correlation analysis shows the existence of strong correlation between inputs and output. The analysis has revealed that only Split Airport and Dubrovnik Airport are relative efficient performers in comparison to the other airports. Projection values also identified the amounts of relative inefficiency and suggested improvements for all inefficient airports. In that context, the results revealed that all inefficient airports could improve their efficiency by reducing some of the inputs. Furthermore, by decomposing the efficiency scores DEA identifies the area of excess and, in that way, helps allocate resources more efficiently between airports. The decomposition of efficiency scores indicates that the excess of employees dominates the other input in inefficiency. In order to avoid the use of a single year to calculate airports` efficiency, the analysis has been extended by utilising window analysis, which is useful for detecting efficiency trends of DMUs over time. The length of the window is chosen as three, containing periods 2004-2005-2006, 2005-2006-2007 and 2006-2007-2008. The analysis has shown significant disparities in efficiencies among the airports over the period examined. However, the overall average efficiencies of Croatian airports haven`t indicated considerable fluctuations over the five-year period analysed.

It is worth mentioning some potential limitations of our analysis. It primarily refers to model limitations, namely the number of input and output variables. Bearing in mind that there are seven airports handling international air traffic in Croatia, the number of input and output variables was limited. Given the number of DMUs has to be at least twice the sum of the input and output variables, only two inputs and one output were considered when estimating the efficiency scores of Croatian airports. In that respect, the influence of other variables on the performance of Croatian airports is missing and further research is needed.

The research presented here can be extended and improved in at least several ways. First, by continuing to measure airport efficiency, it can be investigated how it has evolved over time. There are several areas worthy of consideration for further research. The input and output variables are not exhaustive. Other inputs (e.g. terminal area, runway area, number of check-in counters, number of gates, number of aircraft parking positions, number of baggage claims, etc.) and outputs (e.g. number of passengers, aircraft movements, amount of cargo handled, commercial revenues, aeronautical revenues, etc.) could be included into the model and analysed. Another interesting direction of research is to compare the efficiency the of Croatian airports with airports in other countries, i.e. relatively similar markets, particularly with regard to size and ownership of airports. The analysis can identify and highlight similarities and differences between airport efficiency in Croatia and other countries. It would also allow the positioning of Croatian airports in a national and international context, i.e. ranking of Croatian airports in a wider context. The above mentioned issues should be considered for further research.

Based on the results of the analysis, there are some suggestions concerning airport managers. By comparing the performances of an airport with the results of the other airports certain pieces of information for self improvements can be gained. This information requires special attention as it can be important in order to enhance the overall airports` performance. In that sense, airport managers should evaluate and benchmark their performances with airports having similar characteristics. The results can also be interesting for airlines. Due to ever-increasing competition from low-cost airlines, they will increasingly focus on efficient airports and choose them for their operations. Furthermore, counties and municipalities could also be interested in performance evaluation of Croatian airports as efficient airports result in an increase in tourist flows and further development of their regions.

With regard to the methodology, the airports` performance in this paper was evaluated by the DEA model. However, other methods (e.g. stochastic frontier analysis, total factor productivity) should be applied as well in order to confirm the results and to provide further information on the subject.

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