Netw Spat Econ (2011) 11:139–157
DOI 10.1007/s11067-008-9096-1

Efficiency Analysis and Target Setting of Spanish Airports

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Published online: 20 January 2009

Abstract In this paper an efficiency analysis of 41 Spanish airports is carried out. A description of the physical infrastructure of the airports, namely total runway area, apron capacity, passenger throughput capacity, number of baggage belts, number of check-in counters and number of boarding gates, is used as inputs. Air Traffic Movements, Passenger Movements and Cargo handled are used as outputs. An output-oriented, Variable-Returns-to-Scale, non-radial Data Envelopment Analysis (DEA) model is used to compute the Russell measure of output technical efficiency. Half of the airports are found technically efficient. Scale efficiency and local Returns to Scale have also been assessed, indicating that except for a few airports that operate at their Most Productive Scale Size, for most Spanish airports Increasing Returns to Scale prevail. An original DEA model for target setting and scenario analysis is also proposed. The model uses two parameters (Plane Load Factor and Passenger/Cargo Ratio) that allow the relating of two of the outputs to the third. The model computes efficient targets given the value of these two parameters and the vector of available inputs. The results of this target-setting DEA model for Seville airport for different values of the two parameters and different future input scenarios are presented.

Keywords Airport operations · Airport infrastructure · Efficiency · Data envelopment analysis · Target setting · Scenario analysis

1 Introduction

One of the evident manifestations of globalization is the spectacular growth of air transportation all over the world, something which has often stretched the limits of existing airport infrastructures. The perceived interest, both in researchers and in management, in assessing airport operations efficiency is, therefore, not surprising. Such interest exists, indeed, in Spain. Take into account that in 2006 the Spanish airport system serviced more than 193 million passengers and handled more than 600.000

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tonnes of cargo. Table 1 lists the top 25 European airports in 2006. Note that there are two Spanish airports among the top ten European airports and four among the top 25.

AENA ("Aeropuertos Españoles y Navegación Aérea") is the state-owned corporation that manages the whole Spanish airport system. AENA is among the top five providers of air navigation in Europe, one of the top 50 Spanish companies and one of the world's leading air transport companies. The company manages 74 airports in Europe and America and its traffic totals 241 million passengers per year (AENA 2006). AENA owns and manages all Spanish airports, which are operated as a network: 47 airports and one heliport serving 193 million passengers. It is also in charge of the Air Traffic Control of Spain's Airports. AENA, a public company, is economically independent and also has the managerial and administrative responsibilities to enhance the earning potential of these airports. Moreover, with an important international presence, AENA is currently one of the world's largest airport operators (AENA 2006).

This paper presents the results of a non-parametric efficiency analysis, for 2006, of 41 Spanish airports managed by AENA. The three common types of outputs are considered (passengers, aircrafts and cargo). The inputs considered in the study include an extensive description of available facilities at each airport, such as runway area, apron capacity, check-in counters, boarding gates and baggage belts, etc. The proposed DEA model uses a non-radial efficiency measure that leaves no output slacks and it is, therefore, preferable to the radial and directional distance function previously used in the literature. In addition to the performance assessment of the airports (and of the whole Spanish airport system), a new model for scenario analysis

Table 1 Top 25 European airports in 2006

Airport city, country	Airport code	Total passengers (10^3)
London, UK	LHR	67,530.2
Paris, FR	CDG	56,809.0
Frankfurt, DE	FRA	52,810.7
Amsterdam, NL	AMS	46,088.2
Madrid, ES	**MAD**	**45,530.0**
London, UK	LGW	34,172.5
Munich, DE	MUC	30,758.0
Rome, IT	FCO	30,100.5
Barcelona, ES	**BCN**	**30,008.2**
Paris, FR	ORY	25,622.2
London, UK	STN	23,686.8
Manchester, UK	MAN	22,773.0
Palma de Mallorca, ES	**PMI**	**22,408.3**
Milan, IT	MXP	21,767.3
Dublin, IE	DUB	21,196.9
Copenhagen, DK	CPH	20,799.4
Zurich, CH	ZRH	19,194.2
Oslo, NO	OSL	17,672.2
Stockholm, SE	ARN	17,667.5
Vienna, AT	VIE	16,855.7
Brussels, BE	BRU	16,649.9
Düsseldorf, De	DUS	16,589.9
Athens, GR	ATH	15,066.3
Málaga, ES	**AGP**	**13,076.3**
Lisbon, PT	LIS	12,313.6

of the resources and activity of a given airport is proposed. This allows computing efficient output targets as a function of the given inputs and two industry parameters, namely Plane Load Factor and Passenger/Cargo Ratio.

Both the efficiency analysis and the target-setting approach proposed in this paper use models based on Data Envelopment Analysis (DEA). DEA (Thanassoulis 2001; Cooper et al. 2004, 2006; Zhu 2002) is a non-parametric, production frontier approach aimed at assessing the relative performance of a set of comparable units. Each unit uses given amounts of resources (inputs) and produces given amounts of outputs. DEA models can identify the units that are relative efficient and for which an efficiency score and a target operation point is computed.

DEA has been applied in a number of previous airport efficiency studies which are reviewed in Section 2. In Section 3, input and output data of Spanish airports are presented, an output-oriented, non-radial DEA model is formulated and the corresponding results are discussed. In Section 4, a new airport efficiency target setting DEA model is proposed and illustrated for the Seville airport. The last section summarises and concludes.

2 Literature review

As mentioned above, different DEA airport efficiency studies have been published in the literature. Table 2 summarises them. These studies are very varied in their geographical scope. Most of them deal with a single country, often the US, but also Brazil, Taiwan, Japan, Australia, Italy and Spain. There are also some studies at a European level and a few that benchmark airports from different countries. The inputs and outputs considered by the different researchers are very varied but the most common outputs are those related to passengers, aircraft operations and cargo. Some recent studies consider undesirable outputs such as delays (e.g. Pathomsiri et al. 2008) or aircraft noise (e.g. Yu 2004; Yu et al. 2008). On the input side, there are two common approaches: studies that consider factors such as capital, labour and other operational costs and studies that consider physical infrastructure such as runways, terminal area, apron capacity, check-in desks, boarding gates and baggage belts.

Note that there is no consensus on the Returns to Scale (RTS) to use, with some studies assuming Constant Returns to Scale (CRS) and others assuming Variable Returns to Scale (VRS). The studies are also divided in terms of their orientation: some use an input orientation, others an output orientation and the rest a mixed (i.e., graph) orientation. The two metrics commonly used to measure the distance to the efficient frontier are the Farrell efficiency measure and the directional distance function. Some studies carry out an efficiency analysis, often using crossefficiency and superefficiency models to further discriminate among efficient units. Other studies, however, use panel data and compute total factor productivity using either Malmquist productivity indexes or Luenberger productivity indicators.

With respect to the five studies that analyse the efficiency of Spanish airports, most of them use labour, capital and other expenses as inputs, and passengers, aircraft operations and cargo as outputs. Three of these studies use 1997 data and another computes Malmquist productivity indexes for 1992–1999. There is a more recent study (Tapiador et al. 2008) that uses data from 2005 but considers a single output (passengers) and, as

Table 2 Summary of DEA approaches in the literature

Reference	Inputs	Outputs	RTS	Orientation	Efficiency score	Geographical scope
Barros and Dieke (2008)	Labor costs; capital invested; other operational costs	Passengers; aircraft operations; cargo; aeronautical revenue; commercial revenue; handling receipts	VRS	Output	Farrell	Italy
Barros and Peypoch (2008)	Operational costs; Capital invested	Passengers; Aircraft operations; Cargo; Aeronautical revenue; Commercial revenue; Handling receipts	VRS	(−Input, Output)	Luenberger (Directional distance)	Italy and Portugal
Fung et al (2008)	Total runway length; Terminal area	Passengers; aircraft operations; cargo	CRS	Output	Malmquist (Farrell)	China
Pathomsiri et al (2008)	Landarea; number of runways Total runway area	Passengers; not delayed aircraft operations; cargo; delayed aircrafts (undesirable); flights delays (undesirable)	CRS	(Desirable output, −undesir. output)	Directional distance	US
Tapiador et al (2008)	Leisure services index; total population; economic activity index; commercial activity index; tourism activity index; intermodality index; European resident population; industrial activity index	Passengers	CRS	Input	Farell	Spain
Yu et al (2008)	Labour costs; capital stock; operating expenditures; passengers; aircraft operations	Airport revenue; noise (undesirable)	CRS	(Desirable output, −undesir. output)	Luenberger (directional distance)	Taiwan
Barros and Dieke (2007)	Labor costs; capital invested; other operational costs	Passengers; aircraft operations; cargo; aeronautical revenue; commercial revenue; handling receipts	VRS	Output	Farrell Crossefficiency Superefficiency	Italy
Martín and Román (2007)	Labour costs; capital costs; material costs	Passengers; aircraft operations; cargo	VRS	Output	Farrell	Spain

Lin and Hong (2006)	Number of employees; number of runways; parking spaces; number of aprons; baggage belts	Passengers; aircraft operations	CRS VRS FDH	NA	Farrell Crossefficiency Superefficiency	International
Martín and Román (2006)	Labour costs; capital costs; material costs	Passengers; aircraft operations; cargo	VRS	Output	Farrell Crossefficiency Superefficiency Virtual efficiency	Spain
Pacheco et al (2006)	Number of employees; payroll; operating expenditures	Passengers; cargo; operating revenues; commercial revenues; other revenues	VRS	Input	Farrell	Brazil
Barros and Sampaio (2004)	Number of employees; capital invested	Passengers; aircraft operations; cargo; mail cargo; sales to planes #sales to passengers	VRS	Input	Allocative efficiency (Farrell)	Portugal
Sarkis and Talluri (2004)	Operating costs; FTE employees; boarding gates; number of runways	Passengers; aircraft operations; cargo; operating revenues	CRS	Input	Farell Crossefficiency	US
Yoshida and Fujimoto (2004)	Total runway length; terminal area; access cost; labour	Passengers; aircraft operations; cargo	VRS	Input	Farrell	Japan
Yu (2004)	Runway area; terminal area Apron area; routes connecting other airports; population	Aircraft operations; noise (undesirable)	CRS	(Desirable output, −undesir. output)	Directional distance	Taiwan
Bazargan and Vasigh (2003)	Operating expenses; non-operating expenses; number of runways; boarding gates	Passengers; air carrier operations; other operations; aeronautical revenues; non-aeronautical revenues; % on-time operations	CRS	Input	Virtual efficiency (Farrell)	US
Pacheco and Fernandes (2003)	Number of employees; payroll; operating expenditures	Passengers; cargo and mail; operating revenues; commercial revenues; other revenues	VRS	Input	Farrell	Brazil
Pels et al (2003)	Airport area; aircraft parking positions; number of runways	Aircraft operations	VRS	Input	Farrell	Europe
	Aircraft operations; load factor; check-in desks; baggage belts	Passengers	VRS	Input	Farrell	Europe
Abbot and Wu (2002)	Total runway length; number of staff; capital stock	Passengers; cargo	CRS	Output	Malmquist (Farrell)	Australia

Table 2 (continued)

Reference	Inputs	Outputs	RTS	Orientation	Efficiency score	Geographical scope
Fernandes and Pacheco (2002)	Apron area; departure lounge area; check-in desks; baggage claim area; curb frontage; vehicle parking places	Passengers	VRS	Output	Farrell	Brazil
Adler and Berechman (2001)	Haul charges; number of terminals^{-1}; number of runways^{-1}; distance to city center; connecting times	Suitability to airlines; operational reliability and convenience; cost of using airport; overall satisfaction and quality; demand	VRS	Input	Superefficiency (PCA-DEA)	International
Martín and Román (2001)	Labour costs; capital costs; material costs	Passengers; aircraft operations; cargo	VRS	Output	Farrell	Spain
Pels et al (2001)	Terminal area; aircraft parking positions; check-in desks; baggage belts	Passengers; aircraft operations	VRS	Input	Farrell	Europe
Sarkis (2000)	Operating costs; FTE employees; boarding gates; number of runways	Passengers; aircraft operations; cargo; operating revenues	CRS VRS	Input	Farell Crossefficiency Superefficiency Radii classification	US
Murillo-Melchor (1999)	Number of employees; capital stock; operating expenditures	Passengers	CRS	Output	Malmquist (Farrell)	Spain
Parker (1999)	Number of employees; capital costs; other operating costs	Turnover; passengers; cargo and mail	VRS	Input	Farrell	UK
Gillen and Lall (1997)	Number of runways; terminal area; boarding gates; number of employees; baggage belts; public parking slots	Passengers; cargo	VRS	Output	Farrell	US
	Airport area; number of runways; total runway area; number of employees	Aircraft operations; commuter movements	CRS	Output	Farrell	US

inputs, a number of variables related to the geographical location of the airports and its related catchment area (e.g., population, local economic activity, accessibility and tourism potential).

None of the existing studies on Spanish airports, therefore, considers the efficiency of the airports in the use of their physical infrastructure, which is the main aim of this study. Also, as will be described in the next section, we propose a different, non-radial efficiency measure which allows us to gauge the potential improvement in every output dimension, leaving no output slacks—a problem that occurs with the Farrell efficiency measure and with the directional distance function approaches.

3 Efficiency analysis of Spanish airports

In this section we will present the results of a DEA efficiency study of 41 Spanish airports using the 2006 data. The inputs represent a basic description of the equipment and facilities available at the airports. This means that the efficiency analysis that will be carried out is related to the efficiency in the use of this physical infrastructure. Specifically, the inputs considered are total runway area, apron capacity, passenger throughput capacity, number of baggage belts, number of check-in counters and number of boarding gates. These inputs represent the current infrastructure of these airports and are considered as non-discretionary. As an alternative to the total runway area, the total runway length could have been used as input. However, although the results in both cases are similar, we believe that runway area is, in principle, a better descriptor of the input resource because not all runways have the same width. Passenger and aircraft traffic movements as well as Cargo handled are considered to be the three main outputs obtained exploiting this infrastructure. Table 3 shows the units of measurement and labels used for these inputs and outputs.

There is a large variation in the data, with the sample including some big airports (such as Madrid Barajas or Barcelona) together with rather small ones (like Albacete, Córdoba or Salamanca). Table 4 shows the five airports with the largest and the smallest Air Traffic Movements (ATM). Some descriptive statistics on the sample are also shown.

One of the tests that can be performed to check the validity of the inputs and outputs chosen is their isotonicity. This concept means that outputs should be significant and positively correlated with inputs (Charnes et al. 1985). Table 5 shows

Table 3 Units of measurement and labels for inputs and outputs

	Variable	Units	Label
Inputs	Total runway area	square meters	RUNAREA
	Apron capacity	number of stands	APRON
	Passenger throughput capacity	passengers/hour	CAPAX
	Number of baggage belts	number of belts	BAGB
	Number of check-in counters	number of counters	CHECKIN
	Number of boarding gates	number of gates	BOARDG
Outputs	Annual passenger movements	thousand passengers	APM
	Aircraft traffic movements	thousand operations	ATM
	Cargo handled	Tonnes	Cargo

Table 4 Sample data descriptive statistics

Airport	RUNAREA	APRON	CAPAX	BAGB	CHECKIN	BOARDG	APM	ATM	Cargo
Madrid Barajas	927,000	263	18,000	53	484	230	45,530.010	435.018	315,808.744
Barcelona	475,020	121	8,500	19	143	65	30,008.152	327.636	93,397.869
Palma de Mallorca	295,650	86	12,200	16	204	68	22,408.302	190.280	22,442.448
Málaga	144,000	43	4,500	16	85	30	13,076.252	127.769	5,125.898
Gran Canaria	139,500	55	12,560	19	86	38	10,286.635	114.938	38,360.982
Logroño	90,000	5	611	2	5	2	55.427	3.333	0
La Gomera	45,000	3	760	1	5	2	38.846	3.384	4.593
Salamanca	150,000	6	400	2	4	2	29.308	8.656	0
Córdoba	62,100	23	140	0	1	1	19.568	9.212	0
Albacete	162,000	2	220	1	4	2	17.520	1.347	0
Maximum	927,000	263	18,000	53	484	230	45,530.010	435.018	315,808.744
Minimum	37,500	1	140	0	1	1	17.520	1.347	0
Median	135,000	12	1,680	3	13	5	1,353.030	19.655	554.039

the Pearson correlation coefficients between the six inputs and the three outputs considered. It can be seen that all correlations are significant (at a level of 1%) and positive. Table 5 also shows the correlation coefficients among the different inputs. They are all significant and very high, showing that the different resources and facilities are generally dimensioned jointly to avoid bottlenecks.

With respect to the DEA model used:

- Given the large differences in size between the airports, VRS has been assumed. The limited competition among the airports means that it is unlikely that they are operating at the Most Productive Scale Size (MPSS, Banker 1984) and, therefore, VRS should be considered.
- Since the inputs represent existing facilities, it does not make much sense to reduce them. Therefore, when projecting the airports onto the efficient frontier an output orientation seems more appropriate thus leading to appropriate output targets for each airport
- Instead of the common radial DEA efficiency score, which assumes maintaining the input-output mix constant, a non-radial DEA model has been used and the Russell measure of technical efficiency (Färe and Lovell 1978; Russell 1985) has been computed. This is because the radial efficiency score does not account for output slacks and, therefore, does not measure the inefficiency associated with all possible output increases. In our case, since the inputs are non-discretionary, the Russell efficiency score coincides with the Slacks Based Measure (SBM) of efficiency, which is a well-known DEA approach that has many desirable properties (Tone 2001).

The following notation will be used:

Data

N=41	Number of airports in the data sample
j=1, 2, …,N	Index of airports in data sample
0	Index of a specific airport being evaluated
$RUNAREA_j$	Total runway area of airport j
$APRON_j$	Number of apron stands of airport j
$CAPAX_j$	Passenger/hour capacity of airport j
$BAGB_j$	Number of baggage belts of airport j

Table 5 Pearson correlation coefficients among inputs and with outputs

	RUNAREA	APRON	CAPAX	BAGB	CHECKIN	BOARDG
APM	0.886[a]	0.969[a]	0.903[a]	0.945[a]	0.953[a]	0.936[a]
ATM	0.886[a]	0.961[a]	0.883[a]	0.930[a]	0.928[a]	0.919[a]
Cargo	0.933[a]	0.947[a]	0.760[a]	0.906[a]	0.925[a]	0.966[a]
RUNAREA	1.000	0.929[a]	0.749[a]	0.871[a]	0.906[a]	0.927[a]
APRON	0.929[a]	1.000	0.880[a]	0.966[a]	0.977[a]	0.979[a]
CAPAX	0.749[a]	0.880[a]	1.000	0.925[a]	0.899[a]	0.862[a]
BAGB	0.871[a]	0.966[a]	0.925[a]	1.000	0.968[a]	0.961[a]
CHECKIN	0.906[a]	0.977[a]	0.899[a]	0.968[a]	1.000	0.988[a]
BOARDG	0.927[a]	0.979[a]	0.862[a]	0.961[a]	0.988[a]	1.000

[a] Correlation significant at 0.01 (two-tailed)

$CHECKIN_j$	Number of check-in counters of airport j
$BOARDG_j$	Number of boarding gates of airport j
APM_j	Annual Passenger Movements of airport j
ATM_j	Air Traffic Movements of airport j
$Cargo_j$	Cargo handled by airport j

Variables

$(\lambda_1, \lambda_2, ..., \lambda_N)$	Vector of non-negative multiplier used to compute a linear combination of the airports in the data sample
γ_0^{APM}	Increase factor for output APM of airport 0
γ_0^{ATM}	Increase factor for output ATM of airport 0
γ_0^{Cargo}	Increase factor for output Cargo of airport 0
γ_0	Average non-radial output increase of airport 0

Efficiency model

$$
\begin{aligned}
& Max \quad \gamma_0 = \frac{1}{3}\left(\gamma_0^{APM} + \gamma_0^{ATM} + \gamma_0^{Cargo}\right) \\
& s.t. \\
& \sum_{j=1}^{N} \lambda_j RUNAREA_j \leq RUNAREA_0 \\
& \sum_{j=1}^{N} \lambda_j APRON_j \leq APRON_0 \\
& \sum_{j=1}^{N} \lambda_j CAPAX_j \leq CAPAX_0 \\
& \sum_{j=1}^{N} \lambda_j BAGB_j \leq BAGB_0 \\
& \sum_{j=1}^{N} \lambda_j CHECKIN_j \leq CHECKIN_0 \\
& \sum_{j=1}^{N} \lambda_j BOARDG_j \leq BOARDG_0 \\
& \sum_{j=1}^{N} \lambda_j APM_j \geq \gamma_0^{APM} APM_0 \\
& \sum_{j=1}^{N} \lambda_j ATM_j \geq \gamma_0^{ATM} ATM_0 \\
& \sum_{j=1}^{N} \lambda_j Cargo_j \geq \gamma_0^{Cargo} Cargo_0 \\
& \sum_{j=1}^{N} \lambda_j = 1 \\
& \lambda_j \geq 0 \forall j \quad \gamma_0^{APM} \geq 1 \quad \gamma_0^{ATM} \geq 1 \quad \gamma_0^{Cargo} \geq 1
\end{aligned}
$$

This is a simple Linear Programming (LP) model with N+3 variables and 10 constraints. The model is solved for each airport 0 in turn. The Russell Measure of Output Technical Efficiency (RMOTE) is just γ_0^{-1} (Färe and Lovell 1978).

For those few airports that do no handle any amount of Cargo it is assumed that they do not provide that service and therefore no increase factor is computed for that output when evaluating them. In such cases, the average non-radial output increase is computed as $\gamma_0 = \frac{1}{2}\left(\gamma_0^{\mathrm{APM}} + \gamma_0^{\mathrm{ATM}}\right)$. This is a simple and effective solution to this problem of heterogeneity. Let us mention in passing that the Russell efficiency measure (and also the SBM approach) is rather sensitive to small output values since they may lead to a quite large relative improvement and, therefore, to very small efficiency scores.

Table 6 shows the increase factor of each of the three outputs, its average and the RMOTE score for each airport. Note that 21 out of the 41 airports are technically efficient. Some of the airports (such as Santander, Almería or Valladolid) have a very low score because of the very large increase potential in the Cargo they handle. A few airports (namely Salamanca, Logroño and La Gomera) have a large increase potential in APM. Only one airport (Logroño) has a large increase potential in ATM, although four airports (Tenerife South, Santiago, La Gomera and Asturias) can also increase their ATM by more than 30%.

In addition to the individual efficiency scores computed for each airport, the last row of Table 6 shows the global efficiency score for the whole Spanish airport system. Such an aggregate efficiency measure is of interest because the airports are all managed by the same organization (AENA). The weighted average increase potential of the whole Spanish airport system is 1.017 for total APM, 1.036 for total ATM and 1.306 for total Cargo, i.e. only for Cargo there is substantial room for system-wide output improvement (around 30%) while for APM and ATM the system-wide potential improvements are of 1.7% and 3.6% respectively. These low figures are not surprising since, as can be seen in Table 6, the APM and ATM increase factors are larger than one only for a few small airports. Consistent with the definition of the RMOTE for the airports, a RMOTE for the whole system may be analogously computed giving an overall efficiency score of 0.893, which is rather high. Take into account, however, that this efficiency analysis only benchmarks Spanish airports. With a larger sample, including airports from other countries, the efficiency scores would be necessarily lower.

Solving the proposed efficiency model above but without the constraint that imposes that the sum of the lambda multiplier is equal to unity corresponds to assuming CRS. Table 7 shows such CRS non-radial efficiency scores. Table 7 also presents the scale efficiency which results from dividing the CRS efficiency score by the RMOTE. For convenience, the latter, already shown in Table 6, has been included as the second column of Table 7. Moreover, solving a third time the DEA model substituting the mentioned multiplier constraint by $\sum_{j=1}^{N} \lambda_j \leq 1$, which corresponds to assuming Non-Increasing Returns to Scale (NIRS), allows the determining of the prevailing RTS in the case of each airport and is shown in the last column of Table 7.

Note that of the 21 airports that are technically efficient, only 13 (shown in bold in Table 7) are scale efficient, i.e., operate at their MPSS. In particular, all the five biggest airports are scale efficient. Some technically efficient airports, and all the

Table 6 Output increase factors and technical efficiency score

Airport	γ_0^{APM}	γ_0^{ATM}	γ_0^{Cargo}	γ_0	γ_0^{-1}
A Coruña	1.000	1.000	2.012	1.337	0.748
Albacete	1.000	1.000	0.000	1.000	1.000
Alicante	1.000	1.000	1.000	1.000	1.000
Almería	1.000	1.100	617.243	206.448	0.005
Asturias	1.000	1.332	26.466	9.599	0.104
Badajoz	1.000	1.000	0.000	1.000	1.000
Barcelona	1.000	1.000	1.000	1.000	1.000
Bilbao	1.000	1.000	6.575	2.858	0.350
Córdoba	1.000	1.000	0.000	1.000	1.000
El Hierro	1.000	1.000	1.000	1.000	1.000
Fuerteventura	1.000	1.071	6.803	2.958	0.338
Girona-Costa Brava	1.000	1.000	1.000	1.000	1.000
Gran Canaria	1.000	1.000	1.000	1.000	1.000
Granada-Jaén	1.000	1.000	1.000	1.000	1.000
Ibiza	1.031	1.000	4.630	2.220	0.450
Jerez	1.000	1.000	1.000	1.000	1.000
La Gomera	4.278	1.354	53.590	19.741	0.051
La Palma	1.000	1.000	1.000	1.000	1.000
Lanzarote	1.000	1.271	2.325	1.532	0.653
León	1.000	1.000	0.000	1.000	1.000
Logroño	5.183	2.823	0.000	4.003	0.250
Madrid Barajas	1.000	1.000	1.000	1.000	1.000
Málaga	1.000	1.000	1.000	1.000	1.000
Melilla	1.000	1.000	1.000	1.000	1.000
Menorca	1.000	1.041	4.857	2.299	0.435
Murcia	1.000	1.000	1.000	1.000	1.000
Palma de Mallorca	1.000	1.000	1.000	1.000	1.000
Pamplona	1.000	1.000	1.000	1.000	1.000
Reus	1.000	1.000	1.000	1.000	1.000
Salamanca	9.758	1.044	0.000	5.401	0.185
San Sebastián	1.261	1.000	8.772	3.678	0.272
Santander	1.065	1.000	2,973.130	991.732	0.001
Santiago	1.000	1.417	8.892	3.770	0.265
Saragossa	1.000	1.232	2.408	1.547	0.647
Seville	1.000	1.000	1.597	1.199	0.834
Tenerife North	1.000	1.000	1.000	1.000	1.000
Tenerife South	1.000	1.451	2.252	1.567	0.638
Valencia	1.489	1.000	1.277	1.255	0.797
Valladolid	1.001	1.000	83.389	28.463	0.035
Vigo	1.000	1.127	7.180	3.102	0.322
Vitoria	1.000	1.000	1.000	1.000	1.000
Weighted average	*1.017*	*1.036*	*1.306*	*1.120*	*0.893*

technically inefficient airports, have Increasing Returns to Scale. This means that they may increase their scale efficiency if they increase their size, thus increasing both their infrastructure and their outputs. In particular, the smallest airports (except Córdoba) have very low scale efficiencies. The interpretation of these results can have different policy implications with respect to new airport infrastructure investments.

Table 7 Efficiency scores, scale efficiency and RTS

Airport	RMOTE	CRS eff. score	Scale efficiency	NIRS eff. score	RTS
A Coruña	0.748	0.210	0.281	0.210	Increasing
Albacete	1.000	0.051	0.051	0.051	Increasing
Alicante	**1.000**	**1.000**	**1.000**	**1.000**	**Constant**
Almeria	0.005	0.005	0.937	0.005	Increasing
Asturias	0.104	0.061	0.588	0.061	Increasing
Badajoz	1.000	0.431	0.431	0.431	Increasing
Barcelona	**1.000**	**1.000**	**1.000**	**1.000**	**Constant**
Bilbao	0.350	0.341	0.976	0.341	Increasing
Cordoba	**1.000**	**1.000**	**1.000**	**1.000**	**Constant**
El Hierro	1.000	0.101	0.101	0.101	Increasing
Fuerteventura	0.338	0.324	0.957	0.324	Increasing
Girona-Costa Brava	**1.000**	**1.000**	**1.000**	**1.000**	**Constant**
Gran Canaria	**1.000**	**1.000**	**1.000**	**1.000**	**Constant**
Granada-Jaen	1.000	0.027	0.027	0.027	Increasing
Ibiza	0.450	0.384	0.853	0.384	Increasing
Jerez	**1.000**	**1.000**	**1.000**	**1.000**	**Constant**
La Gomera	0.051	0.003	0.055	0.003	Increasing
La Palma	1.000	0.474	0.474	0.474	Increasing
Lanzarote	0.653	0.506	0.775	0.506	Increasing
Leon	1.000	0.330	0.330	0.330	Increasing
Logroño	0.250	0.091	0.364	0.091	Increasing
Madrid Barajas	**1.000**	**1.000**	**1.000**	**1.000**	**Constant**
Malaga	**1.000**	**1.000**	**1.000**	**1.000**	**Constant**
Melilla	1.000	0.186	0.186	0.186	Increasing
Menorca	0.435	0.352	0.808	0.352	Increasing
Murcia	**1.000**	**1.000**	**1.000**	**1.000**	**Constant**
Palma de Mallorca	**1.000**	**1.000**	**1.000**	**1.000**	**Constant**
Pamplona	1.000	0.027	0.027	0.027	Increasing
Reus	**1.000**	**1.000**	**1.000**	**1.000**	**Constant**
Salamanca	0.185	0.067	0.364	0.067	Increasing
San Sebastian	0.272	0.103	0.378	0.103	Increasing
Santander	0.001	0.001	0.757	0.001	Increasing
Santiago	0.265	0.257	0.968	0.257	Increasing
Saragossa	0.647	0.560	0.866	0.560	Increasing
Seville	0.834	0.813	0.975	0.813	Increasing
Tenerife North	**1.000**	**1.000**	**1.000**	**1.000**	**Constant**
Tenerife South	0.638	0.521	0.817	0.521	Increasing
Valencia	0.797	0.620	0.778	0.620	Increasing
Valladolid	0.035	0.032	0.906	0.032	Increasing
Vigo	0.322	0.250	0.777	0.250	Increasing
Vitoria	**1.000**	**1.000**	**1.000**	**1.000**	**Constant**

4 The proposed target-setting DEA model

Although the above DEA model is useful to derive technical, global and scale efficiency scores as well as to assess RTS, in this section we propose an original DEA model for airports output target setting to be used for the scenario analysis. This type of model is rather innovative since it uses the non-parametric production technology estimated by DEA to compute target operating points lying on the efficient frontier and satisfying certain given conditions. A similar approach has been proposed in Lozano and Gutiérrez (2008) to estimate the maximum Gross Domestic Product of a country as a function of Population, Energy Intensity and Carbon Intensity. The reason why such a type of model is rare is the difficulty of formulating them due to the multidimensional character of the inputs and outputs. In the present application, this problem has been solved through two commonly used parameters that allow relating two of the three outputs with the third. The two parameters are called Plane Load Factor (PLF) and Passenger/Cargo Ratio (PCR). PLF (measured in passengers/operation) is the ratio of APM to ATM while PCR (measured in thousand passengers/tonne or, equivalently, in passenger/kg) is the ratio of APM to Cargo. Let $TAPM_0$ be the target APM value for given airport 0. The target values for ATM and Cargo can be expressed as $TATM_0=TAPM_0/PLF$ and $TCargo_0=TAPM_0/PCR$ respectively.

The proposed DEA model, therefore, computes the maximum feasible value for the APM output given the input values and the values of the two parameters PLF and PCR. In this way, an efficient output target is determined for the given inputs. Mathematically, the model can be formulated as

Target setting model

$$
\begin{aligned}
& Max \quad TAPM_0 \\
& s.t. \\
& \sum_{j=1}^{N} \lambda_j RUNAREA_j \leq RUNAREA_0 \\
& \sum_{j=1}^{N} \lambda_j APRON \leq APRON_0 \\
& \sum_{j=1}^{N} \lambda_j CAPAX_j \leq CAPAX_0 \\
& \sum_{j=1}^{N} \lambda_j BAGB_j \leq BAGB_0 \\
& \sum_{j=1}^{N} \lambda_j CHECKIN_j \leq CHECKIN_0 \\
& \sum_{j=1}^{N} \lambda_j BOARDG_j \leq BOARDG_0 \\
& \sum_{j=1}^{N} \lambda_j APM_j \geq TAPM_0 \\
& \sum_{j=1}^{N} \lambda_j ATM_j = \frac{1}{PLF} \, TAPM_0 \\
& \sum_{j=1}^{N} \lambda_j Cargo_j = \frac{1}{PCR} \, TAPM_0 \\
& \sum_{j=1}^{N} \lambda_j = 1 \\
& \lambda_j \geq 0 \, \forall j \quad TAPM_0 \geq 0
\end{aligned}
$$

This simple LP model has only 10 constraints and N+1 variables. The constraints define a convex linear combination of observed data so that this linear combination corresponds to a feasible operating point that represents the maximum APM value that can be attained given the infrastructure of airport 0 and the values of the two parameters, PLF and PCR.

In order to illustrate the working of the model we will show its application to the Seville airport. Table 8 shows the existing infrastructure of the Seville airport as well as its observed outputs and associated PLF and PCR.

Table 9 shows the results of the proposed target setting model for different combinations of PLF and PCR. Note that, for a fixed value of PCR, both TAPM and TCargo increase as PLF increases while TATM decreases. This means that, for fixed PCR, as PLF (the number of passengers per flight) increases, more passengers and cargo may be transported with a smaller number of aircrafts. Similarly, for a fixed value of PLF, both TAPM and TATM increase as PCR increases while TCargo decreases, i.e. a larger Plane/Cargo Ratio means more passengers, more flights and less cargo. Not only are these effects interesting to learn, but, more importantly, the model allows its quantification for different possible combinations of the values of the parameters. Note that the interplay and trade-offs among the three outputs along the efficient frontier are complex and not easy to ascertain a priori. That is why the proposed approach is an useful tool to determine efficient targets. Thus, for example, for PLF=75 and PCR=0.35 the target APM should be 4,350,000 passengers (approx. 500,000 more than in 2006), the target ATM should be 58.002,000 operations (which is close to the ATM value for 2006) and the target Cargo should be 12,429 tonnes (900 tonnes more than in 2006).

The proposed target-setting model is not only able to calculate efficient output targets for different parameter values using the current infrastructure but also allows for analysing future scenarios, thus giving estimations of the outputs that might be achieved if the current infrastructure is expanded. In this way, Table 10 shows the output targets corresponding to five scenarios in which the airport infrastructure increases gradually (except the total runway area which is kept constant for the first four scenarios and is increased in the fifth by an amount corresponding to going from one to two runways). PLF and PCR have been kept constant at 75 and 0.35 respectively.

Note that, as expected, all three outputs increase as the infrastructure is expanded with the biggest leap occurring if a second runway is built. Again, it can be expected for something like this to happen. The usefulness of the proposed model derives from its ability to quantify the resulting efficient output targets and the ease with which different

Table 8 Inputs, outputs and ratios of Seville airport

Inputs					
RUNAREA	**APRON**	**CAPAX**	**BAGB**	**CHECKIN**	**BOARDG**
15,1200 square metres	23 Stands	3,250 passengers/ hour	6 baggage belts	42 check-in counters	10 boarding gates

Outputs			Ratios	
APM	**ATM**	**Cargo**	**PLF**	**PCR**
3,870.600 thousand passengers	58.565 thousand operations	11,530.23 tonnes	66.091 passengers/ operation	0.336 passengers/kg

scenarios can be evaluated. The results shown in this section are just an example of the multiple experiments that can be carried out with the proposed model.

5 Summary and conclusions

In this paper the technical efficiency of airports in the exploitation of their physical infrastructure is assessed using an output-oriented DEA approach. A novelty of the efficiency analysis carried out is the use of a non-radial efficiency measure, which allows for exhausting all possible output increases.

The results for 2006 show that half of the Spanish airports are technical efficient and half of them, in turn, operate at their MPSS. The rest of the airports operate at Increasing RTS, with very low scale efficiency in some cases. This can have different interpretations. One is that, instead of investing in more airport infrastructure in the larger airports, which in a few cases may already be reaching congestion, it might make sense from an efficiency point of view to make investments into small and medium size airports with growth potential. Another interpretation, kindly suggested by a reviewer, is that the low scale efficiencies of some airports suggest that there is some room for rationalising the number of existing airports. In any case, AENA seems to be planning opening its ownership to the Spanish Regional Governments, some of which (Madrid is clearly an exception) may be interested in promoting second-tier airports. This trend may also appeal to low-cost airlines, which would logically be interested in distributing the flow of passengers more evenly and to less costly airports.

Also, from the scale efficiency results, the fact that no airport seems to have reached an operating point in which Decreasing Returns to Scale prevail suggests that there are certain self-regulation mechanisms in place that preclude airports from achieving an oversize scale. Some of these mechanisms are the increase in the fees charged by airports and the delays due to congested airspace. Beyond certain thresholds, these mechanisms should bring about a slowdown of output growth.

With respect to the low technical efficiency scores of some airports, they are mainly related to Cargo handled, while, in general, the increase potential of APM and ATM is modest. Thus, the computed weighted average increase potential of the whole Spanish airport system is 1.7% for total APM, 3.6% for total ATM and 30.6% for total Cargo, i.e. only for Cargo there is substantial room for system-wide output improvement. The overall system-wide efficiency is slightly below 90%, which is not as high as it seems given that this score results from assessing a sample of only Spanish airports.

In addition to the efficiency analysis study, a new DEA target-setting model has been proposed making use of two parameters: the Plane Load Factor and the Ratio of Passenger to Cargo. The working of the model has been illustrated computing output targets corresponding to different combinations of the values of these parameters. In this way the complex interactions among the outputs and these two key parameters can be studied. The proposed target setting model can also be used for estimating output targets for different hypothetical input scenarios. Thus, for the specific airport used for illustration, it has been shown how much would all three

Table 9 Target outputs of Seville airport for different PLF and PCR combinations

TAPM	ATM	Cargo	PLF	PCR
3,950	60.763	11,530	65	0.25
4,086	58.372	15,798	70	0.25
4,195	55.933	16,344	75	0.25
4,019	61.836	16,780	65	0.3
4,161	59.439	13,398	70	0.3
4,292	57.221	13,869	75	0.3
4,071	62.626	14,305	65	0.35
4,216	60.225	11,631	70	0.35
4,350	58.002	12,429	75	0.35

outputs increase as the existing infrastructure is expanded, with the biggest leap occurring if a second runway is built. This can help gauge and prioritize new investments in infrastructure.

Given the multidimensional character of the outputs, it is complex to guess a priori the trade-offs among the different outputs along the efficient frontier. The usefulness of the proposed target setting model lies in its ability to arrive at reliable quantitative results and in the built-in efficiency of the targets computed. Add to this the ease with which the results can be obtained just solving an LP model and the proposed approach becomes a rather convenient tool for activity analysis and strategic planning.

As a line for further research, it would be desirable to carry out an international benchmarking of Spanish airports. With a larger, multinational sample, a more complete assessment of the technical efficiency of airports would be possible. Another interesting study would involve the consideration of some undesirable outputs (such as flight delays) in the efficiency analysis. In this way, the negative consequences of the congestion due to increased airport traffic could also be taken into account.

Table 10 Target outputs of Seville airport for five scenarios of infrastructure expansion

	Scenario				
	S1	S2	S3	S4	S5
RUNAREA	151,200	151,200	151,200	151,200	300,000
APRON	25	27	30	32	50
CAPAX	3,600	3,900	4,200	4,500	8,000
BAGB	7	8	9	10	15
CHECKIN	45	48	51	54	100
BOARDG	11	12	13	14	25
TAPM	4,777	5,201	5,578	5,938	10,518
ATM	63.687	69.342	74.380	79.170	140.235
Cargo	13,647	14,859	15,939	16,965	30,050
PLF	75	75	75	75	75
PCR	0.35	0.35	0.35	0.35	0.35

Acknowledgements The authors would like to thank the three anonymous reviewers and the area editor because their constructive comments and suggestions have helped to improve this paper.

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