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Air Transport Performance and Efficiency: MCDA vs. DEA Approaches

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Abstract

The general aim of this work is the development of airports performance and efficiency predictive models using robust but flexible methodologies, and incorporating traditional indicators as well as new constraints. Particularly it shows and compares the efficiency evolution of the same airport along several years, under several constraints, based on two multidimensional tools: Multi Criteria Decision Analysis (MCDA, by Measuring Attractiveness by a Categorical Based Evaluation Technique - MACBETH) and Data Envelopment Analysis (DEA).The results evidence how MACBETH (MCDA) approach seems to be a very promising one when compared with those (DEA based) traditionally in use.

Keywords: Airports; Performance; Efficiency; MCDA; DEA.

1. Introduction

The airport business has changed quickly over the last decades since it has been a consistent growing segment inside travel and transportation industries. The annual growth of global aviation industry has sustained rates of five to six percent (Graham, 2003). More than 5 billion passengers passed through the world's airports in 2010 (ACI, 2010). However, due to economic downturn demand for air transport slowed in recent years (Fodness and Murray, 2005). The jet fuel prices and credit crisis has also a negative impact on consumers and consequently in the number of air travelers. However, new business models adopted by airlines allowed some growth return in the last years, as the case of low-cost carriers (LCC), being a major proportion of the business volume generated by

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airports. Off course, mostly this is a political decision and local governments to "attract" the LCC, especially in small airports, strongly subsidize for example the landing fees.

Airports have become not only nodes of new intermodal transport systems for people and goods, but also new cities, in a worldwide scale competition (Marques and Galves, 2009). Another important issue, as presented by (Oum et al., 2003) is the worldwide liberalization of the airline industry. It has increased the demand for more efficient and faster processing of aircraft, passengers, cargo and baggage. Airport managers are being confronted with new challenges every day in an era of growing commercial pressures. Thus, it is important for airports to provide services in the most efficient ways. This work shows the efficiency evaluation of three airport along several years based on two multidimensional tools: Multi Criteria Decision Analysis (MCDA, particularly Measuring Attractiveness by a Categorical Based Evaluation Technique - MACBETH) and Data Envelopment Analysis (DEA): Furthermore it compares the obtained results evidencing the pros and cons of each tool, searching for the best conditions to apply one or other within airport management decision processes.

2. Scope and purpose

The last years revealed a growing interest in measuring the economic and operational performance of airports with benchmarking studies inside and outside the airport sector. Airport managers have facing increasingly requests from government agencies which have sought airport benchmarking as an aid to form or adjust regulations, and to create legislation (Morrison, 2009).

ACI (2006) describes benchmarking as an important part of an airport's strategic planning process. It is a statistical and accounting process that is used to monitor and compare airport economic, operational and service performance. The airport's strategic objectives are assessed in order to measure the performance of its functions, and the best practices for possible incorporation into the organization's procedures are identified, to increase efficiency, quality and customer satisfaction.

2.1. Description and Interest

International airports are complex and dynamic organizations providing a challenge in establishing an appropriate performance measure system. There are many interacting issues that make complex the development of performance measure systems (airlines, passengers, handling agents, etc.); therefore it is a critical management activity. The optimization of operational performance is becoming increasingly important to all stakeholders along the air transport infrastructure. They can be airports or air navigation service providers desiring to improve their performance in order with strategic business objectives, whilst their customers wish to be assured that services are being delivered in an efficient and effective way to meet their requirements (Humphreys and Francis, 2002).

2.2. Methodologies to Evaluate Airport Performance and Efficiency

There are two main research lines on airport performance: the productivity evaluation approach and the efficiency evaluation approach; the difference lies in a concept of maximum attainable outputs. Whereas productivity considers actual infrastructure outputs, efficiency does not take into account the maximum potential output which can be produced with the available inputs. The underlying meanings of these two terms are not identical despite of being often used as synonyms. Also changes in productivity are due to changes in efficiency, among other factors (Lai et al., 2010).

Lay et al. (2010) referred that previous studies often adopted quantitative methods, relying on numerical and secondary data, in order to evaluate efficiency and productivity: using Total Factor Productivity (TFP) method in order to examine the performance of six Australian airports over a 4-year period; analyzing airport quality and performance, from the airline's point of view using DEA; comparing the relative performance of Spanish airports using either a Surface Measure of Overall Performance (SMOP) and a DEA; and applying Stochastic Frontier Analysis (SFA) to a panel data of world's major airports to study the effects of ownership forms on airport's cost efficiency. Methodologies used in several case studies followed MCDA principles (Lay et al., 2010) too.

Following the study of Braz (2011) we developed our work using both a MCDA tool and a DEA approach.

2.3. Efficiency Indicators

Taking into account each airport characteristics and a set of indicators, managers will be in a key position to decide how many or which indicators that an airport in particular should follow; over time the set of indicators of an individual airport will change as new issues arise (ACI, 2012).

Since we used two different approaches in this work, for MCDA we used complex indicators (composed by an output/input structure) and for DEA we used single ones, as shown in Table 1.

Table 1. Single and Complex Indicators

Single indicator (DEA)	
Input	Number of Runways; Aircraft Parking Stands; Passenger Terminal Area; Cargo Terminal Area; Number of Boarding Gates; Number of Check-In Desks; Number of Baggage Carousels
Output	Aircraft Movements, Processed Passengers, Processed Cargo (Ton.)
Complex indicator (MACBETH)	
PAX/PAX TA	Processed Passengers / Passenger Terminal Area
CARGO/CARGO TA	Processed Cargo (ton.) / Cargo Terminal Area
MOVS/STANDS	Aircraft Movements / Number of Aircraft Parking Stands
MOVS/RWS	Aircraft Movements / Number of Runways
PAX/GATES	Number of Processed Passengers / Number of Boarding Gates
PAX/CHK-IN	Number of Processed Passengers / Number of Check-In Desks
PAX/PAX TA	Number of Movements / Number of Boarding Gates
MOVS/BELTS	Number of Movements / Number of Baggage Claim Belts (arrivals)

3. Multicriteria Decision Analysis (MCDA) and Data Envelopment Analysis (DEA)

3.1. Multicriteria Decision Analysis (MCDA)

Multicriteria Decision Analysis (MCDA), or Multi Criteria Decision Making (MCDM), is a decision-making tool aimed to support decision makers who are faced with numerous and conflicting evaluations. It appeared in 1960 in order to highlight these conflicts and deriving a way to compromise in a transparent process. To improve the quality of decisions involving multiple criteria numerous MCDA methods have been developed by making choices more explicit, rational and efficient. The aim is to compare a structured process from different perspectives, identifying objectives and creating alternatives (Marttunen, 2010).

3.1.1. Measuring Attractiveness by a Categorical Based Evaluation Technique (MACBETH)

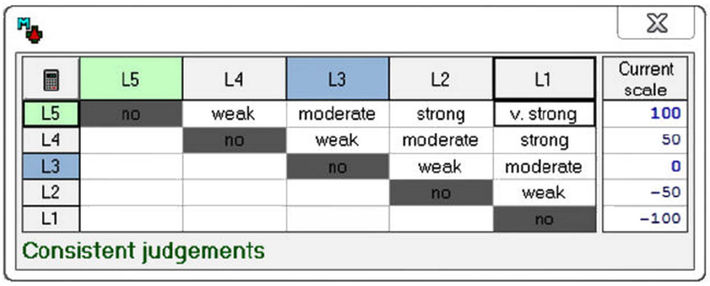
MACBETH, the acronym for Measuring Attractiveness through a Category Based Evaluation Technique, is a decision making evaluation method of options within multiple criteria methodologies. The main distinction between other Multiple Criteria Decision Analysis (MCDA) methods and MACBETH is that it only needs qualitative judgments about the difference of attractiveness between two elements at a time in order to generate numerical scores for the options in each criterion and to weight the criteria. The judgments expressed by the evaluator enter in the M-MACBETH software so their consistency is automatically verified and suggestions are offered to solve inconsistencies if they arise. Thus, MACBETH decision aid process involves the construction of a quantitative evaluation model. A value scale for each criterion and weights for the criteria are constructed from the evaluator's semantic judgments. The options value scores are subsequently aggregated additively to calculate the overall value scores that reflect their attractiveness taking all the criteria into consideration (Gómez et al., 2007).

MACBETH is a Humanistic, an Interactive, and a Constructive tool (Bana e Costa et al., 2003):

- Humanistic: because helps decision makers pondering, communicating, and discussing their value systems and preferences;
- Interactive: as this reflection and learning process can best spread through socio-technical facilitation sustained by straightforward question-answering protocols;
- Constructive: the idea that full-bodied convictions about the kind of decision to make do not (pre-) exist in the mind of the decision maker, nor in the mind of each of the members of a decision advising group, but that it is possible to provide them with help to form such convictions and to build robust (shared) preferences concerning the different possible options to solve the problem.

Before the development of any model, and in order to turn the final result more robust, it is necessary the larger data collection one may obtain about what is going to be studied; this first step led the decision group to have a global view about the decisions to be taken.

After the indicators choice the next step is to get data needed to fill the performance table of each indicator - in our case, each airport data. The next step is to create a decision tree with nodes, that is, a decision model; the nodes correspond to indicators that are going to be taken into account; each decision maker defines the attractiveness of each indicator in the tree as presented in Figure 1 for the MOVS/RWS indicator (just as an example). Macbeth divides the scale of attractiveness between its highest value and 0 in seven verbal values: no difference, very weak, weak, moderate, strong, very strong and extreme, Bana e Costa et al. (2005); after considering the attractiveness of each node the decision makers must define the attractiveness difference between each indicator in the model in order to make them consistent at the end.



	L5	L4	L3	L2	L1	Current scale
L5	no	weak	moderate	strong	v. strong	100
L4		no	weak	moderate	strong	50
L3			no	weak	moderate	0
L2				no	weak	-50
L1					no	-100

Consistent judgements

Fig.1. MACBETH Attractiveness Table (example)

After the introduction of these values for each node it is possible to produce a robustness table still giving the opportunity to the decision maker to adjust the sensibility of the model. Gómez et al. (2007) describe the basics in the mathematical foundations of this tool. As stated by Bana e Costa et al. (2004), MACBETH has a complex formulation.

3.2. Data Envelopment Analysis (DEA)

The mathematical tool called DEA provides analysis of different productivity factors and can help the decision-making of directing the administrative efforts towards the company weakness with the objective of increasing its performance. As stated before there exists other methods available in the literature, but this technique besides it is of common application in such studies has been selected by its objectivity and usefulness for this work.

DEA is a non-parametric method used to measure a firm/infrastructure performance on whatever is produced, in a DEA parlance, by a decision-making unit (DMU), which in our case will be the airports. This analysis was earlier proposed by some authors who described it as a mathematical model that provided a new way of obtaining empirical estimates of external relationships (Martín and Roman, 2006). This was the origin of a based method on a multi-criteria approach used to evaluate the performance of different DMUs depending on the multidimensionality of a variety of inputs and outputs. Since then, numerous DEA applications have been used in different areas, such as education, health care, banking, armed forces, sports, transport areas, agriculture, retail sources and electricity suppliers covering the basic aspects of DEA models, notation, formulation and geometric interpretation (Martín and Roman, 2006). DEA is divided into three basic models: variable returns to scale (VRS), constant returns to scale (CRS), and additive models.

DEA solves a linear programming model for each DMU; for n DMUs n LPPs are solved, with $r+s$ decision variables. The model is the base for all other models developed in DEA (Meza et al., 2003). Thus, the relationship between the goods produced (outputs) and the material spent in its production (inputs) is maximized by defining the weight of each output / input, and taking into account that efficiency of all DMUs, when using the weight assigned to the analyzed DMU, cannot be greater than the unit value. In this study we used the input-oriented CCR model, as stated by Ferreira et al. (2010); the *software* used for this application was the ISYDS v.3.0 software (Integrated Decision Support System v.3.0).

3.2.1. Integrated Decision Support System (ISYDS)

For Meza et al. (2005) a fundamental step for the development of any DEA software is the set-up and choice of the algorithm to solve the LPPs associated with this methodology. The Simplex algorithm is widely used for solving LPPs, and the Interior Points algorithm is mostly used for large scale LPPs (the EMS package uses this algorithm for solving DEA LPPs). ISYDS uses Simplex algorithm for solving the DEA LPPs. ISYDS uses an approach which includes a subroutine to avoid degenerating problems. Degeneration is a common problem in DEA models due to the typical structure of DEA LPPs. Those models present a large number of redundant constraints for the inefficient DMUs and also a large number of variables and restrictions.

The structure of DEA models often leads to multiple optimal solutions in the multipliers formulation and to degenerate problems when the envelopment approach is used. ISYDS uses the multipliers formulation and, in the case of multiple optimal solutions, shows only the first one reached. We used a unique method for solving the LPPs. The format of the LPPs is variable in order to include different DEA models and orientation. Internally the input data must be in the proper format (in a matrix structure as in Figure 2) depending on the used model. Data ordering process in the referred matrix is the most difficult part in the software implementation.

Figure 2 shows a simple data structure, an example from our study cases, in which it’s necessary to indicate: at first the DMU, input and output numbers (6 DMU, 7 INPUT and 3 OUTPUT, respectively); then the input

(RUNWAYS, STANDS, PASSENGER TERMINAL AREA, ATC, CHECK-IN, GATES and BELTS) and output data (PAX, MOVEMENTS and CARGO); and finally values for each DMU (PDL2006, (…), PDL2011).

6	7	3								
DMU	RUNWAYS	STANDS	ATPAX	ATC	CHK-IN	GATES	BELTS	PAX	MOVS	CARGO
PDL 2006	1	9	13637	2200	14	3	3	909609	12165	8593
PDL 2007	1	9	13637	2200	14	3	3	944904	12604	6679
PDL 2008	1	9	13637	2200	14	3	3	925766	12875	6431
PDL 2009	1	9	13637	2200	14	3	3	899266	13449	6245
PDL 2010	1	14	13637	2200	14	3	3	935207	13115	5995
PDL 2011	1	14	13637	2200	14	3	3	933763	12327	5901

Fig.2. ISYDS Entry Data Format (example)

4. Self-Benchmarking Study

An interesting improvement for benchmarking studies is the possibility of both DEA and MACBETH tools to compare efficiency values of a given airport over several years, e.g., a self-benchmarking, in which the airport measures its own performance over time. This feature is particularly interesting when observing the answer given by the airport when there are/were investments in such infrastructure. Thus, this case study performs specifically a self-benchmarking analysis on three Iberian airports where, over the last few years, some expansion works were made. This self-benchmarking analysis uses the annual performance data for each airport separately to compare DEA and MACBETH approaches thus not comparing airports among themselves.

In order to use the MACBETH tool it was necessary to attribute a weight to each indicator; thus, we ask for the opinion of 28 (national and international) aeronautical specialists (from research, airports, airlines, regulation, air traffic control, and industry sectors). The average weights attributed to each of the complex indicators of Table 1 are those of Table 2.

Table 2. Complex Indicators Weights for MACBETH Study Cases

Indicator	**Weight**
MOVS / STANDS	16,61%
MOVS/ RWS	12,78%
PAX / PAX TA	18,01%
CARGO / CARGO TA	12,93%
PAX / CHK-IN	10,93%
PAX / GATES	10,05%
MOVS / GATES	09,56%
MOVS / BELTS	09,09%
	100,0%

4.1. Lisbon Airport (LIS)

Lisbon Airport (IATA code LIS, and ICAO code LPPT) is an international airport located 7 km (4.3 mi) north of Lisbon city centre, the capital of Portugal. The airport is surrounded by urban development, being one of the few airports in Europe located inside a major city. It is operated by ANA – Aeroportos de Portugal. There were several expansion works at the airport during last year's, changing: the Number of Parking Stands (STANDS) due to the construction of new aprons; the Passenger Terminal Area (PAX TA) due to the addition of the Terminal 2, increasing the Number of Check-In Desks (CHK-IN) and the Number of Boarding Gates (GATES) as well as a new pier in Terminal 1; and the Cargo Terminal Area (CARGO TA) since it was rebuilt and expanded. Data for this airport was acquired for the period 2006-2011 (ANA, 2011). The changes in the airport infrastructure were taken into account just from the next year to that they really happened, since there was no monthly division.

MACBETH and DEA tools got the airport efficiency ranking based on a combination of the above mentioned indicators on Table 1, and its related weights on Table2.

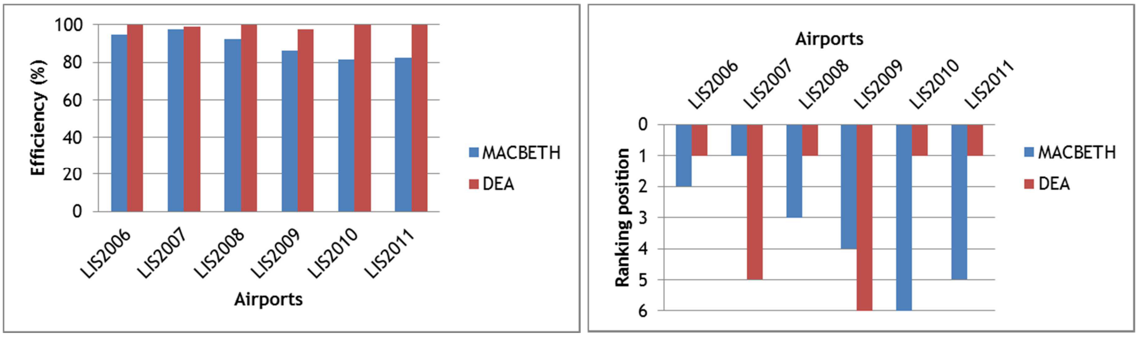


Fig. 3. (a) Comparative Efficiency between MACBETH and DEA for Lisbon Airport ; (b) Balance between MACBETH and DEA Rankings for Lisbon Airport

Figure 3 (a) shows a comparison between MACBETH and DEA efficiency values. As expected DEA values are higher than MACBETH ones. The main differences between both tools are for 2010 and 2011. Based on MACBETH efficiency decreased between 2007 and 2010. It is true that the terminal areas were increased in 2008 and 2010 but the number of produced outputs was not enough to increment the global efficiency. However, in 2011the airport began to achieve better results. Lisbon airport got the best value in both approaches for 2007.

Figure 3 (b) shows a comparison between MACBETH and DEA rankings, that is, a comparison among ranking positions. The main differences are for 2010, probably due to different accuracy of both tools. Curiously there is an opposite phenomenon for 2007 and 2011: see as in 2007 Lisbon got the 1st position based on MACBETH and the 5th on DEA, and as in 2011 these positions were reversed between tools. Lisbon airport got the 1st position for MACBETH on 2007, and for DEA on 2006, 2008, 2010 and 2011. The less efficient years were 2010 for MACBETH and 2009 for DEA.

4.2. Ponta Delgada Airport (PDL)

João Paulo II Airport (IATA code PDL, and ICAO code LPPD) is an international airport located on the island of São Miguel, 2 km (1.2 mi) west of the city centre of Ponta Delgada on the Azores Islands, in Portugal. In terms of traffic, this airport is the busiest in the Azores and is the fourth largest infrastructure managed by ANA - Aeroportos de Portugal. There were several expansion works at the airport during last year's, changing mainly the Number of Parking Stands (STANDS) due to the construction of new aprons. The airport is a hub for the Azorian airline SATA Air Açores and SATA International. Data for this airport was acquired for the period 2006-2011 (ANA, 2011).

MACBETH and DEA tools got the airport efficiency ranking based on a combination of the above mentioned indicators on Table 1, and its related weights on Table2.

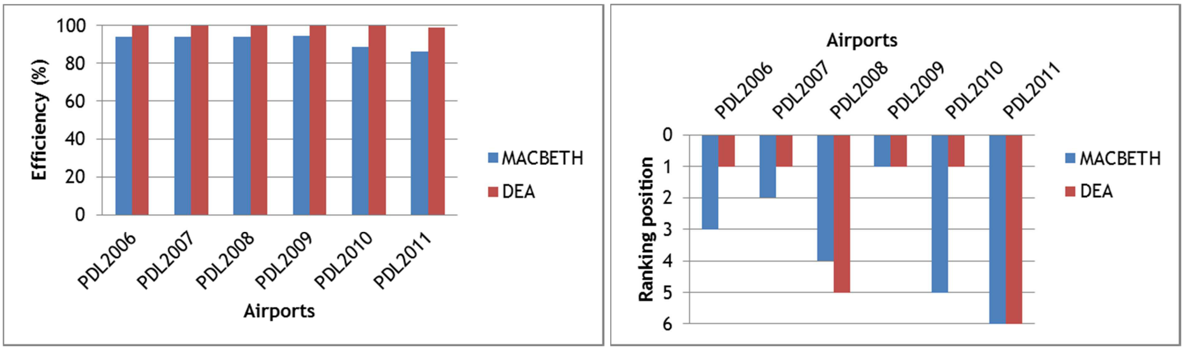


Fig. 4. (a) Comparative Efficiency between MACBETH and DEA for Ponta Delgada Airport; (b) Balance between MACBETH and DEA Rankings for Ponta Delgada Airport

Figure 4 (a) shows a comparison between MACBETH and DEA efficiency values. As expected DEA values are again higher than MACBETH ones. Ponta Delgada airport got the best value in both approaches in the year 2009. The less efficient year was 2011 for both, MACBETH and DEA. Based on MACBETH efficiency decreased slightly between 2010 and 2011. It is true that the numeral of stands increased in 2010 but the number of produced outputs was not enough to increment the global efficiency.

Figure 4 (b) shows a comparison between MACBETH and DEA rankings where the main difference was for 2010, probably due to different accuracy of both tools. Based on both approaches the airport got the 1st position in 2009, and the 6th (and worst) position in 2011.

4.3. Barcelona Airport (BCN)

Barcelona - El Prat Airport (IATA code BCN, and ICAO code LEBL), is an international airport located 12 km (7.5 mi) southwest of the city centre of Barcelona, Catalonia, Spain. It is operated by *AENA Aeropuertos*, being and important hub in this region. Data for this airport was acquired for the period 2006-2011 (AENA, 2011). There were several expansion works at the airport during last year's due to the construction of the new Terminal 1. MACBETH and DEA tools get the airport efficiency ranking based on a combination of the above mentioned indicators on Table 1, and its related weights on Table2.

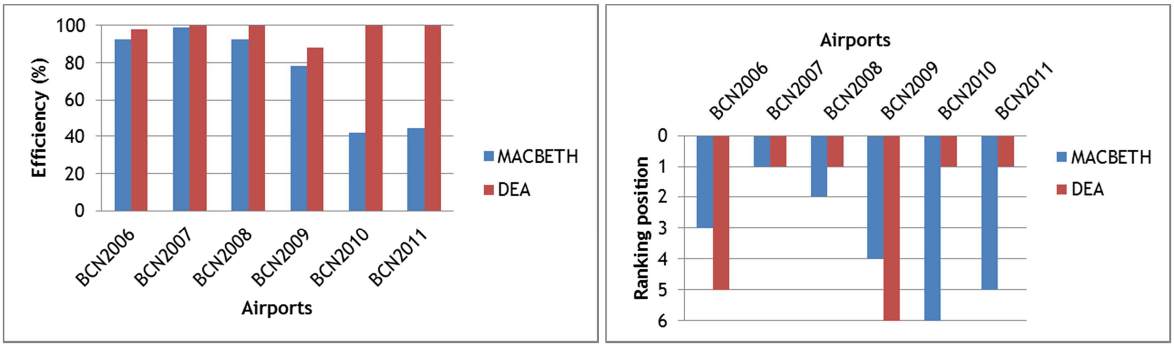


Fig.5. (a) Comparative Efficiency between MACBETH and DEA for Barcelona Airport; (b) Balance between MACBETH and DEA Rankings for Barcelona Airport

Figure 5 (a) shows a comparison between MACBETH and DEA efficiency values. Once again DEA values are again higher than MACBETH ones. Barcelona airport got the best position in both approaches for 2007; based on MACBETH the less efficient year was 2010, and on DEA was 2009. The major differences in both approaches are for 2010 and 2011. Based on MACBETH efficiency decreased between 2007 and 2010. It is true that there was the construction of the new Terminal 1, but surely the produced outputs were not enough to sustain the global efficiency.

Figure 5 (b) shows a comparison between MACBETH and DEA rankings where the main differences were for 2010 (1st on DEA and 6th on MACBETH) and 2011 (1st on DEA and 5th on MACBRTH) probably due to different accuracy between tools. The airport got the 1st position based on both approaches in 2007, and the less efficient years were 2010 for MACBETH and 2009 for DEA.

5. Discussion and conclusion

The general aim of this work is the development of airports performance and efficiency predictive models using robust but flexible methodologies, and incorporating traditional indicators as well as new constraints. As mentioned, airports are complex infrastructures, located in the middle of a chain of agents, and to promote the performance of an airport itself also it is necessary to promote that chain as a whole. To achieve such a goal it is necessary to understand the added value of the airports in particular too, so the choice of the indicators (simple or complex) to construct the rankings to benchmark the infrastructure must be very accurate. There are several sets of indicators as well as several benchmarking techniques; however, airport stakeholders need simultaneously robust and flexible tools, mainly because air transportation acts inside an interactive and iterative world where changes are sudden and quick.

Our study cases were based on three Iberian airports, two in Portugal (Lisbon and Ponta Delgada) and one in Spain (Barcelona). All the infrastructures were submitted to several improvements during the recent past. We chose a set of indicators to perform a self-benchmarking analysis between 2006 and 2011. We used, and compared, the results of two multidimensional tools: a MCDA/MACBETH one and DEA. The preliminary results evidenced how MACBETH approach seems to be a very promising one when compared with those (DEA based) traditionally in use. Mainly because not only MACBETH seems to be more accurate than DEA but also it can be applied easily in managerial practice involving in the process the stakeholders.

However, improvements / developments must be done in this area mainly those focused in the following items:

- To search for the most significant sets of indicators to airports managers, to evaluate emerging situations and/or sudden natural phenomenon that can (also and really) affect the infrastructures performance;

- To search for the best robust and flexible multidimensional tools, that can be used by airport managers in an user-friendly way;
- To improve the self-benchmarking process, which seemed to deserve a special interest from the majority of our specialist and all the stakeholders contacted along the work;
- To extend the evaluation of airports performance to economic and hinterland components too, as the airport itself is only one more element in an integrated chain of multi-actors that needs to be promoted as a whole.

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