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Airports Efficiency Evaluation Based on MCDA and DEA Multidimensional Tools

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Dedicatory

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Abstract

Airport benchmarking depends on airport operational performance and efficiency indicators, which are important issues for business, operational management, regulatory agencies, airlines and passengers. There are several sets of single and complex indicators to evaluate airports efficiency as well as several techniques to benchmark such infrastructures.

The general aim of this work is the development of airport performance and efficiency predictive models using robust but flexible methodologies and incorporating simultaneously traditional indicators (number of movements and passengers, tons of cargo, number of runways and stands, area of terminals both of passenger and cargo) as well as new constraints as emerging situations and/or sudden natural phenomenon (ramp accidents and incidents, and volcano ashes and weather constraints, respectively).

Firstly this work shows the efficiency evaluation of either a set of airports or the same airport along several years and under several constraints based on two multidimensional tools, Multicriteria Decision Analysis (MCDA, particularly through Measuring Attractiveness by a Categorical Based Evaluation Technique - MACBETH) and Data Envelopment Analysis (DEA). Secondly this work compares the obtained results using both MACBETH and DEA evidencing pros and cons of each multidimensional tool and searching for the best conditions to apply one or the other within airport management decision processes.

Keywords: Airports, Efficiency, MCDA, DEA

Resumo

O *benchmarking* de aeroportos depende de indicadores de desempenho e de eficiência operacionais que são ferramentas importantes para o negócio, a gestão operacional, as agências reguladoras, as empresas aéreas e os passageiros. Há vários conjuntos de indicadores simples e complexos para avaliar a eficiência dos aeroportos, bem como várias técnicas para efetuar o *benchmark* de tais infraestruturas.

O objetivo geral deste trabalho é o desenvolvimento de modelos preditivos de desempenho e eficiência aeroportuária, utilizando metodologias robustas mas flexíveis, e incorporando simultaneamente indicadores tradicionais (número de movimentos e de passageiros, toneladas de carga transportada, número de pistas e posições de estacionamento de aeronaves, área de terminais tanto de passageiros como de carga), bem como novas restrições como, por exemplo, situações emergentes e/ou fenómenos naturais súbitos (acidentes e incidentes de placa, e cinzas vulcânicas e restrições meteorológicas, respetivamente).

Em primeiro lugar este trabalho mostra a evolução da eficiência tanto de um conjunto de aeroportos como do mesmo aeroporto ao longo de vários anos e sob vários constrangimentos, com base em duas ferramentas multidimensionais, a Análise Multicritério de Apoio à Decisão (MCDA, particularmente através do MACBETH - *Measuring Attractiveness by a Categorical Based Evaluation Technique*) e o DEA - *Data Envelopment Analysis*. Em segundo lugar este trabalho compara os resultados obtidos usando ambas, MACBETH (MCDA) e DEA, colocando em evidência os prós e os contras de cada uma das ferramentas multidimensionais e procurando estabelecer as melhores condições para incorporar uma ou outra nos processos de decisão da gestão aeroportuária.

Palavras Chave: Aeroportos, Eficiência, MCDA, DEA

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List of Acronyms

AFTK - Available Freight Tonne Kilometers: the measure of a flight's freight carrying capacity. Calculated by multiplying the number of tonnes of freight on an aircraft by the distance travelled in kilometers. Used to measure an airline's capacity to transport freight

AHP - Analytic Hierarchy Process

Apron - Airport Ramp

ASK - Available Seat Kilometers: the measure of a flight's passenger carrying capacity. Calculated by multiplying the number of seats on an aircraft by the distance travelled in kilometers. Used to measure an airline's capacity to transport passengers

ATM – Air Traffic Management

BCC - Banker, Charnes and Cooper

CCR - Charnes, Cooper and Rhodes

CRS - Constant Return to Scale

DEA – Data Envelopment Analysis

DEAP - Data Envelopment Analysis (Computer) Program

DMU - Decision Making Unit

ELECTRE - Elimination and Choice Expressing Reality

EMS - Efficiency Measurement System

EU – European Union

FDH - Free Disposal Hull

IATA - International Air Transport Association

IDEAL - Interactive Data Envelopment Analysis Laboratory

ISYDS - Integrated Decision Support System

km - kilometers

LPP - Linear Programming Problem

m^2 - square meters

MACBETH - Measuring Attractiveness by a Categorical Based Evaluation Technique

MARS - Multiple Aircraft Ramp System

MAUT - Multi-Attribute Utility Theory

MCDA – Multicriteria Decision Analysis

MCDM - Multi Criteria Decision Making

mi - miles

PC - Principle Components

PCA - Principal Component Analysis

PROMETHÉE - Ranking Organization Method for Enrichment of Evaluations

SBM - Slacks-Based Measure

SFA - Stochastic Frontier Analysis

SMOP - Surface Measure of Overall Performance

TFP - Total Factor Productivity

TODIM - Tomada de Decisão Interativa Multicritério (Interactive Multicriteria Decision Making)

Ton - tone

VRS - Variable Return to Scale

IATA code	AIRPORT
ABC	Albacete
ACE	Lanzarote
AEP	Buenos Aires - Aeroparque
AGP	Malaga – Costa del Sol
ALC	Alicante
AMS	Amesterdam - Schipol
ARN	Stockholm - Arlanda
ATH	Athens – Eleftherios Venizelos
ATL	Atlanta
BCN	Barcelona – El Prat
BEG	Belgrade – Nikola Tesla
BIO	Bilbao
BJZ	Badajoz
BRU	Brussels - National
BTS	Bratislava
BUD	Budapest
CDG	Paris Charles de Gaulle
CPH	Copenhagen Kastrup
DUB	Dublin
DXB	Dubai
EAS	San Sebastian
EZE	Buenos Aires - Ezeiza
FAO	Faro
FCO	Roma - Fiumicino
FLW	Flores
FNC	Madeira
FRA	Frankfurt - Main
FUE	Fuerteventura
GIG	Rio de Janeiro - Galeão
GMZ	La Gomera
GRO	Girona
GRU	São Paulo - Guarulhos
GRX	Granada
HEL	Helsinki - Vantaa
HKG	Hong Kong
HOR	Horta
IBZ	Ibiza
JCU	Ceuta Heliport
LCA	Larnaka
LCG	A Coruña
LEI	Almeria
LGW	Gatwick
LHR	London Heathrow
LIS	Lisbon
LJU	Ljubljana
LPA	Gran Canaria
LUX	Luxemburg

IATA code	AIRPORT
MAD	Madrid - Barajas
MAH	Menorca
MAO	Manaus
MLA	Malta - Valeta Luqa
MLN	Melilla
MUC	Munich
MXP	Milan - Malpensa
NGO	Central Japan
NRT	Tóquio - Narita
ODB	Cordoba
OPO	Porto
OTP	Bucarest - Henri Coanda
OVD	Asturias
PDL	Ponta Delgada
PMI	Palma de Mallorca
PNA	Pamplona
PRG	Prague Ruzyne
PXO	Porto Santo
REU	Reus
RIX	Riga
SCQ	Santiago de Compostela
SDR	Santander
SIN	Singapore - Changi
SMA	Santa Maria
SOF	Sofia
SPC	La Palma
SVQ	Seville
SYD	Sydney - Kingsford Smith
TFN	Tenerife Norte - Los Rodeos
TFS	Tenerife Sul - Reina Sofia
TLL	Tallinn
TPA	Tampa
TXL	Berlin - Tegel
VCP	Campinas - Viracopos
VDE	El Hierro
VGO	Vigo
VIE	Vienna Schwechat
VIT	Vitoria
VLC	Valencia
VNO	Vilnius
WAW	Warsaw Chopin
XRY	Jerez de la Frontera
YUL	Montreal - Trudeau
YVR	Vancouver
YYC	Calgary
YYZ	Toronto - Pearson
ZAZ	Zaragoza

Chapter 1 – Introduction

1.1. Motivation

Nowadays the airport business is in rapidly change since have been a consistent growth segment in the travel and transportation industry, over the last several decades. 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 (Airports Council International, 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 have also a negative impact on consumers and consequently in 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, being a major proportion of the business volume generated by the airports.

Figure 1.1 presents the Passenger load and Freight load factors on International markets from 2007 to 2011.

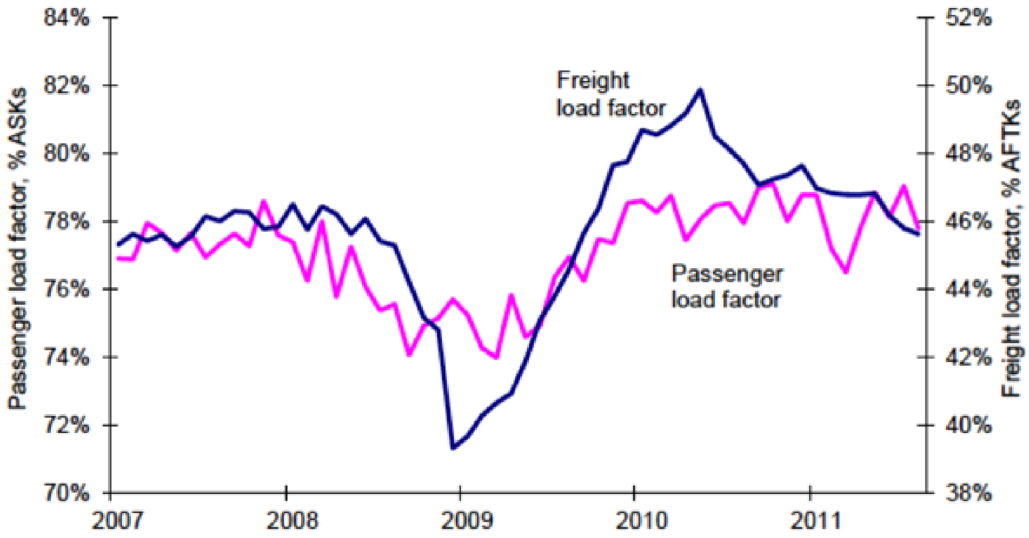

Figure 1.1: Passenger and Freight Load Factors on International Markets from 2007 to 2011 (Centre for Aviation, 2011)

It's possible to see the economic impact on aviation, of the several crisis parameters described before, in which 2009 was the worst year. The Passenger Load Factor decreased below 74% of ASK, while Freight load factor had a decrease to 72% of AFTK. After this decrease in 2008/2009, the same values presented a high increase, but with a tendency to stabilize, now mainly due to the actual economic slowdown in the euro zone and the U.S.A, mainly world business centers, despite Asian market growth.

Over the last few years, challenges that faced airlines and the aviation industry, has forced to rethink how they do business on both at financial and at operational level. In order to face up to these challenges and as a result, most airlines have been remarkably successful at turning around ailing companies, in many cases completely reinventing themselves. Airlines are now in a much stronger position then 2000, due to unprecedented demand for air travel, although high fuel prices are affecting profitability (The Institute of Transport Management, 2012). One of the current situations, in order to minimize negative impacts from markets on airlines, is the creation of alliances or airline groups, allowing a greater flow of air transport network, as well as it extension.

Figure 1.2 presents the three main worldwide airline alliances (Rederer, 2010).

Figure 1.2: The Three Main Worldwide Airline Alliances (Adapted from Rederer, 2010)

Therefore, we are in a different economic era, where aviation, international markets and time-based competition predominate. This new era reveals the introduction of large, high speed jet airplanes, advanced telecommunication technologies, and three aspects of immense significance, namely (Marques and Galves, 2009):

- The business transactions globalization;
- The shift to just-in-time manufacturing and inventory control methods; and, as a result of the first two;
- The growing requirement of industries of all types to ship products quickly by air to distant costumers.

World air cargo traffic had / will have a significant growth between 2000 to 2020, with international air express growing three times faster. Much of the freight will continue to be shipped in the passenger planes, with some Boeing 747’s carrying as much as 35 tons of cargo together with passenger loads and the new Airbus A380-900 much more. As a result of those aspects mentioned above, the role and development of major airports are changing dramatically. To fully leverage airport's new role as multimodal commercial centers, and attracting businesses, planners and developers have been an important and challenging position, since airports are no longer just airports. These platforms have become not only nodes of a new intermodal transport system for both people and goods, but also new cities, in a big worldwide competition (Marques and Galves, 2009).

Another important aspect, as presented by (Oum *et al.*, 2003) is the liberalization of the airline industry worldwide. It has increased the demand for more efficient and faster processing of aircraft, passengers, cargo and baggage. Airlines have freedom of choose where they will base their domestic hubs and which airports they will use to route their connecting traffic, as the continental markets in Europe, North America and Asia become even more competitive. The most efficient airports are chosen by air carriers to allocate and expand operations, so as to improve quality of services and reduce their costs. 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 the services in the most efficient manner. To do this, airports need to know the best practices over airport operations several dimensions within the industry practices.

In the Portuguese case, the aviation sector comprises the airlines and airports together with air navigation and other essential ground services that make up the air transport infrastructure. The sector is divided in two distinct types of activity (Oxford Economics, 2011):

- **Airlines:** transporting passengers and cargo;
- **Ground-based infrastructure:** includes the airport facilities, the services provided for passengers on-site at airports (baggage handling, ticketing and retail) and catering services, together with essential provided services, such as air navigation and air regulation.

The most important airports in Portugal – Lisbon (LIS), Faro (FAO), Porto (OPO), Madeira (FNC), Porto Santo (PXO), Ponta Delgada (PDL), Santa Maria (SMA), Horta (HOR) and Flores (FLW) - carried in 2011 over than 30 million passengers, more than 280,000 aircraft movements and nearly 144,000 tonnes of air freight too, from and within Portugal (ANA/ANAM, 2011).

Figure 1.3 presents the Regional distribution of scheduled passenger trips originated in Portugal.

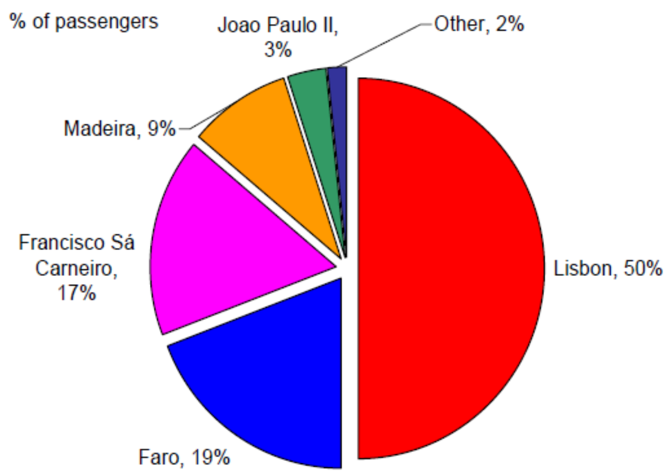

Figure 1.3: The Regional Distribution of Scheduled Passenger Trips Originated in Portugal (Oxford Economics, 2011)

As showed, Lisbon is Portugal's main hub airport. In summary, Lisbon airport situation is described in five main points (INAC, 2010):

1. The number of passengers increased 2.5 times in twenty years, an average annual growth rate of 5%;
2. The traffic volume increase is not reflected in new routes, but dispersed among a larger number of existing ones operated by scheduled flights;
3. The traffic volume increase is not reflected in new carriers, maintaining highly concentrated for both types of traffic;
4. Fourteen of the fifteen main routes operated in 2009 had as origin or destination an European city, and decreased the relevance of domestic routes in total traffic;
5. The non-scheduled traffic tends to be less representative and consists in a greater number of punctual operations of small dimension.

Thus, Portuguese airports are inside an increasing worldwide competition, so there is still space for improvement in efficiency and organization of such airports and airspace management. It is in the field of efficiency and organization of airports that this dissertation is based on applying the method of benchmarking to compare not only Portuguese airports but worldwide ones, and identifying the best practices to evaluate which are the most efficient.

With the increase of market competition, an evolution of management theories and approaches was needed. In this globally competitive environment, the airport sector recognizes the value of Benchmarking as a performance and efficiency analysis tool for each airport; thus it became a powerful tool for supporting and identifying these new approaches, in order to increase the efficiency and continuously monitoring the success of adopted strategies (ACI, 2006).

1.2. Object and Objectives

The main object of this work is the development of airport performance and efficiency predictive models using robust but flexible methodologies and incorporating simultaneously traditional indicators (number of movements and passengers, tons of cargo, number of runways and stands, area of terminals both of passenger and cargo) as well as new constraints as emerging situations and/or sudden natural phenomenon (ramp accidents and incidents, and volcano ashes and weather constraints, respectively).

Therefore this work has two specific objectives: the first one to show the efficiency evaluation of either a set of airports or the same airport along several years and under several constraints based on two multidimensional tools, Multicriteria Decision Analysis (MCDA, particularly through Measuring Attractiveness by a Categorical Based Evaluation Technique - MACBETH) and Data Envelopment Analysis (DEA); the second one to compare the obtained results using both MACBETH and DEA evidencing pros and cons of each multidimensional tool and searching for the best conditions to apply one or the other within airport management decision processes.

The airports that will be analyzed in the benchmarking study are (in this sequence) sets of Worldwide, European, Iberian (Portugal and Spain) and Portuguese ones. Also a self-benchmarking analysis will be conducted for some Iberian airports. Also we will incorporate in the self-benchmarking model for one airport in particular some emerging situations and/or sudden natural phenomenon.

Firstly we will take in account some previous MCDA/Macbeth and DEA case studies over which we will apply both methodologies. Secondly we will add to each airport new efficiency indicators and we will evaluate all of them in different scenarios and based on both Macbeth and DEA. Thirdly a comparison will be done between Macbeth and DEA methodologies, practices and results.

1.3. Dissertation Structure

This dissertation is divided into five chapters.

The first chapter is the work Introduction, and presents the motivation, the main object and the specific objectives, and the dissertation structure.

In chapter two a state of the art review concerning airports benchmarking and airports performance and efficiency evaluation is done, including an overview about the related methodologies. Also is described not only the most common efficiency indicators but also some new ones that may be introduce into the traditional models and related to emerging situations (ramp accidents and incidents) and sudden natural phenomenon (volcano ashes and weather constraints).

The third chapter is an analysis of MCDA and DEA multidimensional tools and its importance for our study. We begin with a state of the art review about MCDA and DEA in general, to justify Macbeth and ISYDS option in particular, respectively. Also operational details and well as strengths and limitations of both MCDA/Macbeth and DEA/ISYDS are explained to support our choices.

The chapter 4 describes six case studies: cases I to IV are related to benchmarking studies about (in this sequence) sets of Worldwide, European, Iberian and Portuguese airports; case V is related to a self-benchmarking study involving some Iberian airports; and case VI is related to a self-benchmarking study about Madeira Airport (FNC) which includes in the evaluation process some emerging situations/sudden natural phenomenon constraints.

The fifth chapter is the work conclusions, and presents the dissertation synthesis, a few concluding remarks, and some insights and challenges for future research.

Chapter 2 – Benchmarking and Airport Efficiency Analysis

2.1. Introduction

This chapter describes the state of the art review concerning airports benchmarking and airports performance and efficiency evaluation, including an overview about the related methodologies. Also is described not only the most common efficiency indicators (simple and complex) but also some new ones that may be introduce into the traditional models and related to emerging situations (ramp accidents and incidents) and sudden natural phenomenon (volcano ashes and weather constraints).

2.2. Airport Benchmarking

The last years revealed a growing interest in measuring the economic and operational performance of airports with benchmarking studies, within and externally the airport sector. Airport managers have increasingly facing 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 economic standard by which business performance is measured, comparing productivity and efficiency, evaluating specific processes, policies and strategies to assess overall organizational performance. The reasons for the increasing interest in airport benchmarking are:

- In the last 15 years, airport industry benchmarking has come into acceptance, particularly as many airports moved from direct public sector control to autonomous authorities;
- Driving the need for performance indicators, as aviation industry liberalization, commercialization and globalization have increased airport business, in its complexity and competitiveness;
- Practices to maximize airport service and efficiency have been adopted by many airports in an aggressive business philosophy;
- To improve efficiency, airport operators are using continuous performance benchmarking internally and against other airports to gain insight into their operations.

Several airports no longer see their role as merely providers of infrastructure; they view themselves more and more as an industry which requires a wide range of business, competencies and skills, together with the adoption of effective management and business techniques, including benchmarking. Therefore, airports are now in a much more competitive environment, under great pressure to find out about the performance of their competitors through benchmarking. This situation is due to the increased airline competition, brought by liberalization in the USA and Europe, and a growing number of other airline markets, an increasingly competitive airline industry which is operating in a much more costly environment, particularly after the September 11th 2001 and other recent events, and is keener than ever before to identify any airport, which is being inefficiently managed or which is providing a poor quality of service (Graham, 2005).

For ACI (2006), airport benchmarking is a part of an airport's strategic planning process. It is described as 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. It's a process in which:

- Management and organizational changes are first, and measurement and technology are second;
- Provides a diagnostic tool to check whether all systems are working properly and in alignment;
- Self-benchmarking is an excellent management tool to monitor improvements in performance;
- External benchmarking is an effective way to identify faulty practices, analyzing if they can be eliminated, as well as best practices and if they can be incorporated into an organization;
- Can be a tool to link strategic goals, employee involvement and productivity, looking to create a continuous performance improvement process.

There are two general types of benchmarking: **partial**, assessing and comparing individual processes/functions/services; and, **holistic**, creating a systematic approach for defining and assessing a critical set of processes/functions/services that, when together, indicate the relative performance of the organization as a whole. Within these, there are two predominant forms of benchmarking: **internal**, self-benchmarking within an organization which compares internal performance of processes/functions/services over time (time-series); and **external**, which compares performance across organizations with peers or other industries (cross-sectional) at single point in time and through time (ACI, 2006).

For Ostblom and Karloff (1993) the process of benchmarking of an organization consists in five stages, namely:

- Decision phase, where the indicators that will be submitted to the benchmarking process are chosen;
- Identification phase, which identify the organizations with which they will make the comparative analysis;
- Data collection phase;
- Analysis phase, under which the rankings are produced;
- Action, which applies best practices in order to increase performance and efficiency of the selected organizations.

In this work, a complementary work of Braz (2011), we will follow the first four steps: identifying indicators and organizations for comparison, collecting information and producing the rankings. The fifth stage is a responsibility of each organization involved to achieve and implement the appropriate means to move up inside the rankings.

2.3. Airport Performance and Efficiency Evaluation

2.3.1. Description and Interest

The process of introducing private participation in the management and operation of airports, and the liberalization of competition among airlines, lead to a competition between airports, for connecting traffic (to become hub airports) and to increase their efficiency. This is the reason for the growing interest in measuring the efficiency and performance of airports during the last years (Perelman and Serebrisky, 2010).

International airports are complex and dynamic organizations, providing a challenge in establishing an appropriate performance measure system. There are many interacting parts that make complex the development of performance measure systems (airlines, passengers, handling agents, etc); it is a critical management activity. Airport managers and governments measure airport performance for several reasons: from a financial and an operational perspective, to evaluate investment strategies, to monitor airport activity from a safety perspective and to monitor environmental impact. This management requires information in order to identify areas that are performing well and those where appropriate corrective action needs to take place. The different stakeholders will have several performance information requirements, since the airport costumers in general that will be interested in assessing its performance, to airlines as the key costumers of the airports, acting as an intermediary between the airport and passengers or freight shippers. The optimization of operational performance is becoming increasingly important to the protagonists 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 manner to meet their requirements (Humphreys *and Francis,* 2002).

Also in order to set realistic performance improvement objectives, it is important that economic regulators have a good understanding of the entire airport. The main components of operational performance in airports and air traffic management (ATM) are efficiency, punctuality, operational resilience and environmental impact, being fully connected with the entire passenger experience (Fairbanks, 2009).

Therefore, the use of Benchmarking can give us useful insights, in measuring airport performance and efficiency.

2.3.2. Methodologies to Evaluate Airport Performance and Efficiency

There are two main research types 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 outputs, efficiency does not take the maximum potential output which can be produced with the available inputs, and offer relies on comparing with other firm. The underlying meanings of these two terms are not identical, despite of being often used as synonyms; changes in productivity are due to changes in efficiency, among other factors (Lai *et al.*,2010).

Previous studies often adopted quantitative methods, relying on numerical and secondary data, in order to evaluate efficiency and productivity. For example, Hooper and Hensher (1997)[1] used Total Factor Productivity (TFP) method in order to examine the performance of six Australian airports over a 4-year period. Adler and Berechman (2001)[1] analysed airport quality and performance from the airline's point of view using DEA. Martin and Roman (2006)[1] compared the relative performance of Spanish airports, comparing Surface Measure of Overall Performance (SMOP) and DEA. Oum *et al.* (2008)[1] applied Stochastic Frontier Analysis (SFA) to a panel data of world's major airports, studying the effects of ownership forms on airport's cost efficiency. Another important methodology used in many cases is MCDA. Evaluation methods which have been employed in the airport industry, to evaluate efficiency and productivity can be divided into four major types. Table 1 shows these different types of benchmarking techniques that have been applied by previous studies.

[1] Cited by *Lay et al.* (2010)

Table 1: Airport Performance Evaluation based on Different Methods (Lai *et al.*, 2010)

Methodology		Weakness
Partial Measure	This method uses partial ratio data to carry out performance comparison of target sample in single dimension such as on financial and cost performance of an airport.	This method only focuses on certain fields of airport performance. The evaluation result of this method would not be able to provide a more comprehensive evaluation of an airport's performance.
Multi-Criteria Analysis (MCDA)	One of the widely adopted methods. Traditionally, employing this method can be divided into two main steps: first step is to acquire relative weights, and second step is to rank the options. This method first selects evaluation indicators through expert survey or interview, and then chooses optimal solution bases on those selected indicators.	Because the selection of indicators is based on expert's experience and their own judgment, the result may be affected by subjective factors.
Frontier Analysis: Parametric approach	Stochastic Frontier Analysis (SFA) SFA, sometimes referred to as econometric frontier approach, is one of the main parametric approaches used by researchers to evaluate efficiency.	Although the parametric approaches take into account the effect error, which is not considered in non-parametric approach, the parametric methods still faces challenges on separating random error from efficiency.
Frontier analysis: Non-parametric approach	**Data Envelopment Analysis (DEA)** is a non-parametric approach, which requires no assumptions about the functional form and calculates a maximal performance measure for each airport relative to all other airports.	The key drawback of the technique is that it does not allow for random error in the data, assuming away measurement error and luck as factors affecting outcome, which implies that the measured inefficiency is likely to be overstated.
	Total Factor Productivity (TFP). In economies, TFP is a variable which accounts for effects in total output not caused by inputs. TFP allows for measuring cost efficiency and effectiveness and for distinguishing productivity differences in airport performance. This technique can also be used for investigating the impact of variations of input and output price on an airport's performance.	TFP requires an aggregation of all outputs into a weighted output index and all inputs into a weighted input index using pre-defined weights which can be biased.

A careful analysis had been taken of these different methods to evaluate performance/efficiency of an airport, its features, advantages and disadvantages. We choose to develop our work with a Multicriteria Decision Aid (MCDA) analysis, since it is a complement of a previous study done by Braz (2011) in which it was used, and also the DEA analysis for reasons specified in the next chapter.

2.3.3. Efficiency Indicators

There are many different circumstances related with airport operations, i.e. aviation activities, commercial activities, location constraints, etc., and individual airports need to find different performance indicators in order to be most relevant and useful. For example, larger airports are likely to focus on different indicators than smaller ones; airports with large developable land areas will focus on different indicators than high constrained airports in large urban areas; and privatized airports on different financial performance indicators, than non-profit government-owned airports. Regarding which indicators are most important and each airport characteristics, managers will have a key position to decide which indicators are most important, and how many the airport should track; over time, this set of indicators to an individual airport will change as new issues arise (ACI, 2012).

Thus, when there are a limited amount of correlated indicators to take into account, Benchmarking is a viable tool, being also important to establish previously and carefully the goal of the ranking to be produced. For example, if the goal is concerning the passengers and their satisfaction the number of runways may be out of focus; but if the goal is concerning the airport management, the number of passengers will be one of the key elements. So it is crucial to choose the proper indicators for each stakeholder (Braz *et al*, 2011).

The almost entirely work done till nowadays on the efficiency and performance of airports is described by Liebert and Niemeier (2010). Each one of the 59 reported works use different sets of indicators. The most cited are: number of boarding gates, areas of passenger terminals and cargo, number of runways, and operating costs. The less used are: runway length, terminal area, number of check-in counters, and the number of parking spaces for motor vehicles. Among the most frequently used output indicators are: number of passenger and cargo processing, number of aircraft movements. And the less used are: aeronautical and non-aeronautical revenues, and delays.

There are several works on airport benchmarking, each one using different performance indicators; some of them use single indicators, while others consider complex ones. We used both two different approaches in this work, since for MCDA we used complex indicators (composed by an output/input structure) and for DEA we used single ones. This was necessary taking into account the analysis structure of each program, as explained in the related tool description section. So the indicators can be divided in two major groups, single and complex, as those we used with DEA and MACBETH tools respectively. The indicators included in our analysis, namely inputs and outputs, are shown in Table 2 and in figures 2.1 to 2.10.

Table 2: Single and Complex Indicators

Single indicators	DEA	***Inputs***	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 Natural (Factors) Effects
		Outputs	Aircraft Movements Processed Passengers Processed Cargo (Ton.)
Complex indicators	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
		MOVS/GATES	Number of Movements / Number of Boarding Gates
		MOVS/BELTS	Number of Movements / Number of Baggage Claim Belts (arrivals)
		OP TIME/TOTAL T	Natural (Factors) Effects: Operational Time / (24 h $\times$ 365 days)

Figure 2.1: Runway (ANAM, 2012)

Figure 2.2: Aircraft Parking Stand (ANA, 2012)

Figure 2.3: Passenger Terminal (ANAM, 2012)

Figure 2.4: Cargo Terminal (2.bp.blogspot.com, 2012)

Figure 2.5: Boarding Gates (Jetways) (AENA, 2012)

Figure 2.6: Check-in Desks (ANAM, 2012)

Figure 2.7: Baggage Claim Belts (ANAM, 2012)

Figure 2.8: Processed Passengers (dnoticias.pt, 2012)

Figure 2.9: Aircraft Movements (ANAM, 2012)

Figure 2.10: Processed Cargo (Infraton.blogdevoo.com, 2012)

Passengers, includes the number of passengers who arrives and departs into/from the airport; Aircraft Movements, includes the number of aircraft landing/take-off on/from the airport; and Cargo, includes the number of cargo tons that arrives and departs on/from the airport being domestic or international, freight or mail flights. For the boarding gates, both jetway and remote access gates (by bus) was taken into account; and with aircraft parking stands for the airports providing multiple parking positions (depending on aircraft wingspan or length Multiple Aircraft Ramp System (MARS) system utilizes apron space more efficiently through the configuration, e.g. large and Jumbo sized stands to enable two smaller aircraft to park instead of one larger aircraft), the minimum number was referred when available.

2.3.3.1. Impact of Natural (Factors) Effects on Airports Operational Efficiency

It is well known that aviation presents a high sensitivity to weather, with major impacts on safety, efficiency and capacity of aviation operations. Consequently, the capacity of airports is highly reduced by the need to increase the separation between aircraft, for additional holdings, or by the closure of one or even all runways, affecting its operational performance. Such weather phenomenon, and from a point of view of airport operations, includes thunderstorms, turbulence and gusts, heavy snowfall and runway icing, low visibility by fog, and most recently, volcanic ashes on airspace, due to volcanic eruptions (figures 2.11 to 2.13).

Figure 2.11: Heavy Rain at Cancun Airport (Morales, 2012)

Figure 2.12: Volcanic Ash at San Carlos de Bariloche Airport, in Argentina, after Wind have carried the Ash from Chile's Puyehue Volcano in June 2011 (Redrif.com, 2012)

Figure 2.13: Works on Snow Removal at La Guardia airport, New York City, during December 2010 Snowstorms (CSmonitor.com, 2012)

As a result, the operational capacity of a region's entire airspace is reduced through delays, diversions and cancellations of flights – all of which have severe effects for travelers. An example is presented in figure 2.14 (but see also figure 2.15), which presents the arrivals board of London Heathrow airport terminal 5, in 16th April 2010, when Eyjafjallajökull erupted on Iceland; all flights were canceled or highly delayed (Jardim *et al.*, 2012).

Figure 2.14: Arrivals Board of London Heathrow Airport Terminal 5, in 16th April 2010, due to Iceland Volcano (wikipedia.org, 2012)

Figure 2.15: Affected Passengers at London Heathrow Airport, during December 2010 Snowstorms (easydestination.net, 2012)

An airport has an amount of basic characteristics, which all are considered to well combine with specific weather hazards, such as local weather phenomenon and climacteric conditions, topography of the region, orientation of the runways, etc. Due to climate change, these phenomenon will be more common and with highly impacts, therefore, an individual self-benchmarking study has to be done for each airport in order to investigate its susceptibility to adverse weather, since conclusions found for one airport do not automatically hold for others (Sasse and Hauf, 2003).

2.4. Conclusion

An economic benchmark is a standard by which business performance is measured. It is used in any kind of activity, to compare productivity and efficiency, evaluate specific processes, policies and strategies and to assess overall organizational performance. Complex and dynamic organizations such as international airports provide a challenge in establishing an appropriate performance measure system, in order to improve their roles in an increasingly competitive aeronautical activity.

Really airports are nowadays complex infrastructures located in the middle of a chain of agents and to promote the performance of the airport also is necessary to promote that chain as a whole. To achieve such a goal is necessary to understand the added value of the airport in particular, so the choice of the indicators (simple or complex) to construct the rankings to benchmark the airports must be very accurate. There are several sets of indicators as well as several techniques for benchmarking, but the airport stakeholders needs simultaneously robust and flexible tools, mainly because air transportation acts in a very interactive and iterative world where changes are very quick.

Chapter 3 – Multicriteria Decision Analysis (MCDA) and Data Envelopment Analysis (DEA)

3.1. Introduction

This chapter is an analysis of MCDA and DEA multidimensional tools and its importance for our study. We begin with a state of the art review about MCDA and DEA in general, to justify Macbeth and ISYDS option in particular, respectively. Also operational details and well as strengths and limitations of both MCDA/Macbeth and DEA/ISYDS are explained to support our choices.

3.2. 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).

According to Barrico (1998), cited by Raposo (2008), multi-criteria decisions processes could be described by, for example:

- Choosing the right spot to a bridge construction, where the criteria could be the cost, the environmental impact on the river, the volume of traffic, etc.;
- Find the most economic routes to do the pick-up/delivery of products to the clients of a company, considering aspects such as time, distance, delay, traffic, etc.

There are conflicts between several criteria for each one of the described examples, so the decision maker has to consider the pros and cons of each one to reach the final solution. This is the basis of a multi-criteria decision problem.

The potential benefits of the use of MCDA in planning projects are summarized in figure 3.1.

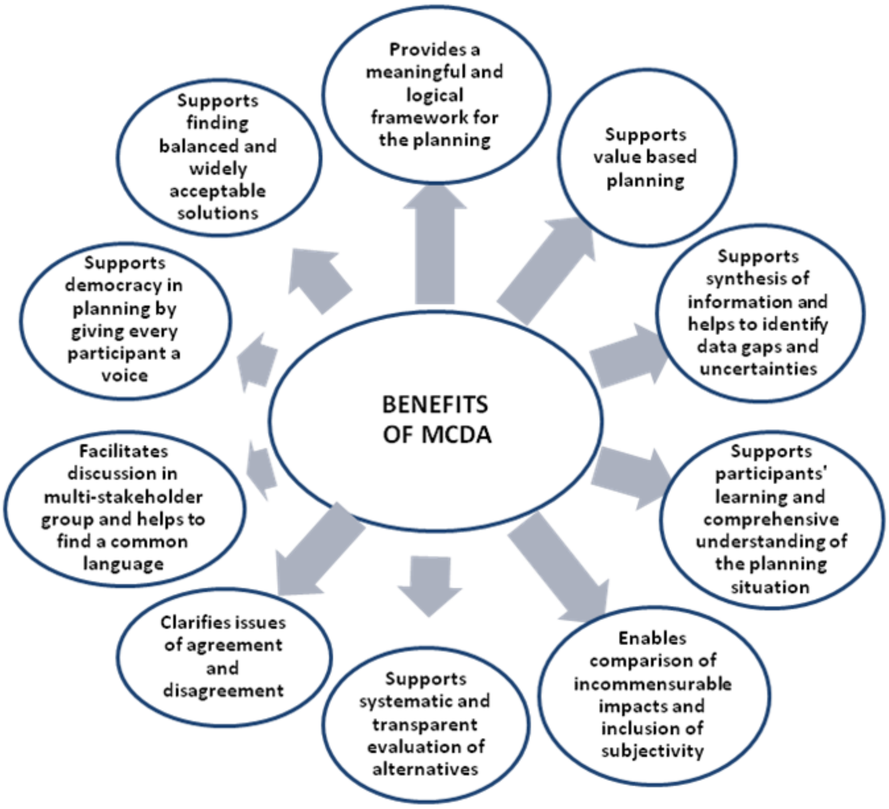

Figure 3.1: Benefits of MCDA (Marttunen, 2010)

According to Gomes *et al.*, cited by Raposo (2008), one may define Multi-Criteria Decision Analysis (MCDA) is a group of techniques which explore several numbers of alternatives together with objectives and multiple criteria in conflict.

From the previous explanation it's easy to understand how important is to all airport stakeholders a MCDA approach supporting a decision making process; and if a significant part of this work is MCDA based it's necessary to choose the related most appropriate tool. However, as mentioned, our work is a complement of Braz (2001) and the author just made this choice after analyze all the available MCDA tools, that is, MAUT, AHP, MACBETH, ELECTRE, TODIM and PROMETHÉE. Finally, Braz (2011) concluded that MACBETH (Measuring Attractiveness by a Categorical Based Evaluation Technique) was the MCDA tool that complied with the requirements needed for such research work. Also, as Bana e Costa *et al.* (2005) underlines this is a user friendly multi-criteria decision analysis approach that requires only qualitative judgments about differences of value to help a decision maker, or a decision-advising group, to quantify the relative attractiveness among several options.

3.2.1. 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, the 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: helps decision makers pondering, communicating, and discussing their value systems and preferences;
- Interactive: 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.

It is worth to mention that the analysis done follow the key stages in a multicriteria decision aiding process, which are usually grouped into three main phases:

- **Structuring:**
  - Criteria: Values of concern and identifying the criteria;
  - Options: To be evaluated as well as their performances.

- **Evaluating:**
    - Scoring: Each option's attractiveness with respect to each criterion;
    - Weighting: Weighting the criteria.

- **Recommending:**
    - Analyzing Results: Overall attractiveness and exploring the model results;
    - Sensitivity Analyses: Sensitivity and robustness of the model's results in light of several types of data uncertainty.

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 data collection, next step is to create a decision tree (decision model), as presented in figure 3.2; in this tree, the nodes correspond to the indicators that are going to be taken into account; so the choice of the nodes are one of the key questions in the development phase. A set of complex indicators had been chosen for this study after consulting some aeronautic specialist and their opinions, because MACBETH does not allow the introduction of INPUTS and OUTPUTS separately as DEA, so it will take into account an OUTPUT/INPUT ratio.

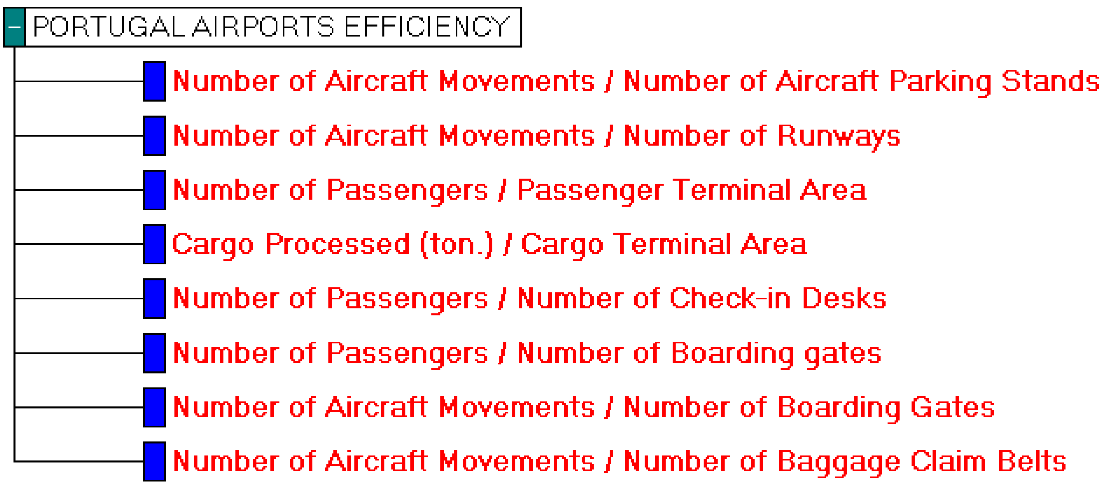

Figure 3.2: Example of a MACBETH Decision Tree

After the indicators choice the next step is to get the data needed to fill the performance table of each indicator, in our case with each airport data as presented in figure 3.3; this is a crucial step even influencing the node choice because only if the data collection fills the performance table for each indicator is possible to use that indicator in the work.

Options	MOVS/STANDS	MOVS/RWS	PAX/PAX TA	CARGO/CARGO TA	PAX/CHK-IN	PAX/GATES	MOVS/GATES	MOVS/BELTS
FAO	1547.55	44879	82.01	0.21	93629.77	133756.81	1068.55	8975.8
FLW	1439	1439	30.29	1.76	15149	45447	1439	1439
FNC	1423.07	21346	51.84	0.68	57784.5	144461.25	1334.13	5336.5
HOR	1550	4650	29.08	2.8	32010.67	96032	2325	4650
LIS	2239.55	71665.5	61.94	5.07	139675.48	302155.12	2925.12	17916.38
PDL	880.5	12327	68.47	2.68	66697.38	311254.33	4109	4109
OPO	1541.18	61647	86.88	1.78	100076.48	240183.56	2465.88	15411.75
PXO	402.29	2816	11.24	1.78	17765.33	21318.4	563.2	2816
SMA	558.83	3353	30.6	20.29	31300.67	46951	1676.5	3353

Figure 3.3: Example of a MACBETH Performance Table

In the next step each decider defines the attractiveness of each indicator in the tree, as presented in figure 3.4 for indicator MOVS/RWS (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; after considering the attractiveness of each node the deciders must define the attractiveness difference between each indicator in the model, in order to make them consistent at the end.

	71665.5	53749.13	35832.76	17916.39	0	Current scale
71665.5	no	very weak	weak	moderate	positive	100
53749.13		no	very weak	weak	moderate	75
35832.76			no	very weak	weak	50
17916.39				no	very weak	25
0					no	0

extreme
v. strong
strong
moderate
weak
very weak
no

Consistent judgements

Figure 3.4: Example of a MACBETH Attractiveness Table

After the introduction of these values for each node it is possible to produce a robustness table still giving the opportunity to the decider to adjust the sensibility of the model.

As presented by Bana e Costa (2004), MACBETH has a complex formulation, and Gómez *et al.* (2007) describe the basics in the mathematical foundations of this tool. Consider X (with $\#X = n \geq 2$) as a finite set of elements (alternatives, choice options, courses of action) that a group or an individual, J, wants to compare their relative attractiveness (desirability, value).

X defines ordinal value scales, which are quantitative representations of preferences, reflecting numerically, the order of attractiveness of the elements of X for J. An ordinal value scale is constructed in a straightforward process; J is able to rank by order of attractiveness the elements of X – either directly or through pair wise comparisons, in order to determine the elements relative attractiveness.

When the ranking is defined, it is necessary to assign a real number v(x) to each element *x* of *X*, in such a way that:

1- v(x) = v(y) if and only if *J* judges equal attractiveness between the elements *x* and *y*;
2- v(x) > v(y) if and only if *J* judges *x* to be more attractive than *y*.

Similarly a value difference scale is defined on *X* as the preferences quantitative representation, in order to be used to reflect, not only the order of attractiveness of the elements of *X* for *J*, but also the differences of their relative attractiveness, *i.e.*, the strength of *J* 's preferences for one element over another. *J* provides preferential information about two elements of *X* at a time, firstly by ordinal judgment (to their relative attractiveness) and secondly, if the two elements are not considered to be equally attractive, by expressing a qualitative judgment about the difference of attractiveness between the most attractive of the two elements and the other.

To ease the judgmental process, six semantic categories of difference of attractiveness are offered to *J* as possible answers: "very weak", "weak", "moderate", "strong", "very strong" or "extreme", or a succession of these (in case hesitation or disagreement arises).

By pair wise comparing the elements of *X*, a matrix of qualitative judgments is filled in, with either only a few pairs of elements, or with all of them (in which case $n \cdot (n - 1)/ 2$ comparisons would be made by *J*).

Thus, before the development of any model it is necessary to obtain the larger amount of data as possible. After such collection, next step is to create a decision tree with nodes, that is, a decision model; those nodes correspond to indicators that are going to be taken into account; so the choice of nodes are one of the key questions in the development phase.

Next step is to get data needed to fill the performance table of each indicator; this is a crucial step even influencing node choice because only if data collection fills the performance table for each indicator it is possible to use that indicator within the work.

Within next step each decider defines the attractiveness of each indicator in the tree; after considering the attractiveness of each node the deciders must define the attractiveness difference between each pair of indicators in the model too. After the introduction of these values for each node it is possible to produce a robustness table still giving the opportunity to the decider to adjust the sensibility of the model (Braz *et al.*, 2011).

3.2.1.1 Weightening Criteria

In order to use the MACBETH analysis, it was necessary to give a weight to each indicator; thus, and in order to make it as real as possible we asked for the opinion of 30 (national and international) aeronautical specialists (from research, airports, airlines, regulation, air traffic control, and industry sectors) about the weights (%) to attribute to those complex indicators, through a survey (Annex). The sum of weights necessarily would be 100.00%. The obtained weight values will be shown later for each case study

3.3. Data Envelopment Analysis (DEA)

The airport efficiency study, which is our aim in this work, needs a deep research. The mathematical tool called DEA provides analysis of different factors of productivity, can help the decision-making of directing the administrative efforts towards the company weakness, with the objective of increasing its performance. As analyzed before, there exists other methods available at 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 (Data Envelopment Analysis) is a non-parametric method used to measure a firm performance on whatever is produced, in DEA parlance, by a decision-making unit (DMU), which in our case will be the airports. This analysis was firstly proposed by Charnes *et al.* (1978)[2], described as a mathematical model that provides a new way of obtaining empirical estimates of external relationships. 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. Charnes *et al.* (1994)[2], Ali and Seiford (1993)[2], Coelli *et al.* (1998)[2] and Cooper *et al.* (2000)[2], are good references to cover the basic aspects of DEA models, DEA notation, formulation and geometric interpretation. DEA is divided into three basic models: variable returns to scale (VRS), constant returns to scale (CRS) and additive models (Martín and Roman, 2006).

Over the years, these basic models have been further developed, resulting in many different DEA models that can be chosen to analyze the efficiency of a group of DMUs. It includes the consideration of non-discretionary variables, non-radial models such as additive form, the estimation of efficiency changes over time, the identification of outliers or introducing statistical inference into DEA. The selection of a particular model is constrained by the

[2] Cited by Martín and Roman (2006)

characteristics of the industry that researchers are analyzing, as presented by (Liebert and Niemeier, 2010) in a critical assessment of important airport benchmarking studies.

Figure 3.5 presents several DEA applications that have been used in airport efficiency studies.

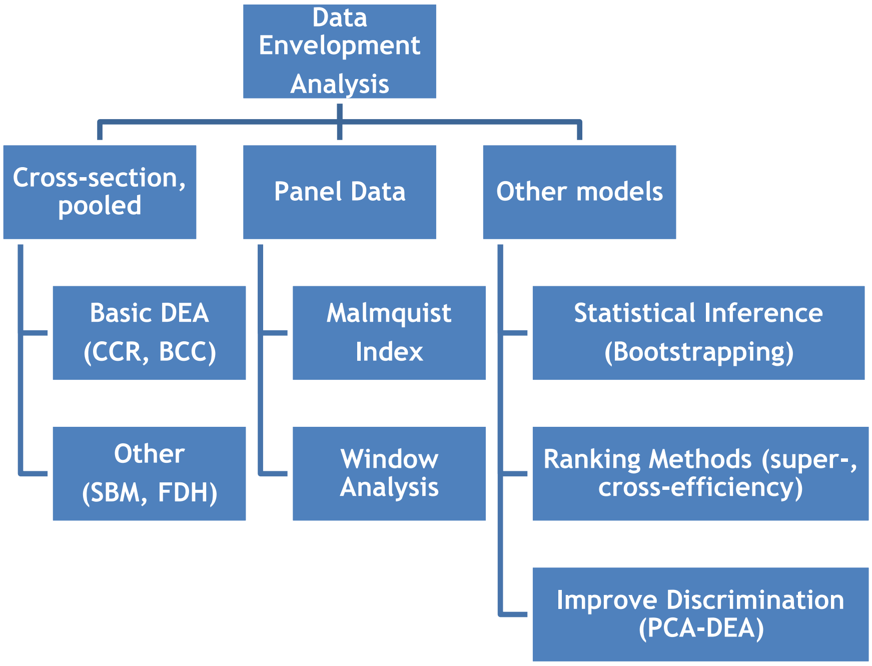

Figure 3.5: The Several DEA Applications that have been used in Airport Efficiency Studies (Liebert and Niemeier, 2010)

As described by Liebert and Niemeier (2010), the majority of studies assumed variable returns to scale with a heterogeneous dataset on the airport size. Some studies, and in order to assess the scale efficiency also applied both scale options, and basic DEA with cross-sectional or pooled data as a sufficient panel structure (often not available). However, the relation between a high number of inputs and outputs and a low number of observations may lead to a large amount of efficient airports.

Andersen and Petersen (1993)[3], to further rank efficient airports, developed the supper-efficiency model where "specialized" DMUs receive excessively high ranking, which can be used to identify outliers and remove them from dataset. The cross-efficiency is an alternative model developed by Sexton *et al.* (1986)[3] and improved by Doyle and Green (1994)[3]. Another approach is (PCA) Principal Component Analysis, combined with DEA, used to replace the original inputs and/or outputs with a smaller group of principle components (PCs). Adler and Berechman (2001)[3] applied this method to reduce five outputs to three PCs which explain

[3] Cited by Liebert and Niemeier (2010)

more than 80% of the variance in the original data over a cross-sectional sample of 26 airports.

The assessment of productivity and efficiency changes over time and depends on the availability of a sufficient panel structure. Malmquist DEA has been applied by e.g. Murillo-Melchor (1999)[4] and Gillen and Lall (2001)[4] on a study including Spanish and US airports. Is not surprising that most studies found positive productivity and efficiency changes over time, since was used traffic volume as outputs and physical data as inputs; the latter having remained fairly constant over time if no capacity expansion took place. Barros and Weber (2009)[4] and Murillo-Melchor (1999)[4], different to the other studies, selected cost information as input which might have increased disproportionately high to the passengers, cargo and air transport movements, finding decreases in TFP over the review period for UK and Spanish airports.

DEA has its limitations of not allowing for hypothesis tests by itself, compared with parametric approaches. A re-sampling technique developed by Efron (1979)[4] and firstly applied to DEA by Simar and Wilson (1998, 2000)[4] was Bootstrapping. It can be used for statistical inference and correct the efficiency wrong tendencies. Assaf (2010)[4] and Barros and Assaf (2009)[4] had recently applied bootstrapping to airport benchmarking studies, but this approach needs to be treated with caution as stated by Simar and Wilson (2000)[4], in which the higher the number of variables to the number of observations the lower the ratios of convergence the bootstrapping provides (Liebert and Niemeier, 2010).

A Slacks-Based Measure (SBM), proposed by Tone (2001)[5], is a non-radial approach and deals with input/output slacks directly (Wang and Huang, 2004). The purpose of this model is to minimize the input and output slacks because while both CCR and the BCC models calculate efficiency scores, neither is able to take into account the resulting amount of slack for inputs and outputs (Schaar and Sherry, 2008).

FDH (Free Disposal Hull), a mathematical programming technique, developed by Deprins, Simar and Tulkens (1984)[6] is other DEA method. Its purpose is to measure and evaluate the performance of a producer, in which it does the measurement of technical efficiency derived from BCC whose condition of convexity (as required by BCC) need not be satisfied (Wilhelm, 2006). Charnes *et al.* (1985)[7] proposed a DEA technique called 'window analysis', in order to capture the variations of efficiency over time. It assesses the performance of a DMU over time by treating it as a different entity in each time period (Talluri, 2000).

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[4] Cited by Liebert and Niemeier (2010)
[5] Cited by Schaar and Sherry (2008)
[6] Cited by Wilhelm (2006)
[7] Cited by Talluri (2000)

As Ferreira *et al.* (2010) explains, DEA allows to evaluate an airport efficiency (DMUs - Decision Making Units in DEA terminology) using the ratio between the real output obtained and the one which could be reached. The measured efficiency shows the distance of each DMU to the efficient frontier, which is formed by DMU (s) which have the greater relation output per input ratio. Efficient firms will serve as a benchmark for the inefficient, as shown in figure 3.6.

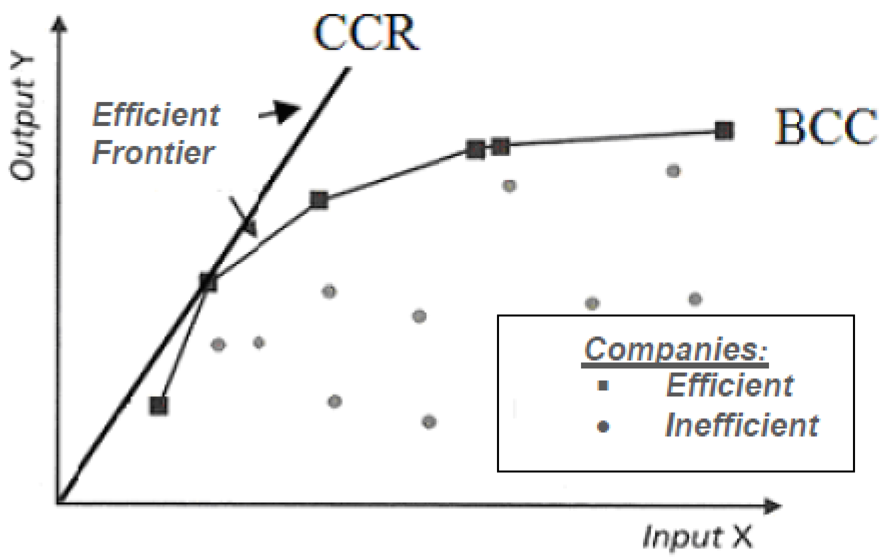

Figure 3.6: Efficient Frontier (Ferreira *et al.*, 2010)

A multicriteria approach is provided by DEA to adequately evaluate the performance of DMUs when several inputs and outputs are being considered. The DEA approach can be focused in inputs minimization (the use of the least amount of resources in order to achieve a particular result) or in the maximization of outputs (the best result achievable by applying a given level of resources). The model entitles the unit as DMU (Decision Making Unit), which are the airports in our study, as mentioned.

As stated DEA has many different models, and the most important ones are probably CCR and BCC. The CCR model assumed its creator's initials (Charnes, Cooper and Rhodes) and it is related to constant returns and the improvement obtained in the output is proportional to that one observed in the inputs. It is also known as CRS (Constant Return to Scale). The BCC (Banker, Charnes and Cooper) model considers that the DMUs have variable returns of scale and there is no proportionality among inputs and outputs. This model is also known as VRS (Variable Return to Scale) and allows the analyses of DMUs of different dimensions, which are subject to different patterns of competition or financial constraints (Meza *et al.*, 2005)

So the purpose of DEA is to measure the efficiency of the decision making unit in the presence of multiple inputs (inputs, production factors or resources) and multiple outputs (outputs or products). The relative efficiency of a DMU is defined as the ratio of the weighted sum of their products (outputs) and the weighted sum of inputs needed to generate them (inputs), as presented in the following mathematical equations.

As Meza *et al.* (2003; 2005) describe, in CCR model mathematical approach, each k_{th} DMU, k = 1, ..., n, is considered to be a production unity that uses r inputs x_{ik}, i = 1, …,r, to produce s outputs y_{jk}, j =1, …, s. The CCR model described by equation (1) maximizes the ratio between the linear combination of outputs and the linear combination of inputs, with the constraint that for each DMU ratio cannot be greater than one, as revealed by equation (2). So, for a particular DMU o, h_o is its efficiency; x_{io} and y_{jo} are its inputs and outputs and v_i and u_j are the calculated weights for the inputs and outputs. After some mathematical manipulations, the model can be rewritten, yielding in a Linear Programming Problem (LPP).

$$\max \ h_o = \frac{\sum_{j=1}^{s} u_j y_{jo}}{\sum_{i=1}^{r} v_i x_{io}} \quad (1)$$

subject to:

$$\frac{\sum_{j=1}^{s} u_j y_{jk}}{\sum_{i=1}^{r} v_i x_{ik}} \leq 1, \quad k = 1,\ldots,n \quad (2)$$

$$u_j, v_i \geq 0 \quad \forall i, j$$

After some mathematical procedures, the model can be rewritten, yielding in a Linear Programming Problem (LPP), as mentioned, and as shown in equations (3) and (4):

$$\max \ h_o = \sum_{j=1}^{s} u_j y_{jo} \quad (3)$$

subject to,

$$\sum_{i=1}^{r} v_i x_{io} = 1$$

$$\sum_{j=1}^{s} u_j y_{jk} - \sum_{i=1}^{r} v_i x_{ik} \leq 0 \ , \quad k = 1,\ldots,n \tag{4}$$

$$u_j, v_i \geq 0 \quad \forall i, j$$

DEA solves a linear programming model for each DMU; for *n* DMUs *n* LPPs are solved, with *r+s* decision variables. The presented 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. So, DEA tool is useful to define benchmark units, in which these references are determined by the projection of the inefficient DMU's on the efficient frontier, as presented before on figure 3.6. The way this projection is made defines the input-output orientation model: the output oriented model (when you want to maximize the results without decreasing its assets) or the input oriented model (when you want to minimize inputs while keeping the values of the output constant).

In this study, we used the input-oriented CCR model, as stated by Ferreira *et al.* (2010), because it would be more feasible to improve and manage the existing resources of the DMU's (at the planning and design stages) than increasing the output: volume of cargo, passenger volumes, etc In most of the cases, the aviation demand is usually independent of airport management control and even federal aviation authorities have a limit on the demand management control. With this approach, airport planners could set the size of the terminals, the number of runways and the apron positions (stands) in order to improve airport efficiency. The results of DEA should be seen as a support technique (among other techniques as well) to determine the DMUs of reference (benchmarks). Moreover, they show a result not exhaustive which does not include other quantitative and qualitative variables that could change the final assessment.

The program used for this method application was the ISYDS v.3.0 software (Integrated Decision Support System v.3.0).

3.3.1. Integrated Decision Support System (ISYDS)

For Meza *et al.* (2005) creators of this tool, 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 use 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 3.7) depending on the used model. The data ordering process in the referred matrix is the most difficult part in the software implementation.

6	7	3								
DMU	RUNWAYS	STANDS	ATPAX	ATC	CHK-IN	GATES	BELTS	PAX	MOVS	CARGO
FNC2006	1	15	44590	7535	40	16	4	2360857	25828	9200
FNC2007	1	15	44590	7535	40	16	4	2418489	21954	6774.6
FNC2008	1	15	44590	7535	40	16	4	2446924	22799	6637.6
FNC2009	1	15	44590	7535	40	16	4	2346649	21955	6228.4
FNC2010	1	15	44590	7535	40	16	4	2233524	22094	6069.5
FNC2011	1	15	44590	7535	40	16	4	2311380	21346	5095

Figure 3.7 – Entry Data Format

Figure 3.7 shows a simple data structure, an example from our study cases, in which it's necessary: first to indicate the DMU, input and output numbers (6 DMU, 7 INPUT and 3 OUTPUT respectively); then the input data (runways, stands, atpax, atc, check-in, gates and belts) and output data (pax, movs and cargo); and finally the values for each DMU (FNC2006,…, FNC2011). This data arrangement must be done in note pad in order to import for ISYDS latter.

3.3.1.1. Software Description

ISYDS was implemented for Windows platform with Delphi 7.0. It is capable of dealing with 150 DMUs, 20 variables (inputs or outputs), and works with a six decimals accuracy. Figure 3.8 displays ISYDS's open window.

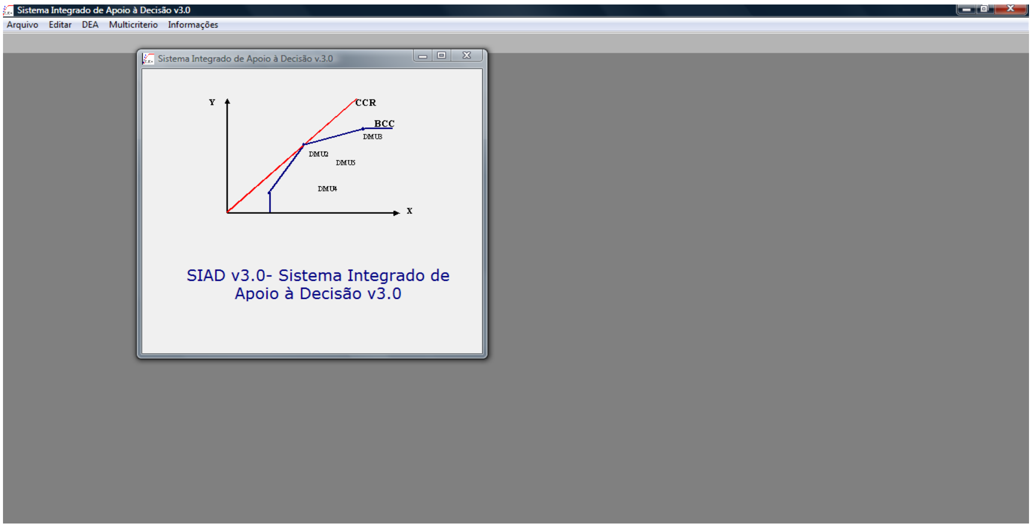

Figure 3.8 - ISYDS's Open Window

Although for other research areas 150 units might be insufficient, for DEA applications this number is able to deal with large-scale situations, once in the literature there are few applications dealing with more than 100 DMUs. As far as the number of variables is concerned, it should be pointed out that in most applications 10 variables are sufficient. In this package, we can choose between the classic models (CCR or BCC) and orientation (input or output). The user can choose only one model and one orientation at a time, and can also change data details, as values and variables names, with the editor toll, as shown in figure 3.9.

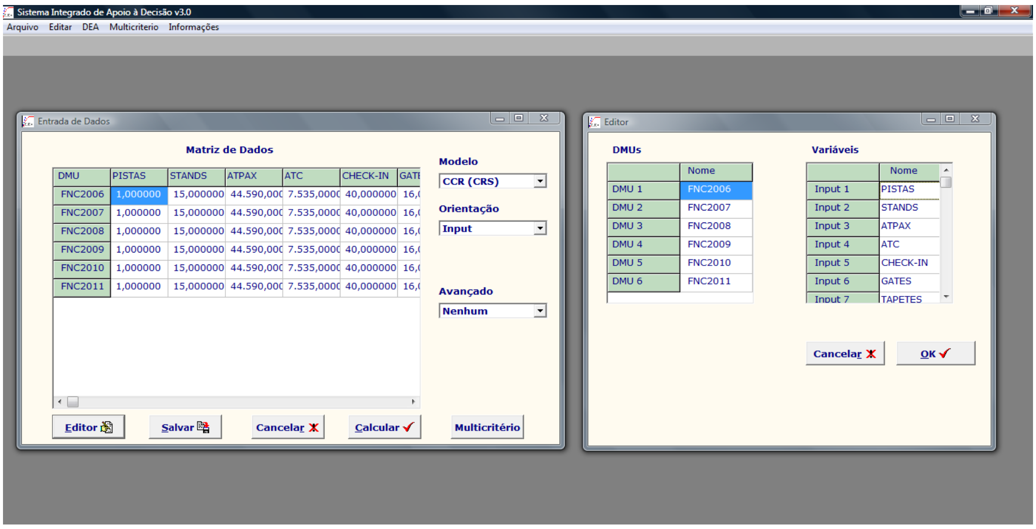

Figure 3.9 – ISYDS's Editing Window

As stated by Meza *et al*. (2003; 2005), one of the objectives of the ISYDS package is to allow new DEA models, so advanced options are also included in this software. They may be chosen along with the model and its orientation. Thus, the user has also the possibility of using two types of weight restrictions: assurance regions and virtual weights (see figure 3.10).

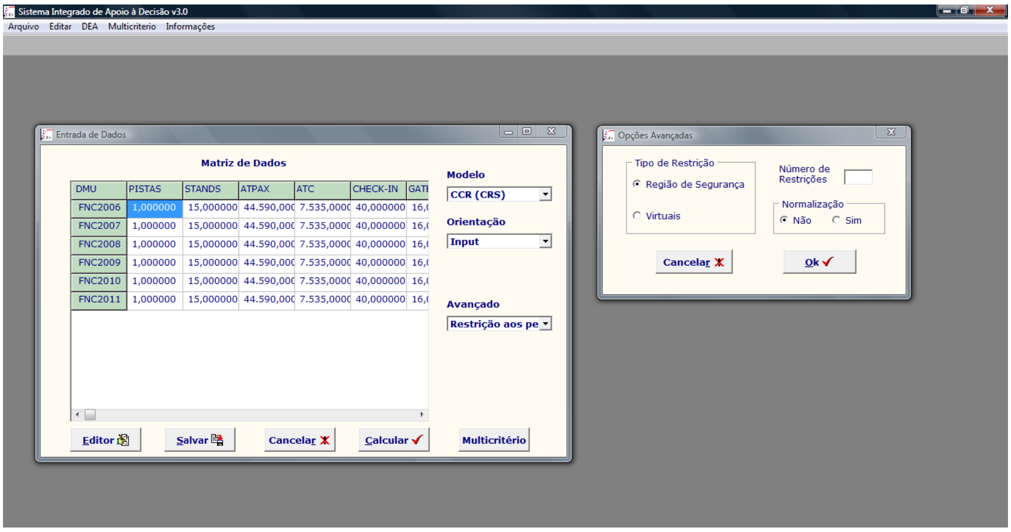

Figure 3.10 – Weight Restrictions Window

Results for any model, advanced or not, are presented in an additional window, as illustrated in figures 3.11 and 3.12, which show the efficiency indexes for all DMUs. Besides, additional options are presented to display other results: inverted frontier (which expands the result window to include the efficiency scores in the inverted frontier), and the composed index (standard and inverted frontier efficiencies).

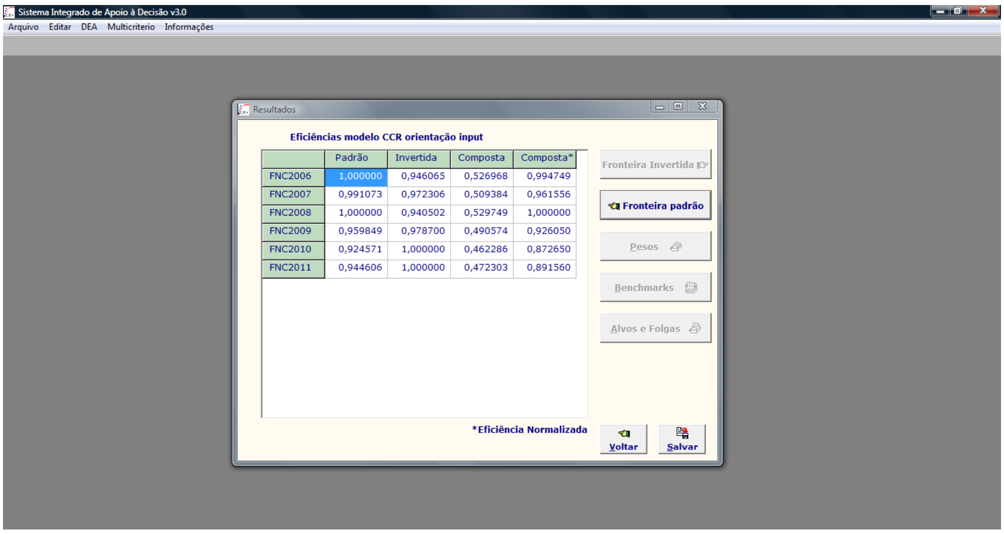

Figure 3.11 – ISYDS's Frontier Results Window

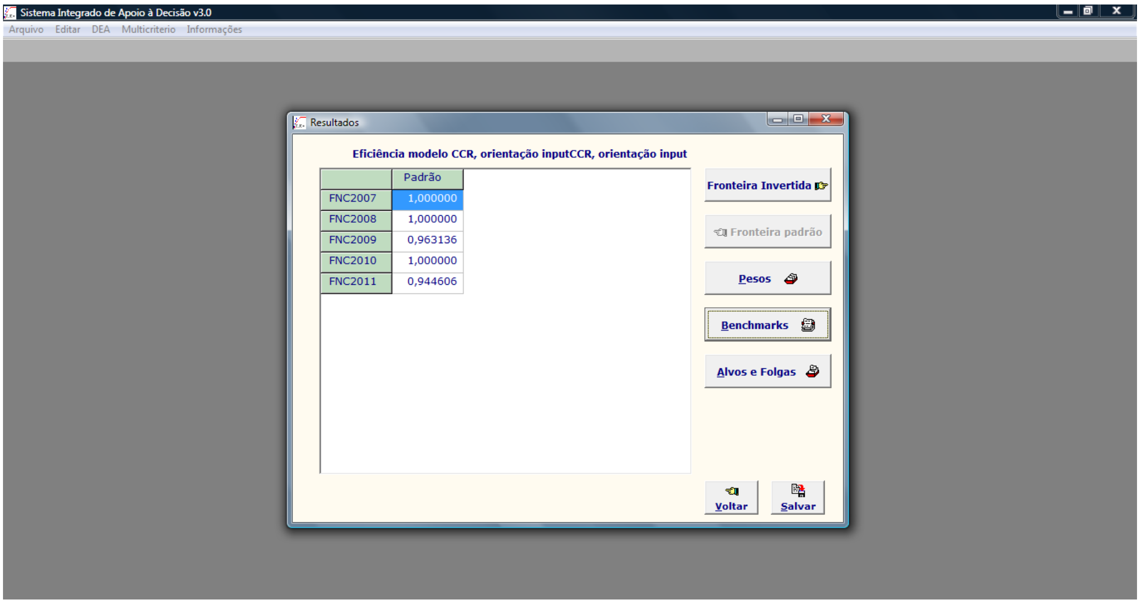

Figure 3.12 - ISYDS's Efficiency Results Window

3.3.1.2. Implemented Models

As Meza *et al.* (2003; 2005) state, the basic DEA, CCR and BCC models are already included in ISYDS. Both models include input or output orientation, producing complete results (efficiency scores, weights, benchmarks, targets, and slacks). Moreover, some advanced models were included, also retrieving complete results. These models were:

a) Inverted frontier, that is a way to measure the inefficiency of a DMU, altogether with a composed efficiency, obtained from the common and inverted frontiers. This composed efficiency index is computed as shown in equation (4). As the common DEA frontier represents an optimist evaluation, and the inverted frontier a pessimistic one, the composed index considers both approaches. Normalized composed efficiency is obtained by dividing each DMU composed efficiency index by the major one along all DMUs. Even when not displayed, those indexes are always calculated as part of DEA results.

$$Composed\ efficiency\ index = \frac{Classic\ efficiency - Inverted\ efficiency + 1}{2} \qquad (4)$$

b) Weight restrictions, using the assurance region (optional).

c) Virtual weight restrictions (optional).

It's important to point out that even using weight restrictions the results show the inverted frontier efficiency index. If using virtual weight restrictions, the results will not show the aforementioned index.

3.3.1.3 Comparing ISYDS with other DEA Software Packages

As mentioned earlier, in recent years, DEA software packages were developed due to the great interest and the large number of applications using this approach. These software packages include mostly basic models and were mainly developed to avoid the effort of running separately LPPs for each DMU in order to get the final evaluation. Although latest theoretical developments were introduced in DEA packages and there exist many options available, we can frequently observe that DEA results can be different from package to package. This happens even for the basic models. Besides, most software packages show only efficiency indexes, benchmarks, and targets, leaving out the actual values for variable weights, which may be useful in a thorough analysis of the DMUs and in later theoretical developments. Table 3 shows some DEA advanced models including some software packages, almost all running in Windows environment.

Table 3 – Some DEA software packages (Meza *et al.* 2005)

Software	*DEA models*	*Characteristics*
Frontier Analyst	CCR and BCC models.	Good graphic interface. The weights are not available. Data entry through editor or Excel Commercial software.
DEAP	CCR and BCC models; Allocative and overall efficiency models; Malmquist index.	Windows interface. Calculates Malmquist indexes, but other widely used model (such us weight restrictions) are not available. Free software.
EMS	CCR and BCC models; Super efficiency Non-discretionary variable models; Weight restrictions, Free Disposal Hull, Non-increasing and Non-decreasing return to scale models.	Results are often different from those obtained running each LPP individually. Data entry only using Excel or ASCII. This package uses the interior point model for solving LPPs. Calculates Malmquist indexes. Free software.
WARWICK DEA	CCR and BCC models; Exogenous variable models; Weight restrictions, Super efficiency, non discretionary variables for BCC.	The software requires input in the form of an ASCII file containing the input/output levels of the unit assessed. Commercial software.

Software (cont.)	*DEA models (cont.)*	*Characteristics (cont.)*
IDEAS 6.1	CCR, BCC, Additive and Multiplicative models (Arquimedian and Non-arquimedian models); Super efficiency, Non-discretionary and categorical variables models.	Data entry trough Editor. Commercial software.
IDEAL - Interactive Data Envelopment Analysis Laboratory)	CCR and BCC models.	Visual tool for tridimensional problems. Free software.
DEAxl	CCR and BCC models Cross Evaluation.	Without weight restrictions of any kind. It has an option for showing the individual LPP for each DMU. It is add-in for Microsoft Excel and needs this software to be installed in the computer in order to run. Free software.
DEAFrontier/DEA Excel Solver	CCR and BCC models, Input and Output oriented.	Uses Excel Solver and does not set any limits on the number of DMUs, inputs or outputs. Free software.
OnFront	CCR and BCC models, Input and Output oriented; Malmquist productivity indexes, Strong and weak disposability.	Was developed by the originators of the Malmquist productivity index. Simulation capability and Malmquist productivity, including decomposition into efficiency and technical change. Commercial software.
ISYDS	CCR and BCC models, Input and Output oriented; Inverted Frontier, Weight Restrictions.	Weight restrictions available for assurance regions (with or without previous normalization) and virtual weights. Data entry through editor or ASCII file. No graphics available. Cut, copy and paste options are not available. Free software.

3.5. Conclusion

Nowadays MCDA and DEA multidimensional methodologies and tools have a wide utilization. Also both have pros and cons when applied to each case in particular and the airport sector and activity is not an exception. So, starting with a state of the art review about both MCDA and DEA we explain our options for Macbeth (MCDA) and ISYDS (DEA) to continue the works of Braz (2011) and Ferreira *et al.* (2010), respectively.

Chapter 4 - Case Studies

4.1. Introduction

This chapter describes six case studies, as presented in figure 4.1: cases I to IV are related to benchmarking studies about (in this sequence) sets of Worldwide, European, Iberian and Portuguese airports; case V is related to a self-benchmarking study involving some Iberian airports; and case VI is related to a self-benchmarking study about Madeira Airport (FNC) which includes in the evaluation process some emerging situations/sudden natural phenomenon constraints.

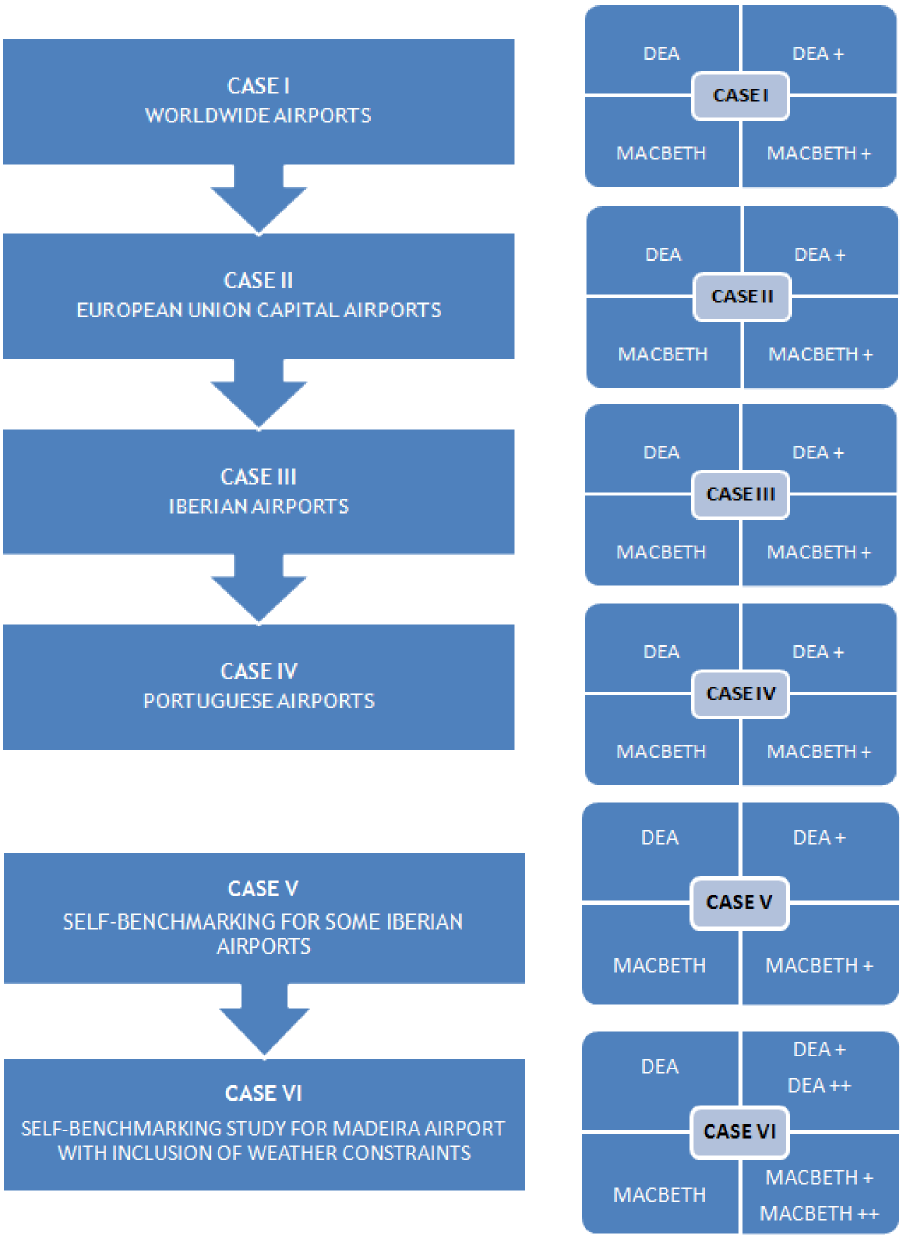

Figure 4.1 - Developed Benchmarking and Self-Benchmarking Studies

We used DEA and MACBEH tools for all the case studies, each one being divided into different four steps: two using DEA (DEA, DEA+) and two using MACBETH (MACBETH, MACBETH+) - where (+) means the addition of new performance indicators in the analysis process, in order to compare differences in the obtained efficiency rankings. Also a comparative analysis was done not only for each tool (DEA vs DEA+, and MACBETH vs MACBETH+), but also between tools (DEA vs MACBETH, and DEA+ vs MACBETH+). For self-benchmarking is also included a natural effects (constraints) analysis for Madeira (FNC) airport, named DEA++ and MACBETH++.

4.2. Airport Ranking with DEA and MACBETH Tools

4.2.1. CASE I - Worldwide Airports Benchmarking Study

The first case study is focused in a set of worldwide airports. It was decided taking into account a geographical order for the case studies, starting in a worldwide case and finishing in the Portuguese case, as presented in figure 4.1. We use airport data from Ferreira *et al.* (2010) adding some more, not only airports, but also performance indicators, both chosen from ATRS 2009 (Air Transport Research Society, 2009) publication, in order to produce an efficiency ranking of a set of worldwide airports, using both DEA and MACBETH tools. An idea of the covered area in this study is presented in figure 4.2, with indication of the used airports:

- 6 in Europe - London-Gatwick (LGW), Barcelona (BCN), Milan-Malpensa (MXP), Munich (MUC), Frankfurt, (FRA), Dublin (DUB) and Belgrade (BEG);
- 6 in North America - Calgary (YYC), Vancouver (YVR), Toronto (YYZ), Montreal (YUL), Tampa (TPA) and Atlanta (ATL);
- 6 in South America - Rio de Janeiro – Galeão (GIG), São Paulo - Guarulhos (GRU), São Paulo – Viracopos (VCP), Manaus (MAO), and Buenos Aires – Aeroparque (AEP) and Buenos Aires – Ezeiza (EZE);
- 5 in Asia - Dubai (DXB), Singapore (SIN), Hong Kong (HKG), Tokyo – Narita (NRT) and Central Japan (NGO); and
- 1 in Oceania - Sydney (SYD).

Figure 4.2: World Map with Indication of the Airports used in this Study (Great Circle Mapper, 2012)

Ferreira *et al.* (2010) obtained an efficiency ranking of some worldwide airports, specially focused on Brazilian infrastructures, using a DEA approach (figure 4.3). They used the same DEA tool as the one used in this work (ISYDS), being an important support in order to decide the steps during the DEA analysis.

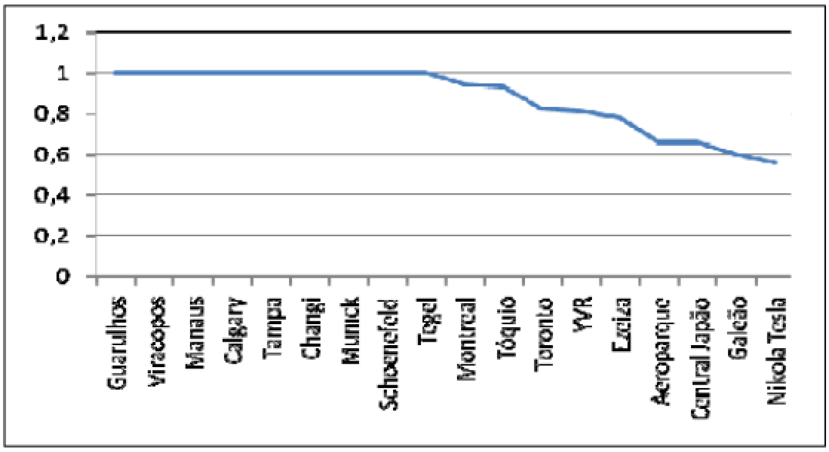

Figure 4.3: Efficiency Ranking for a Set of Worldwide Airports (Ferreira *et al.*, 2010)

The authors used 7 single performance indicators to produce their ranking:

- 4 ***Inputs*** (Number of Runways (RWS), Number of Aircraft Parking Positions (STANDS), Passenger Terminal Area, in m^2, (PAX TA), and Cargo Terminal Area, in m^2, (CARGO TA)) and
- 3 ***Outputs*** (Number of Aircraft Operations (MOVS), Number of Processed Passengers (PAX) and Cargo Volumes, in *tons*, (CARGO)).

After consulting some literature as well as some experts on airport benchmarking, we decided to add some more inputs to this study, namely, Number of Check-In Desks (CHK-IN), Number of Boarding Gates (GATES) and Number of Baggage Claim Belts (BELTS), used as well in the forward case studies.

Also we used some new airports, with a number of Processed Passengers higher than 19,000,000, as presented at ATRS 2009 (Air Transport Research Society, 2009) report. Thus, it was necessary to get the data, as in table 4.

Table 4: Worldwide Airport Data - from the list in the References

											STATISTICS 2011		
				INPUTS							OUTPUTS		
	Country	Airport	IATA	RWS	STANDS	PAX TA	CARGO TA	CHK-IN	GATES	BELTS	MOVS	PAX	CARGO
South America	Brazil	Guarulhos	GRU	2	66	179790	64752	320	61	23	270600	30003428	515175
	Brazil	Galeão	GIG	2	53	280681	41800	150	50	15	139443	14952830	114097
	Brazil	Viracopos	VCP	1	11	8720	67458	70	9	4	99982	7568384	283267
	Brazil	Manaus	MAO	1	15	46266	9300	53	5	4	56298	3019426	179082
	Argentina	Aeroparque[8]	AEP	1	68	30000	10000	55	16	9	81675	5320292	13741
	Argentina	Ezeiza[9]	EZE	2	42	71000	203827	143	23	11	93346	8786807	248692
North America	Canada	Calgary	YYC	3	45	123000	54812	118	50	9	162000	12844523	116000
	Canada	Vancouver	YVR	3	108	255000	96200	250	95	14	296942	17032780	223878
	Canada	Toronto	YYZ	5	141	251054	84575	370	108	24	428477	33400000	492171
	Canada	Montreal[9]	YUL	3	64	72720	135000	208	60	13	217545	13660862	112000
	EUA	Tampa	TPA	3	75	174374	22300	116	59	14	191315	16732051	81822
	EUA	Atlanta	ATL	5	172	340955	130846	124	207	17	923991	84962851	638127
Asia - Pacific	Japan	Tokyo	NRT	2	141	783600	815580	584	67	28	183451	28068714	1898885
	Japan	Central Japan	NGO	1	66	220000	260000	180	28	9	82137	8890683	143134
	Singapore	Changi	SIN	2	85	650000	510000	444	92	15	301711	46543845	1865252
	Australia	Sydney	SYD	3	93	354000	53850	258	56	23	280910	35630549	249159
	China	Hong Kong	HKG	2	120	710000	351600	377	75	12	334000	53904000	3938000
	Dubai	Dubai	DXB	2	144	1444474	78600	400	82	31	326317	50980000	2190000
Europe	Germany	Munich	MUC	2	135	469400	58250	310	200	28	409956	37782256	303655
	Germany	Frankfurt	FRA	4	189	800000	90000	381	120	31	487162	56443657	2169304
	UK	Gatwick	LGW	1	115	258000	20300	348	94	16	244741	33639900	88214
	Serbia	Belgrade	BEG	1	22	40000	7300	47	16	4	44923	3124633	8025
	Italy	Milan	MXP	2	139	142000	45000	313	93	15	186780	19291427	440258
	Spain	Barcelona	BCN	3	168	674759	43692	258	149	28	303054	34398226	96572

[8] STATISTICS data for 2006
[9] STATISTICS data for 2010

Thus we use this data to obtain an efficiency ranking based on MACBETH and DEA approaches. If we introduce these single indicators within MACBETH, as mentioned we would produce not an efficiency ranking but a performance one. Then, it's necessary to create new indicators, which we call complex ones, combining the above inputs and outputs, as presented on table 2. Movements, includes the number of aircraft landing/take-off on/from the airport; Passengers, includes the number of passengers who arrives and departs into/from the airport; and Cargo, includes the number of cargo tons that arrives and departs on/from the airport being domestic or international, freight or mail flights. Then, we divided this analysis in two different parts, in order to verify the position change in the ranking due to additional performance indicators, as presented on table 5.

Table 5: Analysis in Each One of the Cases Studies

1	**DEA**	Include the same inputs and outputs as used by Ferreira *et al.* (2010)
	MACBETH	
2	**DEA+**	Include all the performance indicators as presented in table 2
	MACBETH+	

In order to use the MACBETH analysis, it was necessary to give 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) about the weights (%) to attribute to those complex indicators. The sum of weights necessarily would be 100.00%. For the first case study (MACBETH), the weights were obtained from a previous one done by Braz (2011); for the second one (MACBETH+) it was necessary to search for them as mentioned above. So, according to table 4 we obtained the complex indicators of table 6 (as explained in table 2) for each airport represented by IATA code; the respective average weights based on the opinion of our set of specialists are those of table 7.

Table 6: Complex Indicators for a Set of Worldwide Airports

AIRPORT	PAX/ PAX TA	PAX/ GATES	PAX/ CHK-IN	CARGO/ CARGO TA	MOVS/ STANDS	MOVS/ GATES	MOVS/RWS	MOVS/TAP
Atlanta	249,19	410448,56	685184,28	4,88	5372,04	4463,72	184798,20	54352,41
Frankfurt	70,55	470363,81	148146,08	24,10	2577,58	4059,68	121790,50	15714,90
HongKong	75,92	718720,00	142981,43	11,20	2783,33	4453,33	167000,00	27833,33
Dubai	35,29	621707,32	127450,00	27,86	2266,09	3979,48	163158,50	10526,35
Changi	71,61	505911,36	104828,48	3,66	3549,54	3279,47	150855,50	20114,07
Munich	80,49	188911,28	121878,25	5,21	3036,71	2049,78	204978,00	14641,29
Sydney	100,65	636259,80	138102,90	4,63	3020,54	5016,25	93636,67	12213,48
Barcelona	50,98	230860,58	133326,46	2,21	1803,89	2033,92	101018,00	10823,36
Gatwick	130,39	357871,28	96666,38	4,35	2128,18	2603,63	244741,00	15296,31
Guarulhos	166,88	491859,48	93760,71	7,96	4100,00	4436,07	135300,00	11765,22
Tampa	95,95	283594,08	144241,82	3,67	2550,87	3242,63	63771,67	13665,36
Viracopos	867,93	840931,56	108119,77	4,20	9089,27	11109,11	99982,00	24995,50
Aeroparque	177,34	332518,25	96732,58	1,37	1201,10	5104,69	81675,00	9075,00
Manaus	65,26	603885,20	56970,30	19,26	3753,20	11259,60	56298,00	14074,50
Malpensa	135,86	207434,70	61633,95	9,78	1343,74	2008,39	93390,00	12452,00
Toronto	133,04	309259,26	90270,27	5,82	3038,84	3967,38	85695,40	17853,21
Belgrade	78,12	195289,56	66481,55	1,10	2041,95	2807,69	44923,00	11230,75
Montreal	187,86	227681,03	65677,22	0,83	3399,14	3625,75	72515,00	16734,23
Calgary	104,43	256890,46	108851,89	2,12	3600,00	3240,00	54000,00	18000,00
Vancouver	66,80	179292,42	68131,12	2,33	2749,46	3125,71	98980,67	21210,14
Galeao	53,27	299056,60	99685,53	2,73	2631,00	2788,86	69721,50	9296,20
Tokyo	35,82	418936,03	48062,87	2,33	1301,07	2738,07	91725,50	6551,82
Central Japan	40,41	317524,39	49392,68	0,55	1244,50	2933,46	82137,00	9126,33
Ezeiza	123,76	382035,09	61446,20	1,22	2222,52	4058,52	46673,00	8486,00

Table 7: Complex Indicators Weights for MACBETH Study Cases

Indicators	MACBETH	MACBETH+
MOVS / STANDS	21,60%	16,61%
MOVS/ RWS	27,90%	12,78%
PAX / PAX TA	25,80%	18,01%
CARGO / CARGO TA	24,70%	12,93%
PAX / CHK-IN	-	10,93%
PAX / GATES	-	10,05%
MOVS / GATES	-	9,56%
MOVS / BELTS	-	9,09%
	100%	100%

Then we use MACBETH and DEA tools to get airports efficiency ranking based on a combination of the above mentioned indicators, and its related weights – when necessary (tables 8 to 10, and figures 4.4 to 4.13).

Table 8: Worldwide Airports Scores for MACBETH Study Case

	Overall	MOVS/STANDS	MOVS/RWS	PAX/PAX TA	CARGO/CARGO TA
[tudo sup.]	100.00	100.00	100.00	100.00	100.00
VCP	62.51	100.00	40.85	100.00	15.04
DUB	50.61	24.93	66.67	4.07	100.00
ATL	46.83	59.10	75.51	28.71	17.48
FRA	44.32	28.36	49.76	8.13	86.49
LGW	41.03	23.41	100.00	15.02	15.54
HKG	38.75	30.62	68.24	8.75	40.16
MUC	38.60	33.41	83.75	9.27	18.66
GRU	38.26	45.11	55.28	19.23	28.52
MAO	35.77	41.29	23.00	7.52	69.11
SIN	32.29	39.05	61.64	8.25	13.11
YYZ	26.85	33.43	35.01	15.33	20.85
MXP	26.50	14.78	38.16	15.65	35.06
SYD	25.85	33.23	38.26	11.60	16.58
YUL	23.32	37.40	29.63	21.64	2.97
YVR	22.81	30.25	40.44	7.70	8.35
YYC	20.85	39.61	22.06	12.03	7.59
TPA	20.15	28.06	26.06	11.05	13.14
BCN	19.86	19.85	41.28	5.87	7.92
GIG	19.16	28.95	28.49	6.14	9.78
AEP	18.35	13.21	33.37	20.43	4.91
NRT	17.10	14.31	37.48	4.13	8.35
EZE	15.79	24.45	19.07	14.26	4.37
NGO	14.39	13.69	33.56	4.66	1.97
BEG	13.83	22.47	18.36	9.00	3.94
[tudo inf.]	0.00	0.00	0.00	0.00	0.00
	Weights	0.2580	0.2790	0.2160	0.2470

Table 9: Worldwide Airports Scores for MACBETH+ Study Case

	Overall	MOVS/ STANDS	MOVS/ RWS	PAX/ PAX	CARGO/ CARGO	PAX/ CHK-	PAX/ GATES	MOVS/ GATES	MOVS/ BELTS
[tudo sup.]	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
VCP	67.19	100.00	40.85	100.00	15.04	15.78	100.00	98.66	45.99
ATL	55.63	59.10	75.51	28.71	17.48	100.00	48.81	39.64	100.00
DUB	40.95	24.93	66.67	4.07	100.00	18.60	73.93	35.34	19.37
MAO	40.14	41.29	23.00	7.52	69.11	8.31	71.81	100.00	25.89
HKG	39.90	30.62	68.24	8.75	40.16	20.87	85.47	39.55	51.21
FRA	37.80	28.36	49.76	8.13	86.49	21.62	55.93	36.06	28.91
GRU	34.83	45.11	55.28	19.23	28.52	13.68	58.49	39.40	21.65
LGW	31.99	23.41	100.00	15.02	15.54	14.11	42.56	23.12	28.14
SIN	31.42	39.05	61.64	8.25	13.11	15.30	60.16	29.13	37.01
SYD	30.76	33.23	38.26	11.60	16.58	20.16	75.66	44.55	22.47
MUC	28.74	33.41	83.75	9.27	18.66	17.79	22.46	18.20	26.94
YYZ	26.98	33.43	35.01	15.33	20.85	13.17	36.78	35.24	32.85
YUL	23.93	37.40	29.63	21.64	2.97	9.59	27.07	32.20	30.79
YYC	23.12	39.61	22.06	12.03	7.59	15.89	30.55	28.78	33.12
TPA	22.42	28.06	26.06	11.05	13.14	21.05	33.72	28.80	25.14
AEP	22.15	13.21	33.37	20.43	4.91	14.12	39.54	45.34	16.70
YVR	22.09	30.25	40.44	7.70	8.35	9.94	21.32	27.76	39.02
MXP	21.95	14.78	38.16	15.65	35.06	9.00	24.67	17.84	22.91
EZE	20.05	24.45	19.07	14.26	4.37	8.97	45.43	36.04	15.61
GIG	19.91	28.95	28.49	6.14	9.78	14.55	35.56	24.77	17.10
BCN	19.08	19.85	41.28	5.87	7.92	19.46	27.45	18.06	19.91
NRT	18.19	14.31	37.48	4.13	8.35	7.01	49.82	24.32	12.05
NGO	16.26	13.69	33.56	4.66	1.97	7.21	37.76	26.05	16.79
BEG	15.87	22.47	18.36	9.00	3.94	9.70	23.22	24.94	20.66
[tudo inf.]	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Weights	0.1660	0.1279	0.1802	0.1294	0.1094	0.1006	0.0956	0.0909

The previous tables, present the obtained scores for each airport and each indicator together, through MACBETH to get the efficiency values (in yellow). These scores represent the airport punctuation for each indicator, taking into account all the other airports as well as all indicators respective weights; this is the basic mathematical formulation of MACBETH.

There are established limits, 0 (inferior) and 100 (superior), representing the minimum and maximum values admitted for the efficiency. Thus, it was possible to order these values from highest to lowest and make an efficiency ranking.

The obtained efficiency values and rankings are presented in table 10, for each case.

Table 10: Efficiency Ranking for Worldwide Airports in the Four Cases

Airport	DEA	Rank DEA	DEA+	Rank DEA+	MACBETH	Rank MACBETH	MACBETH+	Rank MACBETH+
Atlanta	100	1	100	1	46,83	3	55,63	3
Frankfurt	100	1	100	1	44,32	4	37,80	5
Hong Kong	100	1	100	1	38,75	6	39,90	8
Dubai	100	1	100	1	50,61	2	40,95	2
Singapore	100	1	100	1	32,29	10	31,42	4
Munich	100	1	100	1	38,6	7	28,74	12
Gatwick	100	1	100	1	41,03	5	31,99	7
Tampa	100	1	100	1	20,15	17	22,42	17
Viracopos	100	1	100	1	62,51	1	67,19	1
Aeroparque	100	1	100	1	18,35	20	22,15	14
Manaus	100	1	100	1	35,77	9	40,14	6
Guarulhos	97,4419	12	100	1	38,26	8	34,83	11
Malpensa	95,6754	13	95,6750	15	26,5	12	21,95	21
Sydney	89,0577	14	100	1	25,85	13	30,76	9
Toronto	76,9192	15	77,0023	16	26,85	11	26,98	18
Barcelona	72,8363	16	100	1	19,86	18	19,08	22
Belgrade	71,8792	17	74,3827	17	13,83	24	15,87	24
Montreal	66,8798	18	66,8798	18	23,32	14	23,93	10
Calgary	63,2856	19	64,4523	19	20,85	16	23,12	13
Galeão	57,0501	20	62,5324	21	19,16	19	19,91	16
Vancouver	53,2939	21	63,4889	20	22,81	15	22,09	15
Tokyo	52,7282	22	58,9331	22	17,1	21	18,19	19
Ezeiza	41,3818	23	51,3938	24	15,79	22	20,05	20
Central Japan	40,6819	24	56,9539	23	14,39	23	16,26	23

Figures 4.4 to 4.8 show a comparative view of the obtained efficiency results.

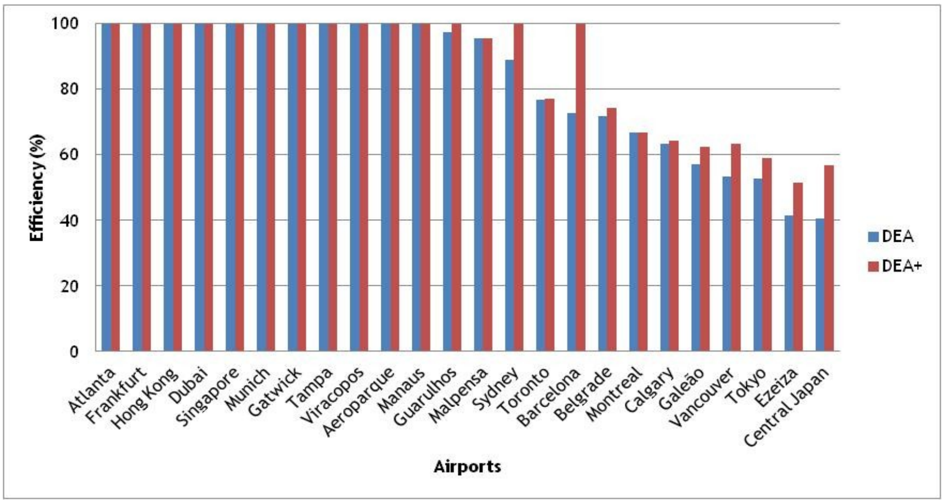

Figure 4.4: Comparative Efficiency between DEA and DEA+ for Worldwide Airports

As presented in figure 4.4, the addition of new performance indicators does not affect the efficiency for some airports as some of them continue with an efficiency value of 100%. However for Sydney, Barcelona, Galeão (Rio de Janeiro), Vancouver, Tokyo, Ezeiza (Buenos Aires) and Central Japan, these values show an increase, mainly Barcelona that changed from 72% to 100%, as in table 10. There were no airports lowing in the efficiency for this case.

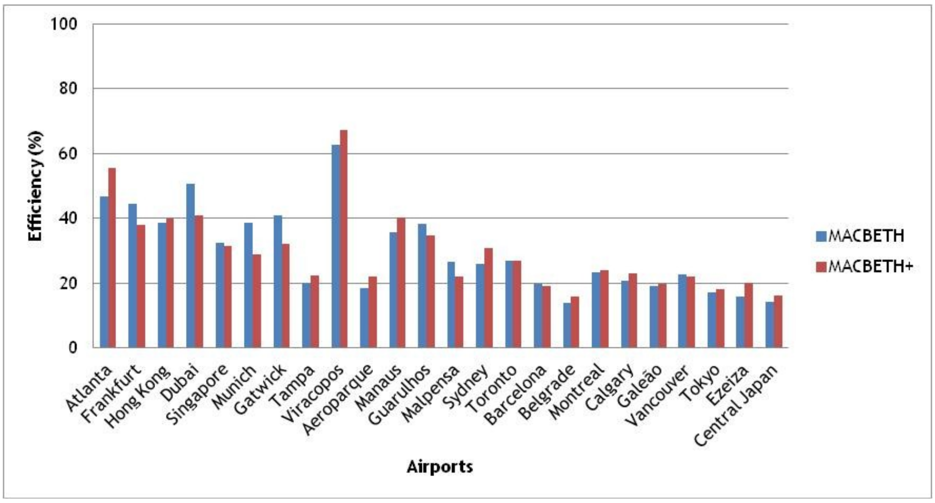

Figure 4.5: Comparative Efficiency between MACBETH and MACBETH+ for Worldwide Airports

For MACBETH cases in figure 4.5, the most relevant increase was for Atlanta, followed by Hong Kong, Tampa, Viracopos, Aeroparque (Buenos Aires), Manaus, Sydney, Belgrade, Montreal, Calgary, Tokyo, Ezeiza and Central Japan. However, the addition of new indicators caused a significant drop in the efficiency value for Dubai, Munich and Gatwick, followed by Frankfurt, Singapore, Guarulhos, Malpensa, Barcelona and Vancouver.

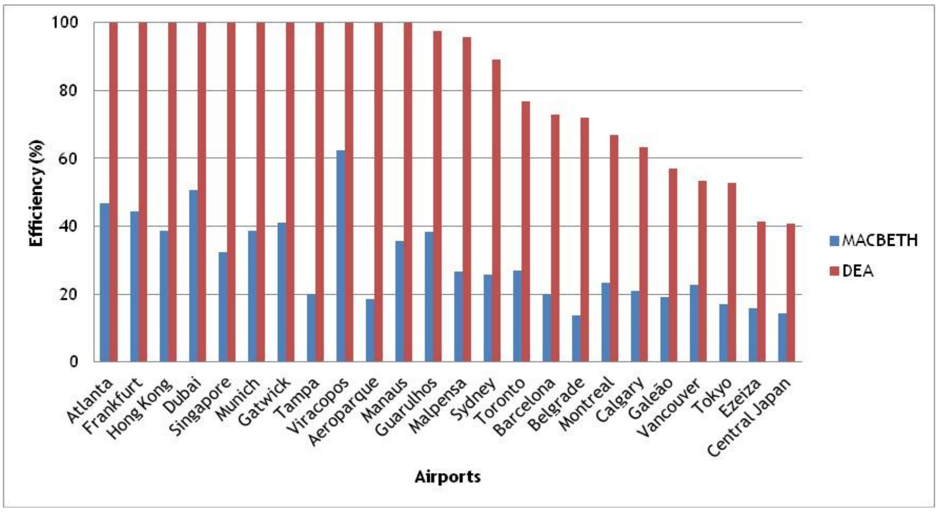

Figure 4.6: Comparative Efficiency between MACBETH and DEA for Worldwide Airports

In figure 4.6 in shown a comparison between MACBETH and DEA efficiency values, where is visible the differences between these two tools. The main differences are for Tampa, Aeroparque, Singapore and Hong Kong, which had 100% efficiency for DEA but not so much for MACBETH. Viracopos airport had the best value in both approaches.

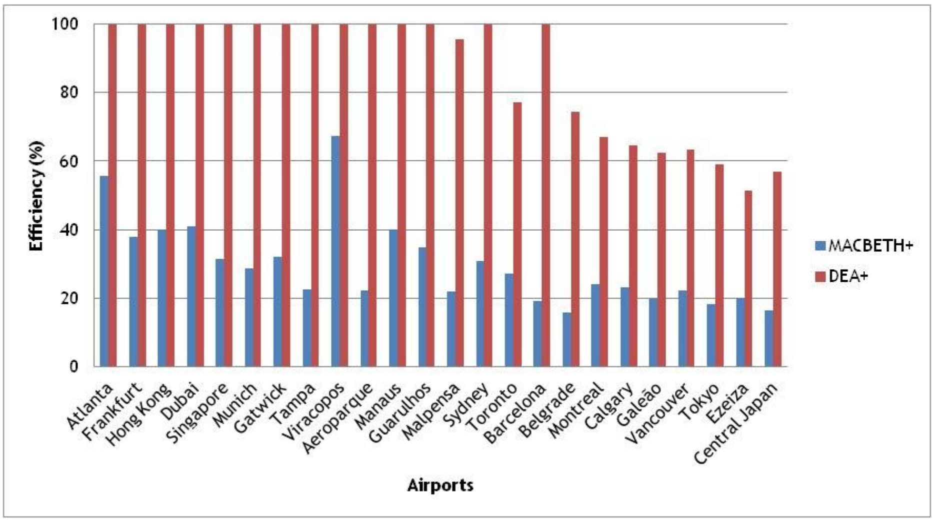

Figure 4.7: Comparative Efficiency between MACBETH+ and DEA+ for Worldwide Airports

Now comparing the efficiency results for both approaches MACBETH+ and DEA+, figure 4.7, after the new indicators addition, the best values belong again to Viracopos airport, and the main differences are now for Tampa Aeroparque, Malpensa and Barcelona.

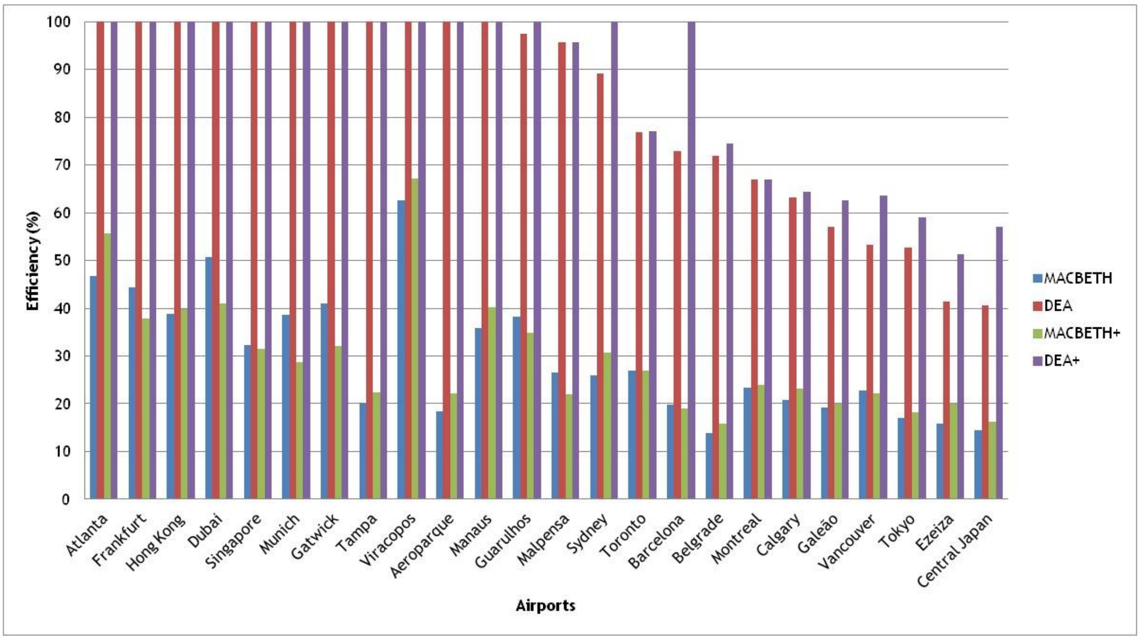

Figure 4.8: Worldwide Airports Comparative Efficiency for all Cases

The efficiency results obtained with MACBETH and DEA approaches are quite different. From figures 4.4 to 4.7, or from figure 4.8 and table 10 (direct comparison), it's possible to observe the variation on efficiency values, due the use of those two different tools. Some airports have different values between approaches, since MACBETH does a thinner approach and presents a non-convergence approach, and DEA presents more than one airport with 100% efficiency. Figures 4.9 to 4.13 permit another perspective, i.e. to observe the efficiency ranking which is the main target of this study.

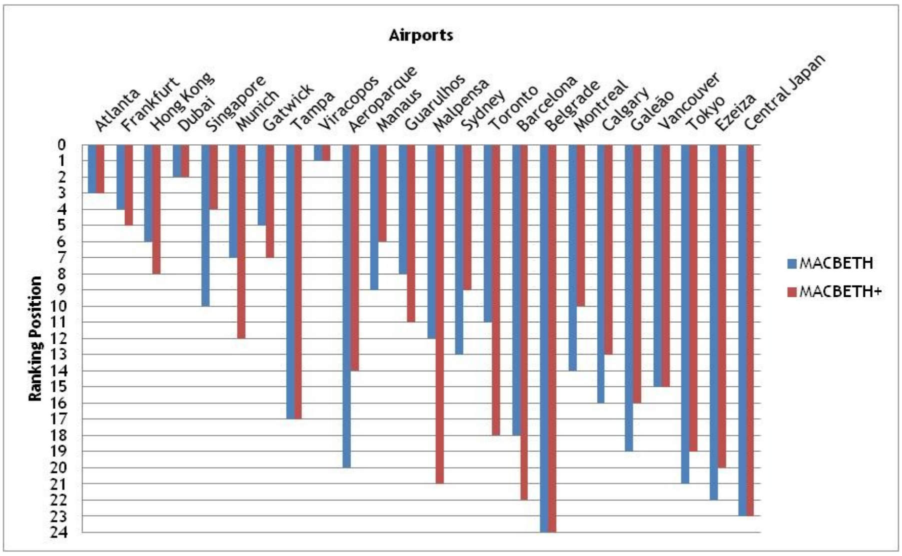

Figure 4.9: Balance between MACBETH and MACBETH+ Rankings for Worldwide Airports

Comparing the transition from MACBETH to MACBETH+, which represents again the adding of new indicators, in figure 4.9 it's possible to observe that there are some similarities as for Atlanta, Dubai, Tampa, Viracopos, Belgrade, Vancouver and Central Japan, but also that there are great discrepancies as for Singapore, Munich, Aeroparque, Malpensa and Toronto.

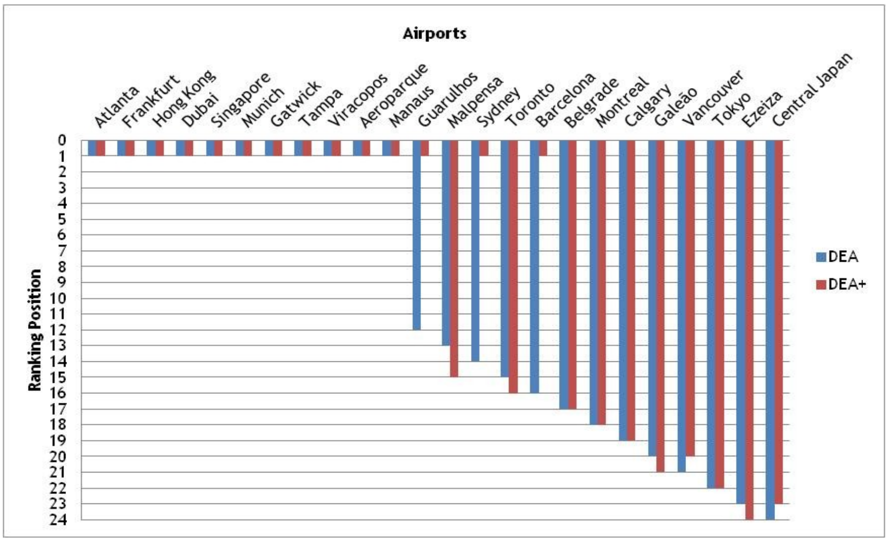

Figure 4.10: Balance between DEA and DEA+ Rankings for Worldwide Airports

Comparing the transition from DEA to DEA+ in figure 4.10, which represent the adding of new indicators, it's possible to observe that there are some similarities as for Atlanta, Dubai, Tampa, Viracopos, Frankfurt, among others, but also there are great discrepancies as for Sidney and Barcelona. Here is visible how DEA does not give a clear understand of which airport got the real 1st place, as many of them are evaluated in this way.

In figures 4.9 and 4.10 a comparison is done between rankings, before and after the addition of new indicators, where is visible the high influence for some airports as Singapore and Malpensa in MACBETH tool (figure 4.9), and Guarulhos, Sidney and Barcelona in DEA one (figure 4.10).

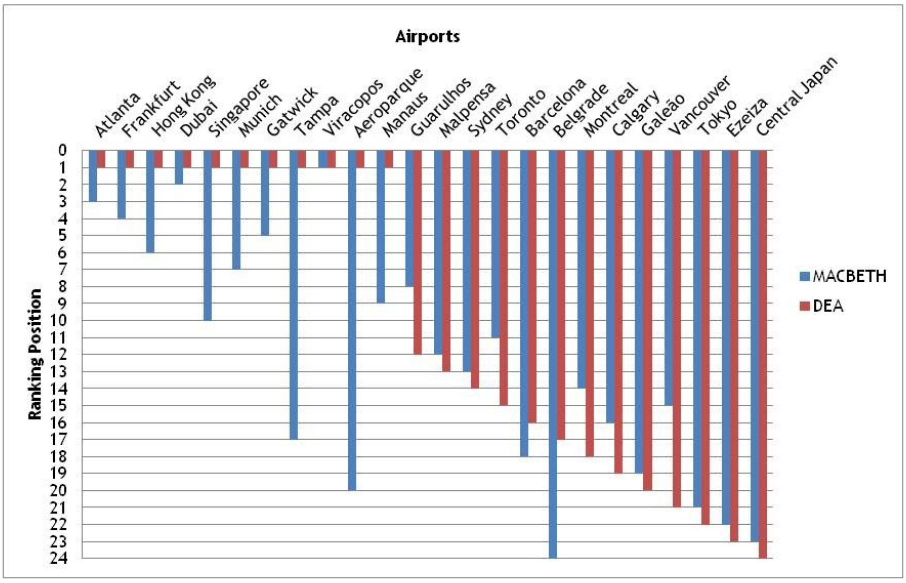

Figure 4.11: Balance between MACBETH and DEA Rankings for Worldwide Airports

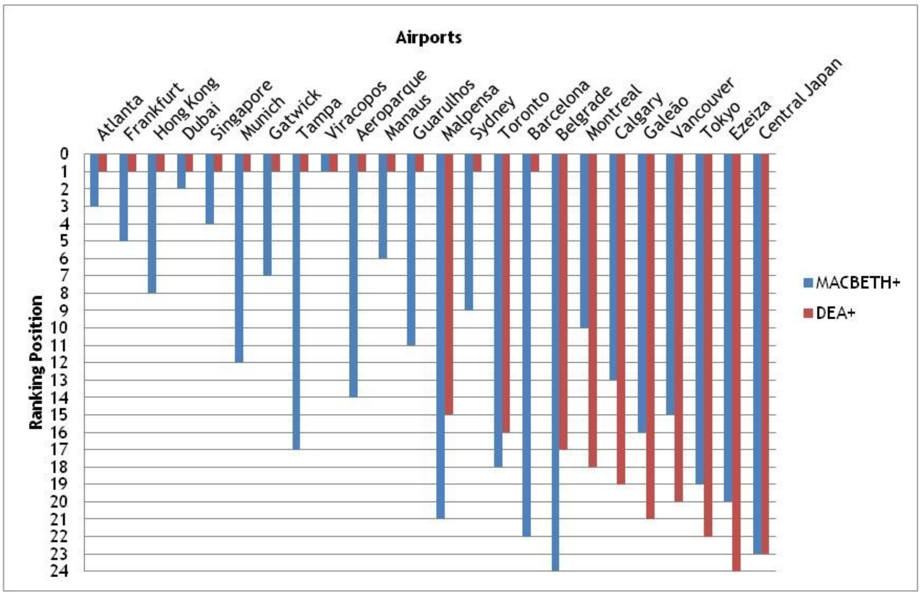

Figure 4.12: Balance between MACBETH+ and DEA+ Rankings for Worldwide Airports

Similarly, in figures 4.11 and 4.12, or in figure 4.13 for direct overview, a new comparison is shown, now between tools, where is visible again the high influence for some airports as Aeroparque, Tampa and Singapore (figure 4.11), and Barcelona, Tampa, Munich and Aeroparque (figure 4.12).

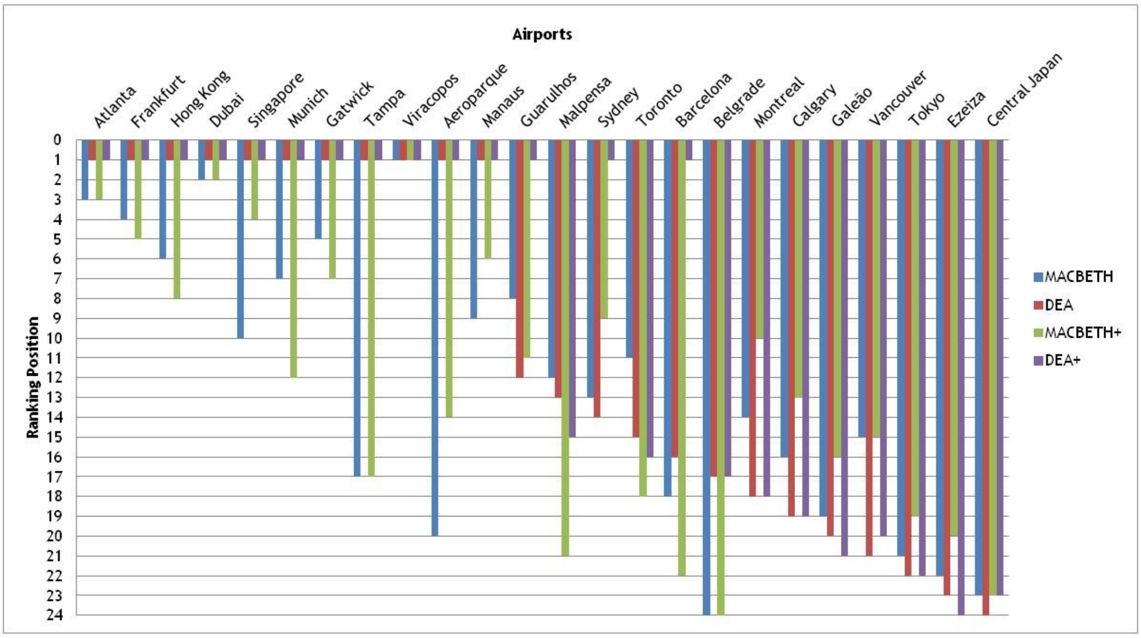

Figure 4.13: Worldwide Airports Comparative Ranking for all Cases

Viracopos airport in Brazil takes a 1st place in the ranking for all case studies, because as visible in tables 8 and 9, it takes the maximum score in three indicators into MACBETH+ analysis: MOVS/STANDS, PAX/PAX TA and MOVS/GATES. Gatwick airport had the best score in MOVS/RWS, Dublin airport in CARGO/CARGO TA, Atlanta airport in PAX/CHK-IN and MOVS/BELTS and Manaus airport in MOVS/GATES. Central Japan airport has a low score followed by Belgrade.

As visible on figure 4.13, is possible to conclude that the addition of new indicators, such as check-in desks, boarding gates and baggage claim belts, in this benchmarking study, has an important, non-negligible, influence for some included airports.

4.2.2. CASE II - European Union Airports Benchmarking Study

After a worldwide analysis, a study focused in main European Union airport infrastructures was done. It was decided, as mentioned, taking into account a geographical order for the case studies, starting in a worldwide case and finishing in the Portuguese case, as presented in figure 4.1. There was no airport data support for that at the beginning of this study, as we had in the previous case supported by Ferreira *et. al* (2010), and so it was decided to include the airports located close to the capitals of the European Union 27 countries (figure 4.14), considering the infrastructures with higher passenger traffic in the cities with more than one airport, in order to produce an efficiency ranking. Thus, the used airports were: Austria – Vienna Schwechat (VIE), Belgium – Brussels National (BRU), Bulgary – Sofia (SOF), Cyprus – Larnaka (LCA), Czech Republic – Prague (PRG), Denmark – Copenhagen Kastrup (CPH), Estonia – Tallinn (TLL), Finland – Helsinki Vantaa (HEL), France – Paris Charles de Gaule (CDG), Germany – Berlin Tegel (TXL), Greece – Athens Eleftherios Venizelos (ATH), Hungary – Budapest (BUD), Ireland – Dublin (DUB), Italy – Rome Fiumicino (FCO), Latvia – Riga (RIX), Lithuania – Vilnius (VNO), Luxemburg (LUX), Malta – Valeta Luqa (MLA), Netherlands – Amsterdam Schiphol (AMS), Poland – Warsaw (WAW), Portugal – Lisbon (LIS), Romania – Bucharest (OTP), Slovakia - Bratislava (BTS), Slovenia – Ljubljana (LJU), Spain – Madrid Barajas (MAD), Sweden – Stockholm Arlanda (ARN) and in United Kingdom London – Heathrow (LHR) airport.

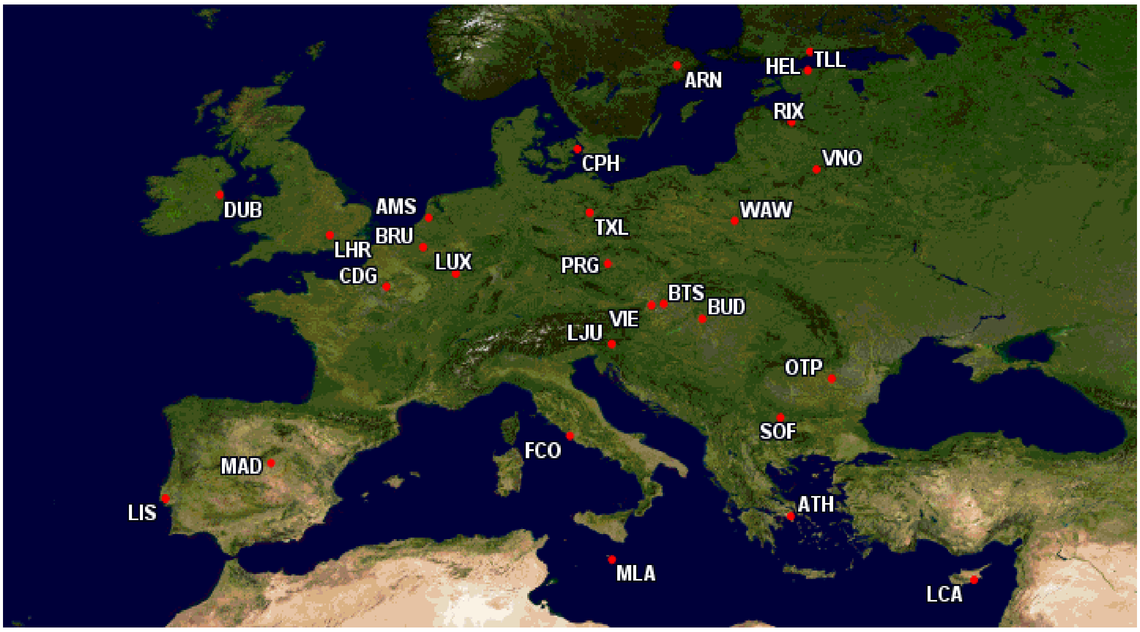

Figure 4.14: Europe Map with Indication of the EU Airports used in this Study (Great Circle Mapper, 2012)

Thus, it was necessary to get the data, as in table 11.

Table 11: European Airport Data - from the list in the References

										STATISTICS 2011		
Country	Airport	IATA	RWS	STANDS	PAX TA	CARGO TA	CHK-IN	GATES	BELTS	MOVS	PAX	CARGO
Austria	**Vienna**	**VIE**	2	101	146536	23116	121	74	7	246157	21106292	277784
Belgium	**Brussels**	**BRU**	3	129	190804	205000	120	114	8	233758	18786034	475124
Bulgaria	**Sofia**	**SOF**	1	33	65800	1250	52	17	6	47153	3474993	15888
Cyprus	**Larnaka**	**LCA**	1	53	100000	2037	64	19	5	48056	5488319	37529
Czech Republic	**Prague**	**PRG**	2	67	90395	24500	122	52	10	150717	11788629	62688
Denmark	**Copenhagen**	**CPH**	3	108	215000	39900	105	80	10	253762	22725517	214513
Estonia	**Tallinn**	**TLL**	1	37	28253	5000	27	12	3	40298	1913172	17164
Finland	**Helsinki**	**HEL**	3	125	122275	21073	89	42	10	95312	14865871	157793
France	**Paris**	**CDG**	4	303	542300	500000	420	124	43	506888	60970551	2087952
Germany	**Berlin**[10]	**TXL**	2	44	41391	11428	65	54	16	164177	16919820	22117
Greece	**Athens**	**ATH**	2	89	180000	30000	144	48	11	173296	14446963	85832
Hungary	**Budapest**	**BUD**	2	52	81161	14871	77	38	12	109949	8920653	106595
Ireland	**Dublin**[10]	**DUB**	2	109	115000	13869	175	72	16	162016	18607651	87458
Italy	**Roma**	**FCO**	4	125	312000	3450	355	84	13	324132	37651222	142836
Latvia	**Riga**	**RIX**	1	60	33000	2000	32	11	2	72855	5106926	12665
Lithuania	**Vilnius**	**VNO**	1	34	15543	2360	30	14	4	27703	1712467	5781
Luxemburg	**Luxemburg**	**LUX**	1	30	41000	67500	26	18	3	59999	1791231	656613
Malta	**Valeta**	**MLA**	2	24	329000	5000	26	10	4	28022	3506521	16843
Netherlands	**Amesterdam**	**AMS**	5	195	650000	525000	310	97	19	453613	53522000	1523806
Poland	**Warsaw**	**WAW**	2	60	140000	12000	130	56	4	119399	9337734	43600
Portugal	**Lisbon**	**LIS**	2	58	236025	18625	128	50	7	139497	14790242	94355
Romenia	**Bucarest**	**OTP**	2	45	36200	4205	104	32	6	76966	5049443	17423
Slovakia	**Bratislava**	**BTS**	2	40	30615	30615	29	8	4	25358	1585064	20530
Slovenia	**Ljubljana**	**LJU**	1	33	13000	4000	13	13	2	39267	1369485	19659
Spain	**Madrid**	**MAD**	4	220	940000	15356	400	230	52	429390	49671270	394154
Sweden	**Stockholm**	**ARN**	3	127	45027	49750	111	76	11	211000	19069065	195000
UK	**London**	**LHR**	2	203	632064	113379	407	264	46	476197	69391400	1484488

In order to use the MACBETH analysis, and following the same idea as in the previous case, it was necessary to obtain the complex indicators of table 12 for each airport represented by IATA code; also the respective weights are those of table 7. Particularly, Bratislava airport has not cargo terminal, but since there is a value for processed cargo, the passenger terminal area was considered equal for both terminals, i.e. passenger and cargo; for other cases in this situation the same assumption was considered.

[10] Cargo value for 2010

Table 12: Complex Indicators for European Airports

AIRPORTS	MOVS/ STANDS	MOVS/ RWS	PAX/ PAX TA	CARGO/ CARGO TA	PAX/ CHK-IN	PAX/ GATES	MOVS/ GATES	MOVS/ BELTS
Vienna	2437,20	123078,50	144,03	12,02	174432,17	285220,16	3326,45	35165,29
Brussels	1812,08	77919,33	98,46	2,32	156550,28	164789,77	2050,51	29219,75
Sofia	1428,88	47153,00	52,81	12,71	66826,79	204411,35	2773,71	7858,83
Larnaka	906,72	48056,00	54,88	18,42	85754,98	288858,89	2529,26	9611,20
Prague	2249,51	75358,50	130,41	2,56	96628,11	226704,40	2898,40	15071,70
Copenhagen	2349,65	84587,33	105,70	5,38	216433,50	284068,96	3172,03	25376,20
Tallinn	1089,14	40298,00	67,72	3,43	70858,22	159431,00	3358,17	13432,67
Helsinki	762,50	31770,67	121,58	7,49	167032,26	353949,31	2269,33	9531,20
Paris	1672,90	126722,00	112,43	4,18	145167,98	491697,99	4087,81	11788,09
Berlin	3731,30	82088,50	408,78	1,94	260304,92	313330,00	3040,31	10261,06
Athens	1947,15	86648,00	80,26	2,86	100326,13	300978,40	3610,33	15754,18
Budapest	2114,40	54974,50	109,91	7,17	115852,64	234754,03	2893,39	9162,42
Dublin	1486,39	81008,00	161,81	6,31	106329,43	258439,60	2250,22	10126,00
Rome	2593,06	81033,00	120,68	41,40	106059,78	448228,83	3858,71	24933,23
Riga	1214,25	72855,00	154,76	6,33	159591,44	464266,00	6623,18	36427,50
Vilnius	814,79	27703,00	110,18	2,45	57082,23	122319,07	1978,79	6925,75
Luxemburg	1999,97	59999,00	43,69	9,73	68893,50	99512,83	3333,28	19999,67
Valeta	1167,58	14011,00	10,66	3,37	134866,19	350652,10	2802,20	7005,50
Amsterdam	2326,22	90722,60	82,34	2,90	172651,61	551773,20	4676,42	23874,37
Warsaw	1989,98	59699,50	66,70	3,63	71828,72	166745,25	2132,13	29849,75
Lisbon	2405,12	69748,50	62,66	5,07	115548,77	295804,84	2789,94	17437,13
Bucharest	1710,36	38483,00	139,49	4,14	48552,34	157795,09	2405,19	12827,67
Bratislava	633,95	12679,00	51,77	0,67	54657,38	198133,00	3169,75	6339,50
Ljubljana	1189,91	39267,00	105,35	4,91	105345,00	105345,00	3020,54	19633,50
Madrid	1951,77	107347,50	52,84	25,67	124178,18	215962,04	1866,91	8257,50
Stockholm	1661,42	70333,33	423,50	3,92	171793,38	250908,75	2776,32	19181,82
London	2345,80	238098,50	109,79	13,09	170494,84	262846,21	1803,78	10352,11

Then we use MACBETH and DEA tools to get airports efficiency ranking based on a combination of the above mentioned indicators, and its related weights (tables 13 to 15, and figures 4.15 to 4.24).

Table 13: European Airports Scores for MACBETH Study Case

	Overall	MOVS/STANDS	MOVS/RWS	PAX/PAX TA	CARGO/CARGO TA
[tudo sup.]	100.00	100.00	100.00	100.00	100.00
TXL	57.28	100.00	34.48	96.52	4.69
FCO	56.56	69.49	34.03	28.49	100.00
LHR	55.98	62.87	100.00	25.92	31.62
ARN	46.00	44.53	29.54	100.00	9.47
VIE	44.48	65.32	51.69	34.01	29.03
MAD	42.41	52.31	45.09	12.48	62.00
CDG	33.88	44.83	53.22	26.54	10.10
CPH	33.16	62.97	35.53	24.96	13.00
DUB	31.72	39.84	34.02	38.20	15.24
PRG	31.32	60.29	31.65	30.79	6.18
AMS	30.84	62.34	38.10	19.44	7.00
BUD	29.65	56.67	23.09	25.95	17.32
LIS	28.94	64.46	29.29	14.79	12.25
RIX	28.77	32.54	30.60	36.54	15.29
ATH	28.02	52.18	36.39	18.95	6.91
LUX	27.07	53.60	25.20	10.31	23.50
BRU	27.00	48.56	32.73	23.25	5.60
OTP	25.38	45.84	16.16	32.93	10.00
LCA	25.21	24.30	20.18	12.96	44.49
SOF	24.60	38.29	19.80	12.47	30.70
WAW	24.16	50.65	25.07	15.75	8.77
LJU	20.84	31.89	16.49	24.87	11.86
HEL	20.01	20.44	13.34	28.70	18.09
TLL	17.20	29.19	16.92	15.99	8.29
VNO	16.14	21.84	11.64	26.01	5.92
MLA	11.06	31.29	5.88	2.52	8.14
BTS	8.71	16.99	5.33	12.22	1.62
[tudo inf.]	0.00	0.00	0.00	0.00	0.00
	Weights :	0.2160	0.2790	0.2580	0.2470

Table 14: European Airport Scores for MACBETH+ Study Case

	Overall	MOVS/ STANDS	MOVS/ RWS	PAX/ PAX TA	CARGO/ CARGO TA	PAX/ CHK-IN	PAX / GATES	MOVS/ GATES	MOVS/ BELTS
[tudo sup.]	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
TXL	62.43	100.00	34.48	96.52	4.69	100.00	56.79	45.90	28.17
FCO	58.48	69.49	34.03	28.49	100.00	40.74	81.23	58.26	68.45
VIE	53.64	65.32	51.69	34.01	29.03	67.01	51.69	50.22	96.54
RIX	52.00	32.54	30.60	36.54	15.29	61.31	84.14	100.00	100.00
ARN	50.84	44.53	29.54	100.00	9.47	66.00	45.47	41.92	52.66
AMS	50.00	62.34	38.10	19.44	7.00	66.33	100.00	70.61	65.54
LHR	49.28	62.87	100.00	25.92	31.62	65.50	47.64	27.23	28.42
CPH	46.59	62.97	35.53	24.96	13.00	83.15	51.48	47.89	69.66
CDG	44.49	44.83	53.22	26.54	10.10	55.77	89.11	61.72	32.36
MAD	38.71	52.31	45.09	12.48	62.00	47.70	39.14	28.19	22.67
LIS	38.11	64.46	29.29	14.79	12.25	44.39	53.61	42.12	54.71
BRU	37.18	48.56	32.73	23.25	5.60	60.14	29.87	30.96	80.21
ATH	36.62	52.18	36.39	18.95	6.91	38.54	54.55	54.51	43.25
PRG	36.58	60.29	31.65	30.79	6.18	37.12	41.09	43.76	41.37
BUD	34.92	56.67	23.09	25.95	17.32	44.51	42.55	43.69	25.15
DUB	34.81	39.84	34.02	38.20	15.24	40.85	46.84	33.97	27.80
WAW	32.31	50.65	25.07	15.75	8.77	27.59	30.22	32.19	81.94
HEL	31.92	20.44	13.34	28.70	18.09	64.17	64.15	34.26	26.16
LUX	31.58	53.60	25.20	10.31	23.50	26.47	18.04	50.33	54.90
LCA	29.75	24.30	20.18	12.96	44.49	32.94	52.35	38.19	26.38
LJU	29.08	31.89	16.49	24.87	11.86	40.47	19.09	45.61	53.90
OTP	28.44	45.84	16.16	32.93	10.00	18.65	28.60	36.31	35.21
SOF	27.66	38.29	19.80	12.47	30.70	25.67	37.05	41.88	21.57
MLA	25.55	31.29	5.88	2.52	8.14	51.81	63.55	42.31	19.23
TLL	25.12	29.19	16.92	15.99	8.29	27.22	28.89	50.70	36.88
VNO	19.76	21.84	11.64	26.01	5.92	21.93	22.17	29.88	19.01
BTS	18.06	16.99	5.33	12.22	1.62	21.00	35.91	47.86	17.40
[tudo inf.]	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Weights :	0.1643	0.1288	0.1756	0.1284	0.1116	0.1034	0.0952	0.0927

Table 15: Efficiency Ranking for European Airports in the Four Cases

Airport	DEA	Rank DEA	DEA+	Rank DEA+	MACBETH	Rank MACBETH	MACBETH+	Rank MACBETH+
Vienna	100,00	1	100,00	1	44,48	5	53,64	3
Brussels	72,55	18	92,73	15	27	17	37,18	12
Sofia	61,48	24	75,40	24	24,6	20	27,66	23
Larnaka	70,10	21	84,93	22	25,21	19	29,75	20
Prague	75,70	15	85,43	21	31,32	10	36,58	14
Copenhagen	78,40	14	100,00	1	33,16	8	46,59	8
Tallinn	55,32	25	69,62	25	17,2	24	25,12	25
Helsinki	71,86	20	96,08	13	20,01	23	31,92	18
Paris	99,13	9	100,00	1	33,88	7	44,49	9
Berlin	100,00	1	100,00	1	57,28	1	62,43	1
Athens	72,17	19	94,25	14	28,02	15	36,62	13
Budapest	74,93	16	83,07	23	29,65	12	34,92	15
Dublin	90,42	12	90,42	17	31,72	9	34,81	16
Rome	100,00	1	100,00	1	56,56	2	58,48	2
Riga	100,00	1	100,00	1	28,77	14	52	4
Vilnius	63,14	23	63,14	26	16,14	25	19,76	26
Luxemburg	100,00	1	100,00	1	27,07	16	31,58	19
Valeta	42,22	26	86,16	20	11,06	26	25,55	24
Amsterdam	91,27	11	100,00	1	30,84	11	50	6
Warsaw	65,81	22	86,17	19	24,16	21	32,31	17
Lisbon	73,61	17	90,53	16	28,94	13	38,11	11
Bucharest	88,14	13	88,14	18	25,38	18	28,44	22
Bratislava	21,94	27	50,73	27	8,71	27	18,06	27
Ljubljana	93,41	10	100,00	1	20,84	22	29,08	21
Madrid	100,00	1	100,00	1	42,41	6	38,71	10
Stockholm	100,00	1	100,00	1	46	4	50,84	5
London	100,00	1	100,00	1	55,98	3	49,28	7

In figures 4.15 to 4.24 is shown a comparison between the obtained efficiency values for each airport in DEA and MACBETH tools, and for each case.

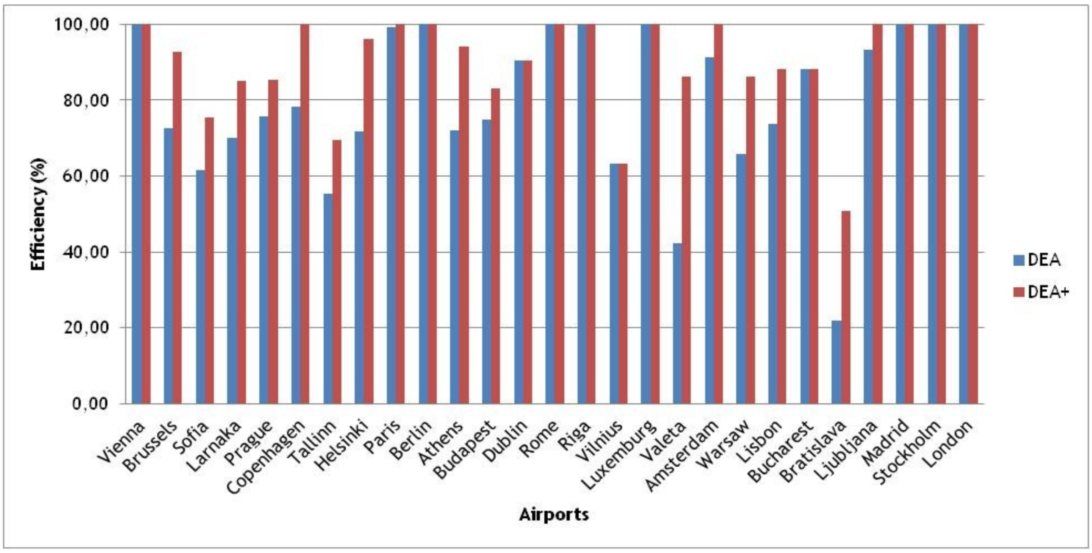

Figure 4.15: Comparative Efficiency between DEA and DEA+ for European Airports

As presented in figure 4.15, the addition of new performance indicators does not affect the efficiency for some airports as some of them continue with an efficiency value of 100%, i.e. Vienna, Berlin, Rome, Riga, Luxemburg, Madrid, Stockholm and London. These values show a high increase for Valeta (Malta) that changed from 42,22% to 86,16%, as seen in table 15, followed by Bratislava, Brussels, Copenhagen and Helsinki, that present a significant increase too. Lisbon airport changed from 73,61% to 90,53%. There were no airports lowing in the efficiency for this case.

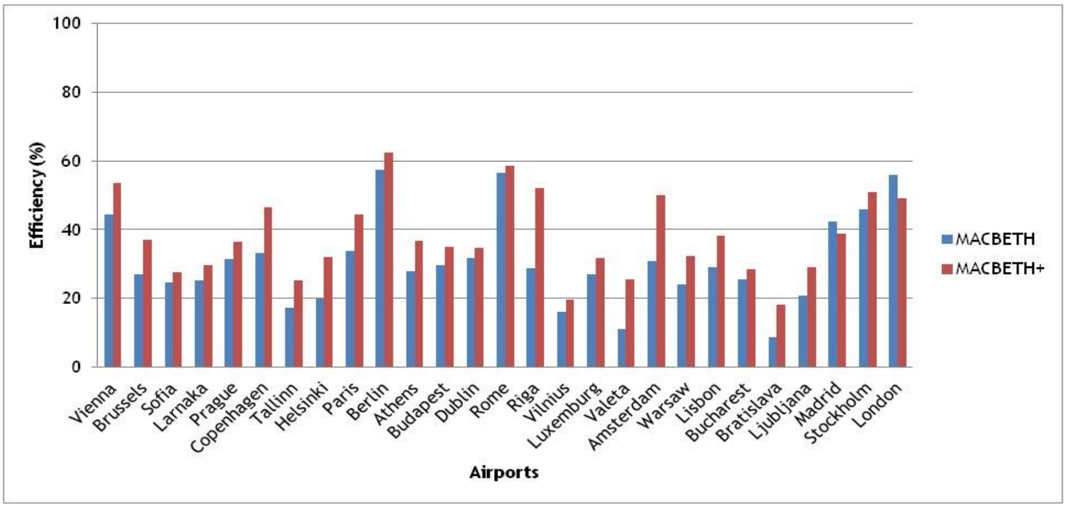

Figure 4.16: Comparative Efficiency between MACBETH and MACBETH+ for European Airports

For MACBETH cases in figure 4.16, the most relevant increase was for Riga and Amsterdam, followed by Vienna, Brussels and Copenhagen. In the case of Lisbon airport, is visible an increase from 28,94% to 38,11%, as seen in table 15. The addition of new indicators caused a drop in the efficiency value only for Madrid and London.

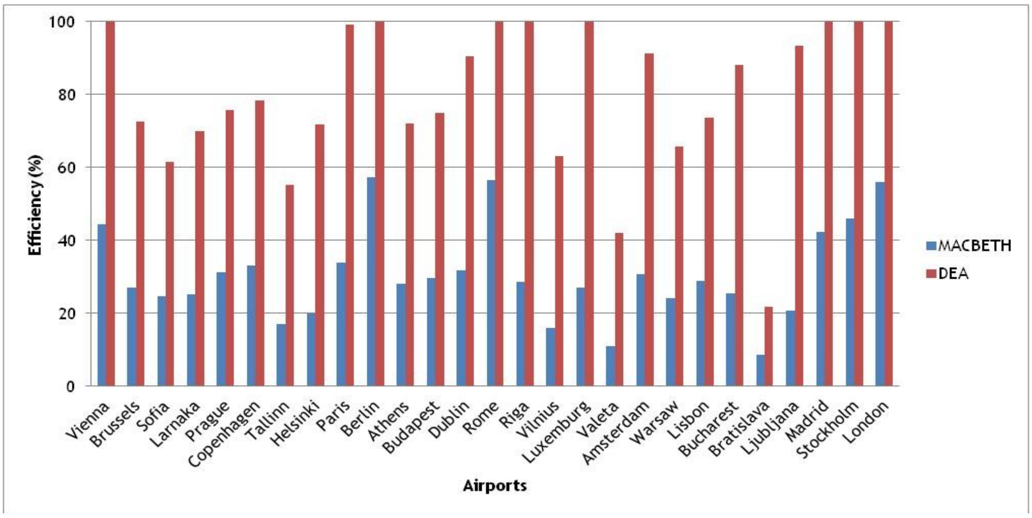

Figure 4.17: Comparative Efficiency Between MACBETH and DEA for European Airports

In figure 4.17 in shown a comparison between MACBETH and DEA efficiency values, where is visible the differences between these two tools. The main differences are for Luxemburg and Ljubljana which had respectively 100% and 93,41% efficiency for DEA but not so much for MACBETH. Berlin-Tegel airport had the best score value in both approaches. Bratislava gets the lower efficiency values. Equally in the case of Lisbon airport is visible these differences, in which DEA gives a better score than MACBETH (73,61% and 28,94%, respectively).

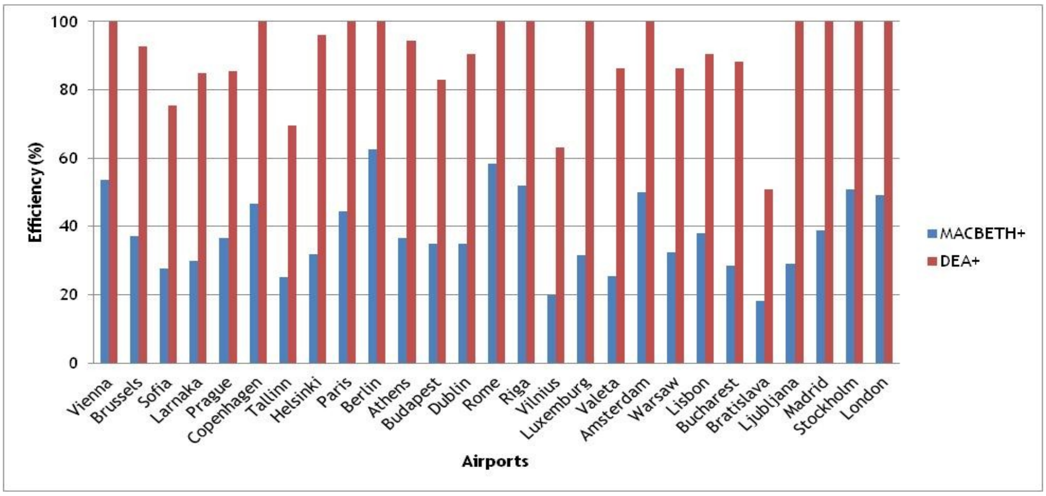

Figure 4.18: Comparative Efficiency between MACBETH+ and DEA+ for European Airports

Now comparing the efficiency results for both approaches, after the new indicators addition, the best values are again to Berlin-Tegel airport, and the main differences are again to Luxemburg, Ljubljana and Madrid, followed by Paris, Copenhagen, Amsterdam, Stockholm, London and Vienna. Bratislava had again the lowest efficiency values and Lisbon 90,53% and 38,11% for DEA+ and MACBETH+, respectively.

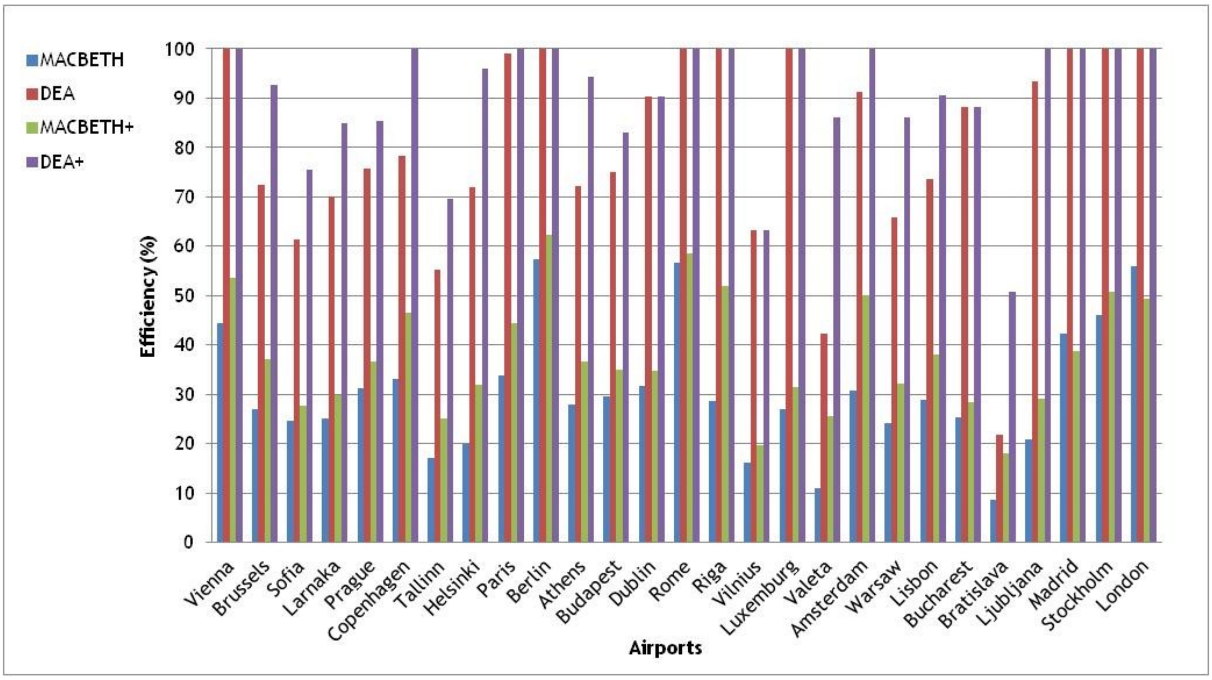

Figure 4.19: European Airports Comparative Efficiency for all Cases

The efficiency results obtained with MACBETH and DEA approaches are quite different. From figures 4.15 to 4.18, or from figure 4.19 and table 15 (direct comparison), it's possible to observe the variation on efficiency values, due the use of those two different tools. Some airports have different values between approaches, and in general, DEA approach gives higher efficiency values than MACBETH, being Bucharest, Ljubljana and Luxemburg the airports with more difference between tools score.

Figures 4.20 to 4.24 allow another perspective, i.e. the efficiency ranking which is the core of this study. Figures 4.20 and 4.21 present a comparison between rankings, before and after the addition of new indicators.

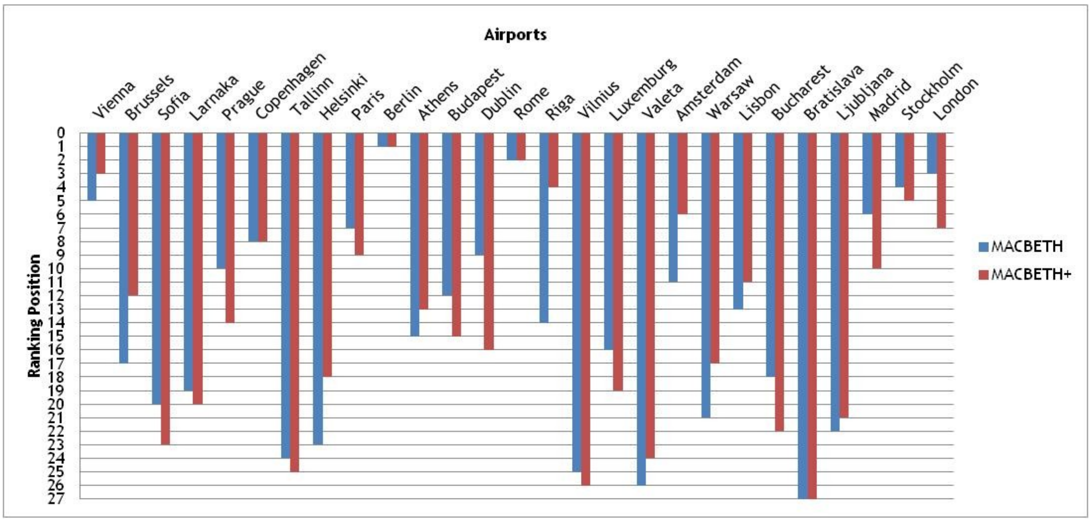

Figure 4.20: Balance between MACBETH and MACBETH+ Rankings for European Airports

Comparing the transition from MACBETH to MACBETH+, which represents again the adding of new indicators, in figure 4.20 it's possible to observe that there are some similarities as for Copenhagen, Berlin, and Rome, but also that there some discrepancies as for Brussels, Helsinki, Dublin, Riga and Amsterdam. Lisbon got 13th position in MACBETH and 11th position in MACBETH+, and Berlin got 1st position in both approaches.

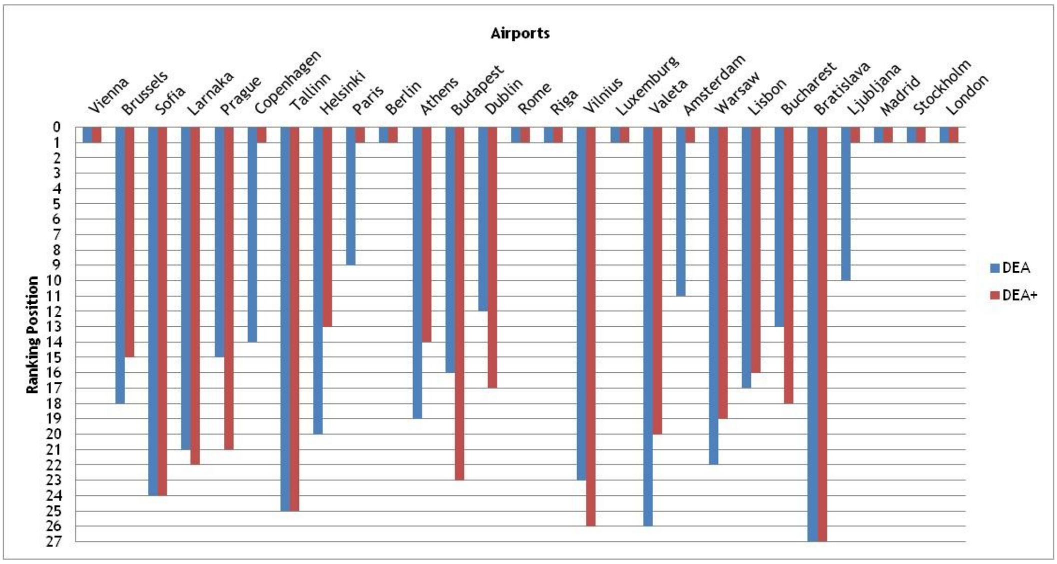

Figure 4.21: Balance between DEA and DEA+ Rankings for European Airports

Comparing the transition from DEA to DEA+ in figure 4.21, which represents the adding of new indicators, it's possible to observe that there are some similarities as for Vienna, Sofia, Tallinn, Berlin, Rome, Riga, Luxemburg, Lisbon, Bratislava, Madrid, Stockholm and London, but also there are great discrepancies as for Paris, Amsterdam and Ljubljana. Lisbon got 17th position in DEA and 16th position in DEA+.

Also in figures 4.22 and 4.23, a new comparison is shown, now between tools.

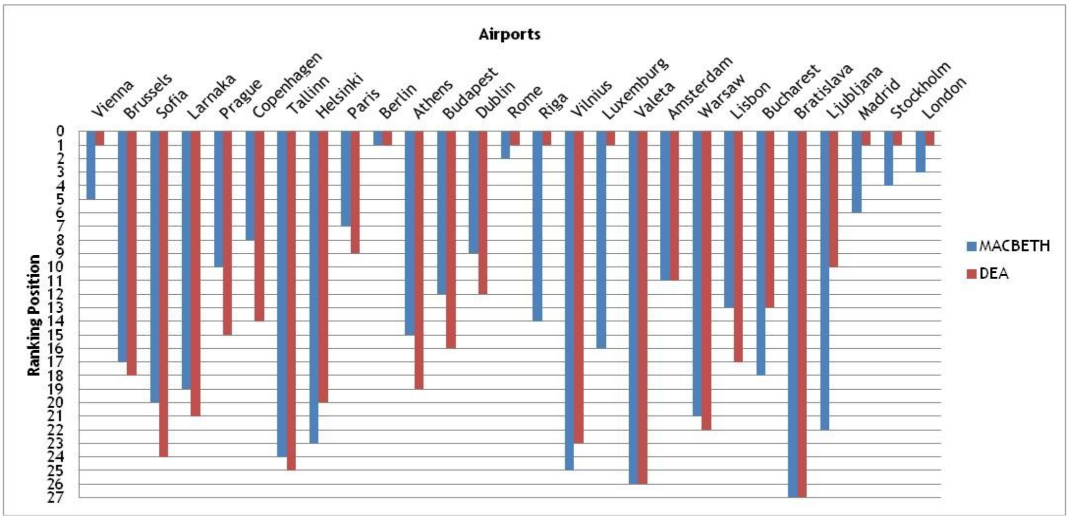

Figure 4.22: Balance between MACBETH and DEA Rankings for European Airports

From ranking comparison between tools of figures 4.22 and 4.23, is visible again the high influence for some airports as Riga, Luxemburg and Ljubljana (figure 4.22), and Copenhagen, Paris, Luxemburg, Ljubljana and Madrid (figure 4.23).

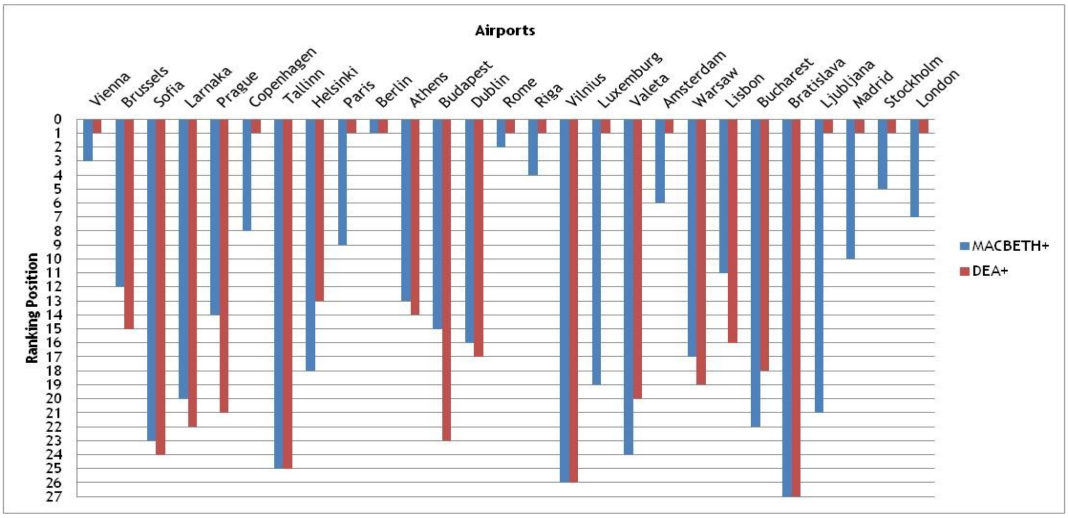

Figure 4.23: Balance between MACBETH+ and DEA+ Rankings for European Airports

In figure 4.24, a direct comparison between cases and tools is done.

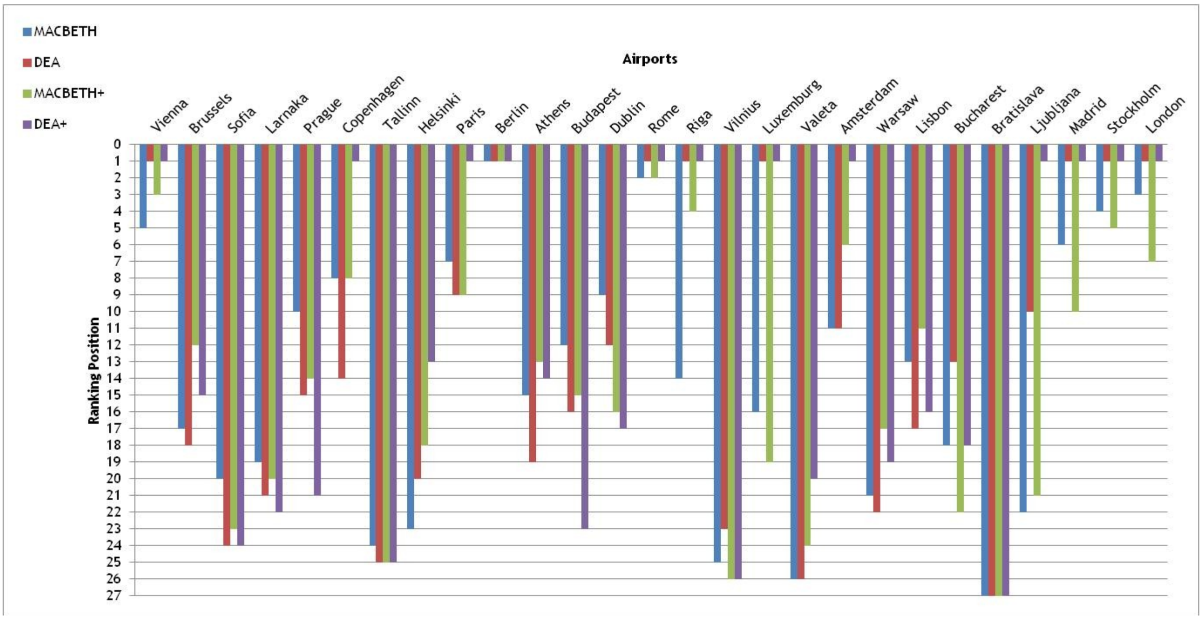

Figure 4.24: European Airports Comparative Ranking for all Cases

Berlin (Tegel) airport in Germany takes 1st place in the ranking for all case studies, because as visible in tables 13 and 14, it takes the maximum score in two indicators (of MACBETH+ analysis): MOVS/STANDS, and PAX/CHK-IN. Heathrow airport had the best score in MOVS/RWS, Stockholm airport in PAX/PAX TA, Rome airport in CARGO/CARGO TA, Amsterdam airport in PAX/GATES, and Riga airport in MOVS/GATES and MOVS/BELTS. Bratislava airport has a low position in all case studies, taking 27th place. Lisbon got 13th in MACBETH, 11th in MACBETH+, and 17th in DEA, 16th in DEA+.

4.2.3. CASE III - Iberian Airports Benchmarking Study

After the European analysis, a study focused in Iberian infrastructures was done. It was decided taking into account a performance study done by Braz (2011) with MACBETH based on a set of airports, using only Passengers, Movements and Cargo from 2006. However, our analysis will include the most relevant airports in a total of 46 infrastructures (37 in Spain and 9 in Portugal) including Azores, Madeira, Canaries and Baleares Islands, and Melilla and Ceuta territories in northwest Africa, as presented in figure 4.25.

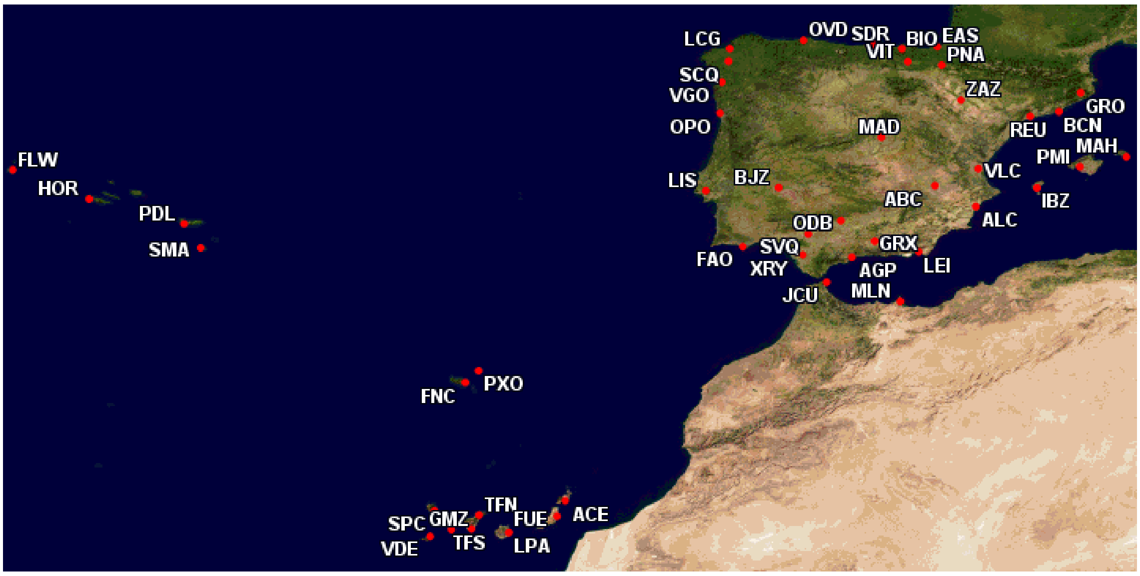

Figure 4.25: Map with Indication of the Iberian Airports used in this Study (Great Circle Mapper, 2012)

As in the previous cases, it was necessary to get the same data for these airports to produce an efficiency ranking, as presented in table 16. In order to this, it was necessary to be in contact with both airport entities, AENA *Aeropuertos* - for Spain and ANA, Aeroportos de Portugal - for the Portuguese ones, and asking for data for each airport. We consulted several Master Plans and updated Statistical data, taking into account, when possible, changes in the infrastructures after the Master Plans publication.

Table 16: Iberian Airports Data - from the list in the References

										STATISTICS 2011		
Country	Airport	IATA	RWS	STANDS	PAX TA	CARGO TA	CHK-IN	GATES	BELTS	MOVS	PAX	CARGO
Spain	**A Coruña**	**LCG**	1	4	5452	5452	10	4	3	16283	1012800	251,966
Spain	**Albacete**	**ABC**	1	2	1700	324	4	2	1	937	8415	0
Spain	**Alicante**	**ALC**	1	26	333500	6705	98	26	16	75576	9913731	3011,643
Spain	**Almeria**	**LEI**	1	14	25000	1180	27	6	4	14946	780853	9,836
Spain	**Asturias**	**OVD**	1	5	10540	712	14	9	3	15348	1339010	136,772
Spain	**Badajoz**	**BJZ**	1	6	2300	2300	9	3	3	2957	56981	0
Spain	**Barcelona**	**BCN**	3	168	674759	43692	258	149	28	303054	34398226	96572,86
Spain	**Bilbao**	**BIO**	2	21	6494	3555	36	14	7	54446	4046172	2633,519
Spain	**Ceuta**	**JCU**	1	3	455	455	1	1	1	5129	46754	1,18
Spain	**Cordoba**	**ODB**	1	5	1150	1150	1	1	1	7273	8442	0
Portugal	**Faro**	**FAO**	1	29	68500	1050	60	36	5	44879	5617786	224,3
Portugal	**Flores**	**FLW**	1	1	1500	120	3	1	1	1439	45447	210,8
Spain	**Fuerteventura**	**FUE**	1	19	93000	224	65	24	13	44549	4948018	1557,664
Spain	**Girona**	**GRO**	1	18	27274	27274	33	15	5	27799	3007977	62,495
Spain	**Gomera**	**GMZ**	1	3	3043	3043	5	2	2	1769	32713	8,239
Spain	**Gran Canaria**	**LPA**	2	55	87072	10680	96	38	16	111271	10538829	23678,51
Spain	**Granada**	**GRX**	1	11	8468	400	12	4	4	13142	872752	34,472
Spain	**El Hierro**	**VDE**	1	3	2564	2564	5	2	1	4674	170225	135,042
Portugal	**Horta**	**HOR**	1	3	6605	270	6	2	1	4650	192064	755,5
Spain	**Ibiza**	**IBZ**	1	24	33496	2406	71	17	10	61768	5643180	2755,176
Spain	**Jerez**	**XRY**	1	12	5270	75	21	7	4	41713	1032493	54,437
Spain	**La Palma**	**SPC**	1	6	5772	891	25	6	4	19455	1067431	851,928
Spain	**Lanzarote**	**ACE**	1	22	40610	770	49	17	7	49675	5543744	2872,585
Portugal	**Lisboa**	**LIS**	2	58	236025	18625	128	50	7	143331	14805601	94355
Portugal	**Madeira**	**FNC**	1	16	44590	4500	40	16	4	21346	2311380	5095
Spain	**Madrid**	**MAD**	4	220	940000	62600	400	230	52	429390	49671270	394154,1
Spain	**Málaga**	**AGP**	1	47	102625	4155	151	47	21	107397	12823117	2991,646
Spain	**Mallorca**	**PMI**	2	132	86600	5400	204	84	18	180152	22726707	15777,1
Spain	**Melilla**	**MLN**	1	5	1837	300	6	3	2	9119	286701	265,905
Spain	**Menorca**	**MAH**	1	20	20064	1410	42	16	6	28042	2576200	2070,983
Spain	**Pamplona**	**PNA**	1	7	3222	3222	9	3	2	9604	238511	34,162
Portugal	**Ponta Delgada**	**PDL**	1	14	13637	2200	14	3	3	12327	933763	5900,9
Portugal	**Porto**	**OPO**	1	35	69112	19141	60	23	4	61647	6004589	34080,7
Portugal	**Porto Santo**	**PXO**	1	7	9480	80	6	5	1	2816	106592	142,6
Spain	**Reus**	**REU**	1	5	3905	3905	23	12	3	21494	1362683	34,818
Spain	**San Sebastian**	**EAS**	1	6	2700	110	6	2	3	9560	248050	32,031
Portugal	**Santa Maria**	**SMA**	1	6	3069	132,5	3	2	1	3353	93902	2688,9
Spain	**Santander**	**SDR**	1	12	4197	728	8	7	3	17072	1116398	1,055
Spain	**Santiago**	**SCQ**	1	28	74000	3244	22	15	5	22322	2464330	1787,504
Spain	**Sevilla**	**SVQ**	1	23	62000	5943	42	15	12	56021	4959359	5126,653
Spain	**Tenerife Norte**	**TFN**	1	20	46108	4080	47	16	6	62604	4095103	15745,28
Spain	**Tenerife Sul**	**TFS**	1	42	64000	11000	87	37	14	58093	8656487	4479,65
Spain	**Valencia**	**VLC**	1	15	37250	3596	63	28	12	70397	4979511	10508,67
Spain	**Vigo**	**VGO**	1	5	7812	1900	12	8	3	14130	976152	1113,664
Spain	**Vitoria**	**VIT**	1	19	6996	2434	6	3	2	7582	28211	34692,26
Spain	**Zaragoza**	**ZAZ**	2	15	10000	10000	15	6	3	11970	751097	48647,4

In order to use the MACBETH analysis, it was necessary again to obtain the complex indicators of table 17 for each airport; the respective weights are again those of table 7.

Table 17: Complex Indicators for Iberian Airports

AIRPORT	MOVS/ STANDS	MOVS/ RWS	PAX/ PAX TA	CARGO/ CARGO TA	PAX/ CHK-IN	PAX/ GATES	MOVS/ GATES	MOVS/ BELTS
A Coruña	4070,75	16283,00	185,77	0,05	101280,00	253200,00	4070,75	5427,67
Albacete	468,50	937,00	4,95	0,00	2103,75	4207,50	468,50	937,00
Alicante	2906,77	75576,00	29,73	0,45	101160,52	381297,35	2906,77	4723,50
Almeria	1067,57	14946,00	31,23	0,01	28920,48	130142,17	2491,00	3736,50
Asturias	3069,60	15348,00	127,04	0,19	95643,57	148778,89	1705,33	5116,00
Badajoz	492,83	2957,00	24,77	0,00	6331,22	18993,67	985,67	985,67
Barcelona	1803,89	101018,00	50,98	2,21	133326,46	230860,58	2033,92	10823,36
Bilbao	2592,67	27223,00	623,06	0,74	112393,67	289012,29	3889,00	7778,00
Ceuta	1709,67	5129,00	102,76	0,00	46754,00	46754,00	5129,00	5129,00
Cordoba	1454,60	7273,00	7,34	0,00	8442,00	8442,00	7273,00	7273,00
Faro	1547,55	44879,00	82,01	0,21	93629,77	156049,61	1246,64	8975,80
Flores	1439,00	1439,00	30,30	1,76	15149,00	45447,00	1439,00	1439,00
Fuerteventura	2344,68	44549,00	53,20	6,95	76123,35	206167,42	1856,21	3426,85
Girona	1544,39	27799,00	110,29	0,00	91150,82	200531,80	1853,27	5559,80
Gomera	589,67	1769,00	10,75	0,00	6542,60	16356,50	884,50	884,50
Gran Canaria	2023,11	55635,50	121,04	2,22	109779,47	277337,61	2928,18	6954,44
Granada	1194,73	13142,00	103,06	0,09	72729,33	218188,00	3285,50	3285,50
El Hierro	1558,00	4674,00	66,39	0,05	34045,00	85112,50	2337,00	4674,00
Horta	1550,00	4650,00	29,08	2,80	32010,67	96032,00	2325,00	4650,00
Ibiza	2573,67	61768,00	168,47	1,15	79481,41	331951,76	3633,41	6176,80
Jerez	3476,08	41713,00	195,92	0,73	49166,33	147499,00	5959,00	10428,25
La Palma	3242,50	19455,00	184,93	0,96	42697,24	177905,17	3242,50	4863,75
Lanzarote	2257,95	49675,00	136,51	3,73	113137,63	326102,59	2922,06	7096,43
Lisboa	2471,22	71665,50	62,73	5,07	115668,76	296112,02	2866,62	20475,86
Madeira	1334,13	21346,00	51,84	1,13	57784,50	144461,25	1334,13	5336,50
Madrid	1951,77	107347,50	52,84	6,30	124178,18	215962,04	1866,91	8257,50
Málaga	2285,04	107397,00	124,95	0,72	84921,30	272832,28	2285,04	5114,14
Mallorca	1364,79	90076,00	262,43	2,92	111405,43	270556,04	2144,67	10008,44
Melilla	1823,80	9119,00	156,07	0,89	47783,50	95567,00	3039,67	4559,50
Menorca	1402,10	28042,00	128,40	1,47	61338,10	161012,50	1752,63	4673,67
Pamplona	1372,00	9604,00	74,03	0,01	26501,22	79503,67	3201,33	4802,00
Ponta Delgada	880,50	12327,00	68,47	2,68	66697,36	311254,33	4109,00	4109,00
Porto	1761,34	61647,00	86,88	1,78	100076,48	261069,09	2680,30	15411,75
Porto Santo	402,29	2816,00	11,24	1,78	17765,33	21318,40	563,20	2816,00
Reus	4298,80	21494,00	348,96	0,01	59247,09	113556,92	1791,17	7164,67
San Sebastian	1593,33	9560,00	91,87	0,29	41341,67	124025,00	4780,00	3186,67
Santa Maria	558,83	3353,00	30,60	20,29	31300,67	46951,00	1676,50	3353,00
Santander	1422,67	17072,00	266,00	0,00	139549,75	159485,43	2438,86	5690,67
Santiago	797,21	22322,00	33,30	0,55	112015,00	164288,67	1488,13	4464,40
Sevilla	2435,70	56021,00	79,99	0,86	118079,98	330623,93	3734,73	4668,42
Tenerife Norte	3130,20	62604,00	88,82	3,86	87129,85	255943,94	3912,75	10434,00
Tenerife Sul	1383,17	58093,00	135,26	0,41	99499,85	233959,11	1570,08	4149,50
Valencia	4693,13	70397,00	133,68	2,92	79039,86	177839,68	2514,18	5866,42
Vigo	2826,00	14130,00	124,96	0,59	81346,00	122019,00	1766,25	4710,00
Vitoria	399,05	7582,00	4,03	14,25	4701,83	9403,67	2527,33	3791,00
Zaragoza	798,00	5985,00	75,11	4,86	50073,13	125182,83	1995,00	3990,00

Then we use MACBETH and DEA tools to get airports efficiency ranking based on a combination of the above mentioned indicators, and its related weights (tables 18 to 20, and figures 4.26 to 4.35).

Table 18: Iberian Airport Scores for MACBETH Study Case

	Global	MOVS/STANDS	MOVS/RWS	PAX/PAX TA	CARGO/CARGO TA
[tudo sup.]	100.00	100.00	100.00	100.00	100.00
VLC	48,97	100	65,55	21,45	14,37
MAD	46,72	41,59	99,95	8,48	31,02
BIO	45,7	55,24	25,35	100	3,64
AGP	44,47	48,69	100	20,05	3,54
PMI	44,1	29,08	83,87	42,12	14,37
REU	39,82	91,6	20,01	56,01	0
BCN	39,34	38,44	94,06	8,18	10,88
TFN	39,04	66,7	58,29	14,25	19
LIS	37,65	47,72	66,73	9,94	24,95
IBZ	36,26	54,84	57,51	27,04	5,66
XRY	35,83	74,07	38,84	31,44	3,59
ALC	34,79	61,94	70,37	4,77	2,21
ACE	33,48	48,11	46,25	21,91	18,36
FUE	33,02	49,96	41,48	8,54	34,22
LPA	31,47	43,11	51,8	19,42	10,93
LCG	30,72	86,74	15,16	29,81	0,25
SVQ	30,12	51,9	52,16	12,84	4,23
SMA	29,41	11,91	3,12	4,91	100
OPO	28,87	32,84	57,4	13,94	8,76
SPC	28,8	69,09	18,12	29,68	4,72
TFS	27,56	29,47	54,09	21,71	2,02
OVD	23,61	65,41	14,29	20,39	0,94
VGO	22,57	60,22	13,16	20,05	2,9
FAO	22,43	32,97	41,79	13,16	1,03
SDR	22	30,31	15,9	42,69	0
VIT	21,32	8,5	7,06	0,65	70,22
MAH	20,84	29,88	26,11	20,61	7,23
GRO	18,9	32,91	25,88	17,7	0
MLN	18,31	38,86	8,49	25,05	4,38
FNC	15,21	28,43	19,88	8,32	5,56
ZAZ	14,25	17	5,57	12,05	23,92
JCU	13,46	36,43	4,78	16,49	0
PDL	13,35	18,76	11,48	10,99	13,19
GRX	13,29	25,46	12,24	16,54	0,44
HOR	12,95	33,03	4,33	4,67	13,78
EAS	12,15	33,95	2,38	14,74	1,43
PNA	11,89	29,23	8,94	11,88	0,05
SCQ	11,52	16,99	20,78	5,34	2,71
VDE	11,19	33,2	4,35	10,65	0,25
FLW	10,39	30,66	1,34	4,86	8,66
LEI	10,09	22,75	13,92	5,01	0
ODB	8,89	30,99	6,77	1,18	0
PXO	5,21	8,57	2,62	1,8	8,76
BJZ	4,06	10,5	2,75	3,98	0
GMZ	3,62	12,56	1,65	1,73	0
ABC	2,6	9,98	0,87	0,79	0
[tudo inf.]	0.00	0.00	0.00	0.00	0.00
	Weights:	0.2160	0.2790	0.2580	0.2470

Table 19: Iberian Airport Scores for MACBETH+ Study Case

	Global	MOVS/ STANDS	MOVS/ RWS	PAX/ PAX TA	CARGO/ CARGO TA	PAX/ CHK-IN	PAX/ GATES	MOVS/ GATES	MOVS/ BELTS
[tudo sup.]	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
BIO	55,81	55,24	25,35	100	3,64	80,54	75,8	53,47	37,99
LIS	52,52	52,66	66,73	10,07	24,95	82,89	77,66	39,41	100
PMI	48,41	29,08	83,87	42,12	14,37	79,83	70,96	29,49	48,88
VLC	47,58	100	65,55	21,45	14,37	56,64	46,64	34,57	28,65
TFN	47,16	66,7	58,29	14,25	19	62,44	67,12	53,8	50,96
MAD	47,15	41,59	99,95	8,48	31,02	88,98	56,64	25,67	40,33
BCN	45,75	38,44	94,06	8,18	10,88	95,54	60,55	27,97	52,86
ACE	44,99	48,11	46,25	21,91	18,36	81,07	85,52	40,18	34,66
IBZ	44,8	54,84	57,51	27,04	5,66	56,96	87,06	49,96	30,17
ALC	44,74	61,94	70,37	4,77	2,21	72,49	100	39,97	23,07
AGP	44,35	48,69	100	20,05	3,54	60,85	71,55	31,42	24,98
XRY	43,61	74,07	38,84	31,44	3,59	35,23	38,68	81,93	50,93
SVQ	43,45	51,9	52,16	12,84	4,23	84,61	86,71	51,35	22,8
OPO	42,7	37,53	57,4	13,94	8,76	71,71	68,47	36,85	75,27
LPA	41,85	43,11	51,8	19,42	10,93	78,67	72,74	40,26	33,96
REU	40,87	91,6	20,01	56,01	0	42,46	29,78	24,63	34,99
LCG	36,94	86,74	15,16	29,81	0,25	7,37	66,4	55,97	26,51
SDR	35,78	30,31	15,9	42,69	0	100	41,83	33,53	27,79
FUE	35,1	49,96	41,48	8,54	34,22	54,55	54,07	25,52	16,74
TFS	34,12	29,47	54,09	21,71	2,02	71,3	61,36	21,59	20,27
SPC	33,96	69,09	18,12	29,68	4,72	30,6	46,66	44,58	21,31
OVD	32,52	65,41	14,29	20,39	0,94	68,54	39,02	23,45	24,99
FAO	30,66	32,97	41,79	13,16	1,03	67,09	40,93	17,14	43,84
VGO	29,74	60,22	13,16	20,05	2,9	58,29	32	24,29	23
GRO	29,52	32,91	25,88	17,7	0	65,32	52,59	25,48	27,15
PDL	29,2	18,76	11,48	10,99	13,19	47,79	81,63	56,5	20,07
MAH	26,5	29,88	26,11	20,61	7,23	43,95	42,23	24,1	22,83
GRX	26,24	25,46	12,24	16,54	0,44	52,12	57,22	45,17	16,05
MLN	24,89	38,86	8,49	25,05	4,38	34,24	25,06	41,79	22,27
SCQ	24,14	16,99	20,78	5,34	2,71	80,27	43,09	20,46	21,8
SMA	23,55	11,91	3,12	4,91	100	22,43	12,31	23,05	16,38
JCU	23,54	36,43	4,78	16,49	0	33,5	12,26	70,52	25,05
EAS	23,03	33,95	2,38	14,74	1,43	29,63	32,53	65,72	15,56
FNC	22,11	28,43	19,88	8,32	5,56	41,41	37,89	18,34	26,06
ZAZ	20,52	17	5,57	12,05	23,92	35,88	32,83	27,43	19,49
ODB	19,89	30,99	6,77	1,18	0	6,05	2,21	100	35,52
HOR	18,89	33,03	4,33	4,67	13,78	22,94	25,19	31,97	22,71
PNA	18,69	29,23	8,94	11,88	0,05	18,99	20,85	44,02	23,45
VDE	18,12	33,2	4,35	10,65	0,25	24,4	22,32	32,13	22,83
LEI	17,21	22,75	13,92	5,01	0	20,72	34,13	34,25	18,26
VIT	17,09	8,5	7,06	0,65	70,22	3,37	2,47	34,75	18,51
FLW	12,16	30,66	1,34	4,86	8,66	10,86	11,92	19,79	7,03
PXO	7,2	8,57	2,62	1,8	8,76	12,73	5,59	7,74	13,75
BJZ	5,54	10,5	2,75	3,98	0	4,54	4,98	13,55	4,81
GMZ	5,1	12,56	1,65	1,73	0	4,69	4,29	12,16	4,32
ABC	3,21	9,98	0,87	0,79	0	1,51	1,1	6,44	4,58
[tudo inf.]	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Weights	0.1643	0.1288	0.1756	0.1284	0.1116	0.1034	0.0952	0.0927

Table 20: Efficiency Ranking for Iberian Airports in the Four Cases

Airport	DEA	Rank DEA	DEA+	Rank DEA+	MACBETH	Rank MACBETH	MACBETH+	Rank MACBETH+
A Coruña	93,91	19	100,00	1	30,72	16	36,94	17
Albacete	12,29	46	12,93	46	2,6	46	3,21	46
Alicante	100,00	1	100,00	1	34,79	12	44.74	10
Almeria	29,09	22	52,57	39	10,09	41	17,21	40
Asturias	92,41	35	98,88	27	23,61	22	32,52	22
Badajoz	15,73	23	16,40	45	4,06	44	5,54	44
Barcelona	94,07	18	100,00	1	39,34	7	45,75	7
Bilbao	100,00	1	100,00	1	45,7	3	55,81	1
Ceuta	100,00	1	100,00	1	13,46	32	23,54	32
Cordoba	68,43	28	100,00	1	8,89	42	19,89	36
Faro	84,43	24	100,00	1	22,43	24	32,52	23
Flores	44,42	36	44,42	42	10,39	40	12,16	42
Fuerteventura	100,00	1	100,00	1	33,02	14	35,1	19
Girona	65,16	30	78,78	34	18,9	28	29,52	25
Gomera	13,55	45	17,52	44	3,62	45	5,1	45
Granada	50,46	33	80,65	33	13,29	34	26,24	28
Gran Canaria	82,95	25	100,00	1	31,47	15	41,85	15
Hierro	41,84	39	49,83	41	11,19	39	18,12	39
Horta	48,17	34	50,29	40	12,95	35	18,89	37
Ibiza	100,00	1	100,00	1	36,26	10	44,8	9
Jerez	100,00	1	100,00	1	35,83	11	43,61	12
Lanzarote	100,00	1	100,00	1	33,48	13	44,99	8
La Palma	91,61	22	91,90	29	28,8	20	33,96	21
Lisbon	100,00	1	100,00	1	38,75	9	52,52	2
Madeira	44,25	37	56,51	37	15,21	30	22,11	34
Madrid	100,00	1	100,00	1	46,72	2	47,15	6
Málaga	100,00	1	100,00	1	44,47	4	44,35	11
Mallorca	100,00	1	100,00	1	44,1	5	48,41	3
Melilla	62,40	32	72,09	35	18,31	29	24,89	29
Menorca	64,76	31	64,76	36	20,84	27	26,5	27
Pamplona	39,33	40	53,77	38	11,89	37	18,69	38
Ponta Delgada	43,78	38	100,00	1	13,35	33	29,2	26
Porto	98,05	17	100,00	1	28,87	19	42,7	14
Porto Santo	15,60	44	27,84	43	5,21	43	7,2	43
Reus	100,00	1	100,00	1	39,82	6	40,87	16
San Sebastian	45,81	35	81,10	32	12,15	36	23,03	33
Santa Maria	100,00	1	100,00	1	29,41	18	23,55	31
Santander	78,87	26	100,00	1	22	25	35,78	18
Santiago	30,78	41	82,86	31	11,52	38	24,14	30
Seville	70,76	27	100,00	1	30,12	17	43,45	13
Tenerife North	92,05	21	100,00	1	39,04	8	47,16	5
Tenerife South	88,09	23	95,49	28	27,56	21	34,12	20
Valencia	100,00	1	100,00	1	48,97	1	47,58	4
Vigo	68,00	29	84,81	30	22,57	23	29,74	24
Vitoria	100,00	1	100,00	1	21,32	26	17,09	41
Zaragoza	100,00	1	100,00	1	14,25	31	20,52	35

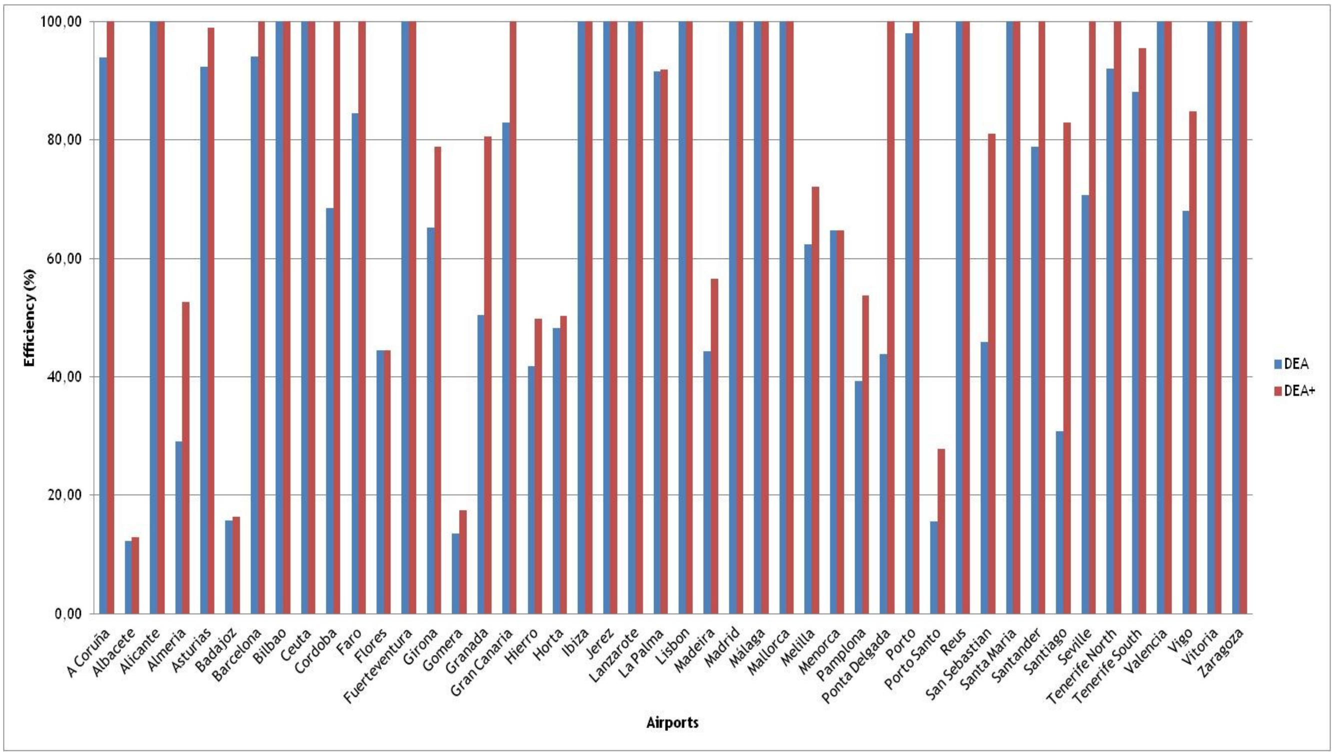

Figure 4.26: Comparative Efficiency between DEA and DEA+ for Iberian Airports

As presented in figure 4.26, the addition of new performance indicators does not affect the efficiency for some airports as some of them continue with the same efficiency value, i.e. Alicante, Bilbao, Ceuta, Flores, Fuerteventura, Ibiza, Jerez, Lanzarote, Madrid, Malaga, Mallorca, Menorca, Reus, Santa Maria, Valencia, Vitoria and Zaragoza. The major increases were for Ponta Delgada (changed from 43,78% to 100%) as seen in table 20, followed by Cordoba, Granada, San sebastian and Santiago de Compostela.

In the case of the Portuguese airports, in the transition from DEA to DEA+, as from table 20, we can observe that Lisbon airport maintain 100%, Porto changes from 98,05% to 100%, Faro from 84,43% to 100$%, Madeira from 44,25% to 56,51%, Porto Santo from 15,60% to 27,84%, Ponta Delgada from 43,78% to 100%, Santa Maria got 100% on both, Horta changes from 48,17% to 50,29% and Flores got 44,42% on both.

There were no airports lowing in the efficiency for this case, where Albacete airport got the lower efficiency value.

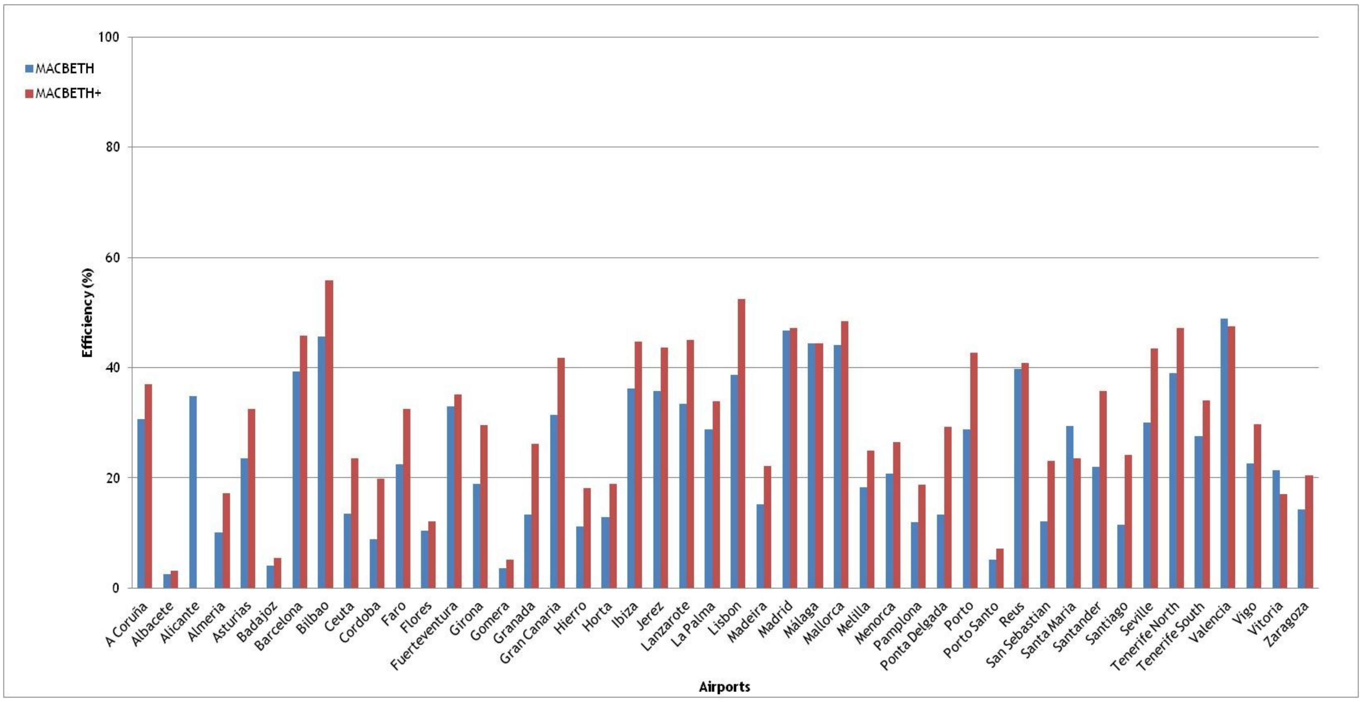

Figure 4.27: Comparative Efficiency between MACBETH and MACBETH+ for Iberian Airports

As presented in figure 4.27, the addition of new performance indicators shows a relevant increase for Lisbon, Ponta Delgada, Porto, Santander, and Seville. For Albacete, Badajoz, Flores, Fuerteventura, Gomera, Madrid, Malaga, Porto Santo, Reus and Valencia it was not a significant change.

In the case of the Portuguese airports, in the transition from MACBETH to MACBETH+, as from table 20, we can observe that Lisbon airport changes from 38,75% to 52,52%, Porto from 28,87% to 42,7%, Faro from 22,43% to 32,52%, Madeira from 15,21% to 22,11%, Porto Santo from 5,21% to 7,2%, Ponta Delgada from 13,35% to 29,2%, Santa Maria from 29,41% to 23,55%, Horta from 12,95% to 18,89% and Flores from 10,39% to 12,16%.

The addition of new indicators caused a drop in the efficiency value only for Santa Maria, Valencia and Vitoria. Valencia and Bilbao got the best efficiency values for MACBETH and MACBETH+, respectively, and Albacete airport got the lower one in both approaches.

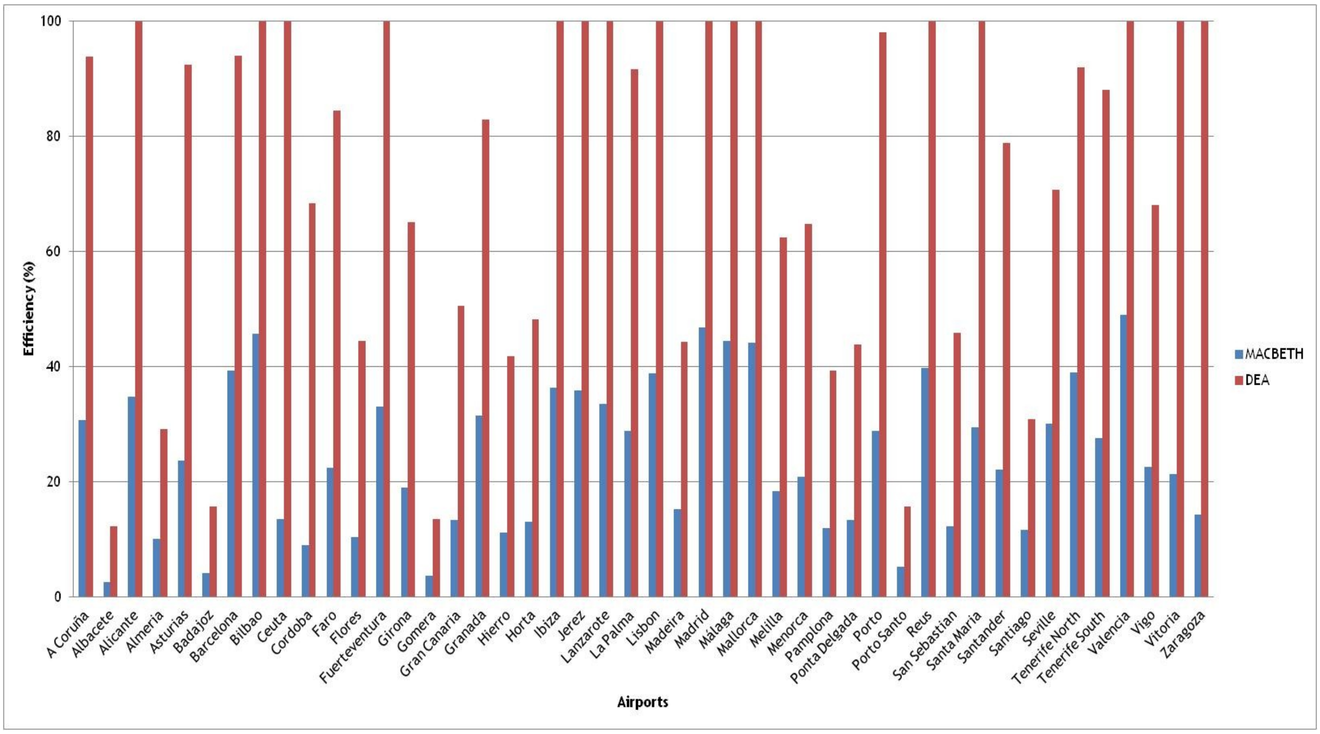

Figure 4.28: Comparative Efficiency between MACBETH and DEA for Iberian Airports

In figure 4.28 is shown a comparison between MACBETH and DEA efficiency values, where in general, DEA values are higher than MACBETH. The main differences are for Alicante, Barcelona, Bilbao, Ceuta, Cordoba, Fuerteventura, Ibiza, Jerez, Lanzarote, Lisbon, Madrid, Malaga, Mallorca, Reus, Santa Maria, Valencia, Vitoria and Zaragoza which had respectively 100% efficiency for DEA but not so much for MACBETH. Valencia airport had the best score in both approaches and Albacete got the lower efficiency values.

In the case of the Portuguese airports, MACBETH and DEA results, as from table 20, were, respectively, for Lisbon airport 38,75% and 100%, Porto 28,87% and 98,05%, Faro 22,43% and 84,43%, Madeira 15,21% and 44,25%, Porto Santo 5,21% and 15,60%, Ponta Delgada 13,35% and 43,78%, Santa Maria 29,41% and 100%, Horta 12,95% and 48,17%, and Flores 10,39% and 44,42%.

The airports which not had significant differences were Albacete, Badajoz, Gomera and Porto Santo.

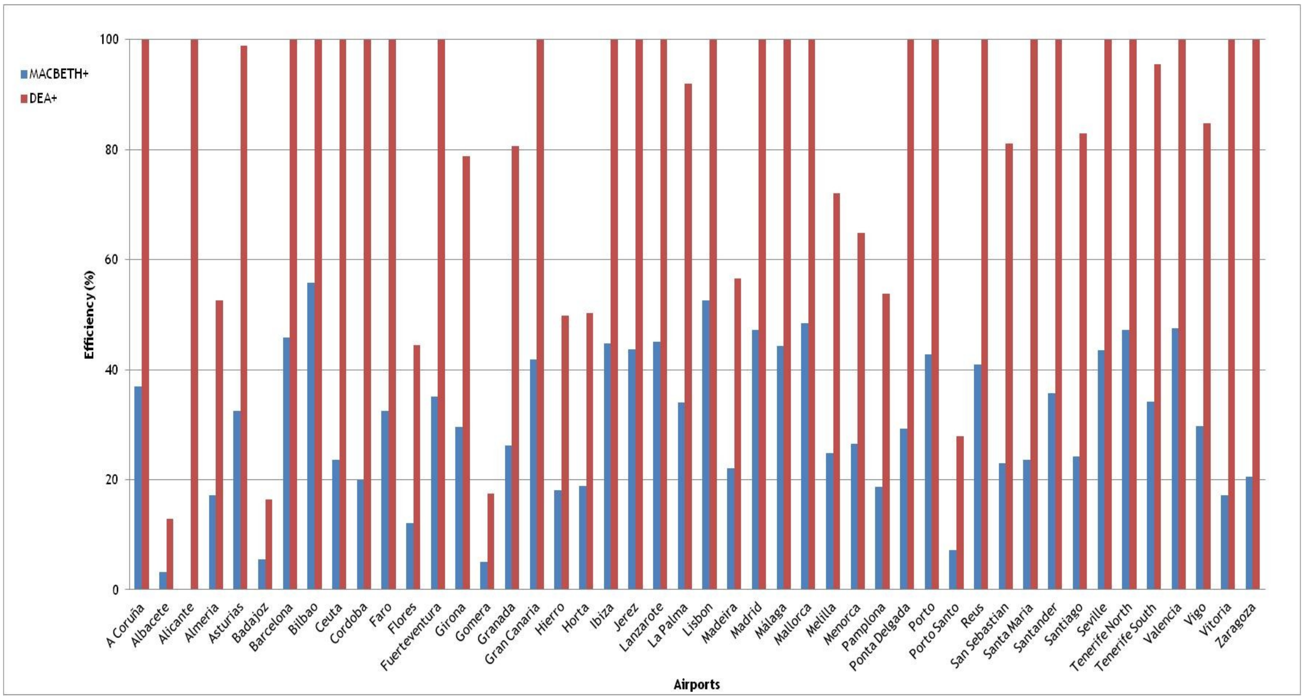

Figure 4.29: Comparative Efficiency Between MACBETH+ and DEA+ for Iberian Airports

In figure 4.29 is shown a comparison between MACBETH+ and DEA+ efficiency values, where in general and as in the previous analysis, DEA+ values are again higher than MACBETH+. The main differences are for Coruña, Alicante, Barcelona, Bilbao, Ceuta, Cordoba, Faro, Fuerteventura, Gran Canaria, Ibiza, Jerez, Lanzarote, Lisbon, Madrid, Malaga, Mallorca, Ponta Delgada, Porto, Reus, Santa Maria, Santander, Seville, Tenerife North, Valencia, Vitoria and Zaragoza which had respectively 100% efficiency for DEA+ but not so much for MACBETH+. Bilbao airport had the best score in both approaches and Albacete got the lower efficiency values.

In the case of the Portuguese airports, for MACBETH+ and DEA+ results,as from table 20, were respectively for Lisbon airport 53,52% and 100%, Porto 42,7% and 100%, Faro 32,52% and 100%, Madeira 22,11% and 56,51%, Porto Santo 7,2% and 27,84%, Ponta Delgada 29,2% and 100%, Santa Maria 23,55% and 100%, Horta 18,89% and 50,29%, and Flores 12,16% and 44,42%.

The airports which not had significant differences were Albacete, Badajoz and Gomera.

The efficiency results obtained with MACBETH and DEA approaches are quite different. From figures 4.26 to 4.29, or from figure 4.30 and table 20 (direct comparison), it's possible to observe the variation on efficiency values, due the use of those two distinct tools. Some airports have different values between approaches, and in general, DEA approach gives higher efficiency values than MACBETH.

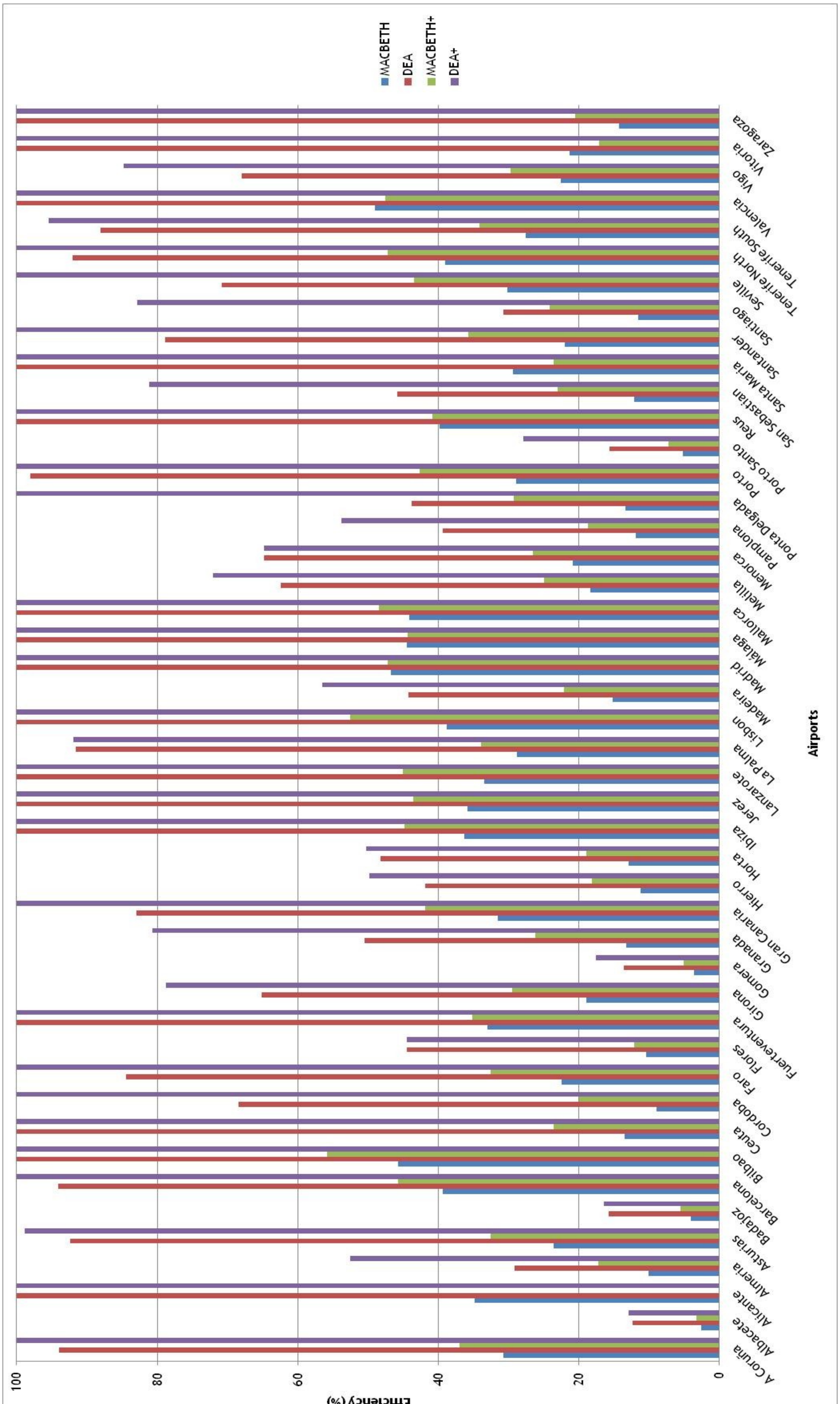

Figure 4.30: Iberian Airports Comparative Efficiency for all Cases

Figures 4.31 to 4.35 permit another perspective, i.e. the efficiency ranking which is the main target of this study. The first and the second ones present a comparison between rankings, before and after the addition of new indicators, and the last one present a comparison between tools, as in the previous analysis.

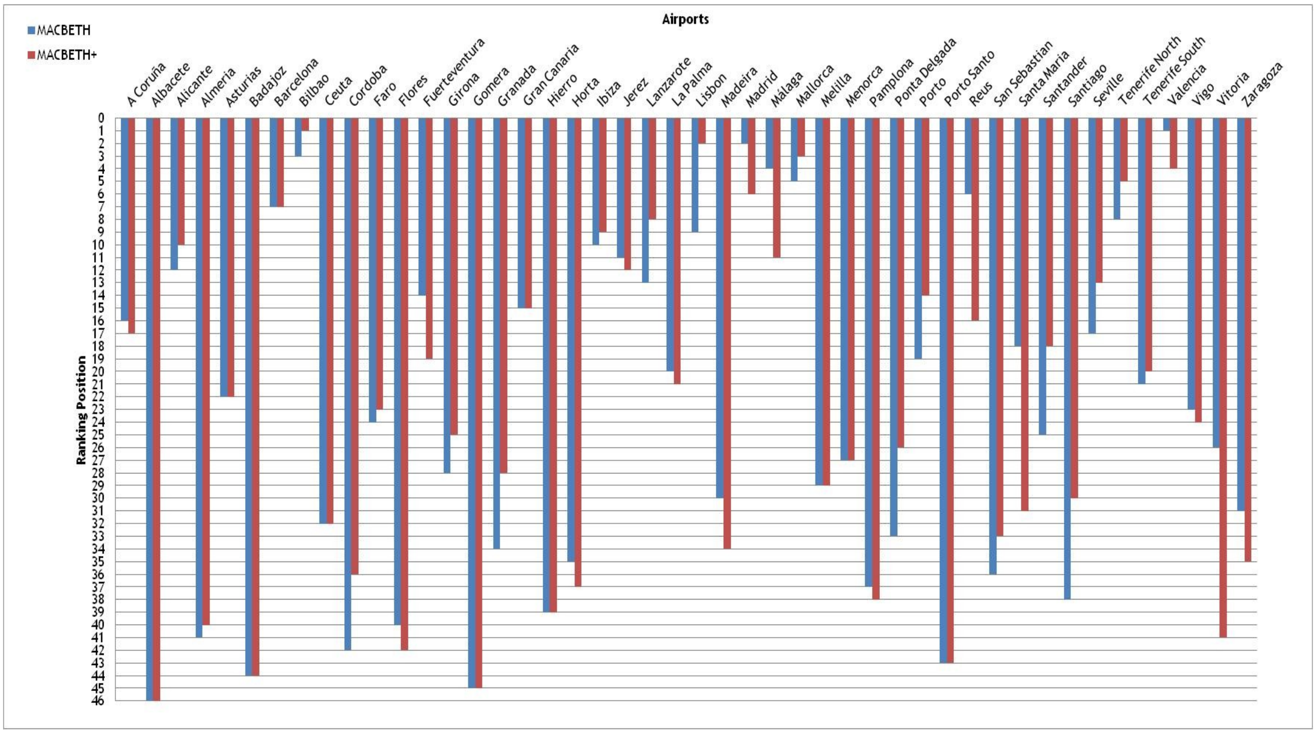

Figure 4.31: Balance between MACBETH and MACBETH+ Rankings for European Airports

Comparing the transition from MACBETH to MACBETH+, which represents the adding of new indicators, in figure 4.31, it's possible to observe that there are some similarities in the ranking as for Albacete, Asturias, Badajoz, Barcelona, Gomera, Gran Canaria, Hierro, Melilla, Menorca and Porto Santo, but also that there some discrepancies as for Cordoba, Granada, Lisbon, Malaga, Ponta Delgada, Santa Maria, Santiago, and Vitoria. Bilbao got 1st place in MACBETH+ and Valencia in MACBETH.

In the case of the Portuguese airports, in the transition from MACBETH to MACBETH+, as from table 20, we can observe that Lisbon airport change in the ranking from 9th position to 2nd position, Porto from 19th to 14th, Faro from 24th to 23rd, Madeira from 30th to 34th, Porto Santo maintained 43rd position, Ponta Delgada from 33rd to 26th, Santa Maria from 18th to 31nd, Horta from 35th to 37th and Flores from 40th to 42nd.

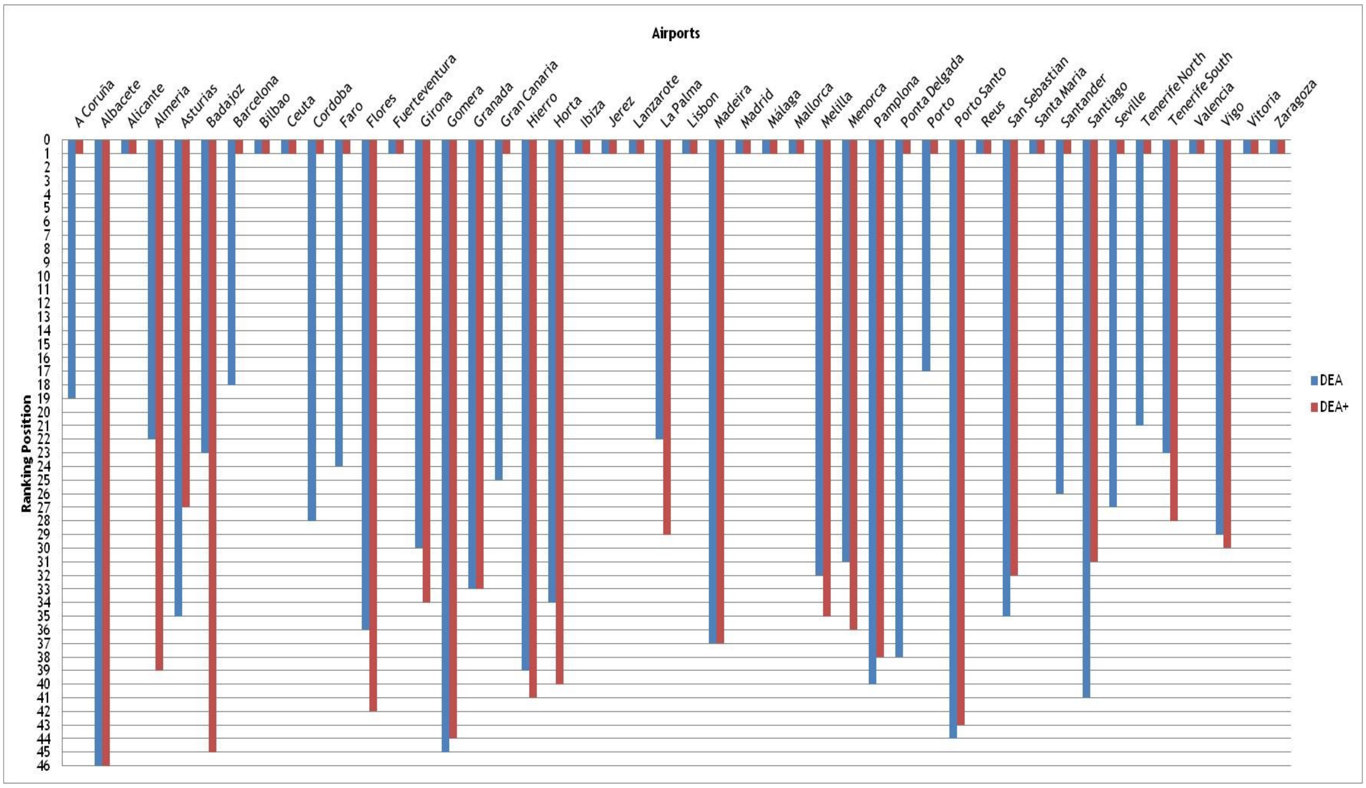

Figure 4.32: Balance between DEA and DEA+ Rankings for Iberian Airports

Comparing the transition from DEA to DEA+, in figure 4.32, which represents again the adding of new indicators, it's possible to observe that there are some similarities as for Albacete, Alicante, Bilbao, Ceuta, Fuerteventura, Granada, Ibiza, Jerez, Lanzarote, Lisbon, Madeira, Madrid, Malaga, Mallorca, Reus, Santa Maria, Valencia, Vitoria and Zaragoza, but also there are great discrepancies as for Coruña, Barcelona, Cordoba, Faro, La Palma, Ponta Delgada, Porto, Santander, Seville and Tenerife North.

In the case of the Portuguese airports, in the transition from DEA to DEA+, as from table 20, we can observe that Lisbon airport maintain 1st position, Porto changes from 17th to 1st, Faro from 24th to 1st, Madeira maintained 37th position, Porto Santo changes from 44th to 43rd, Ponta Delgada from 38rd to 1st, Santa Maria maintained 1st position, Horta changes from 34th to 40th and Flores from 36th to 42nd.

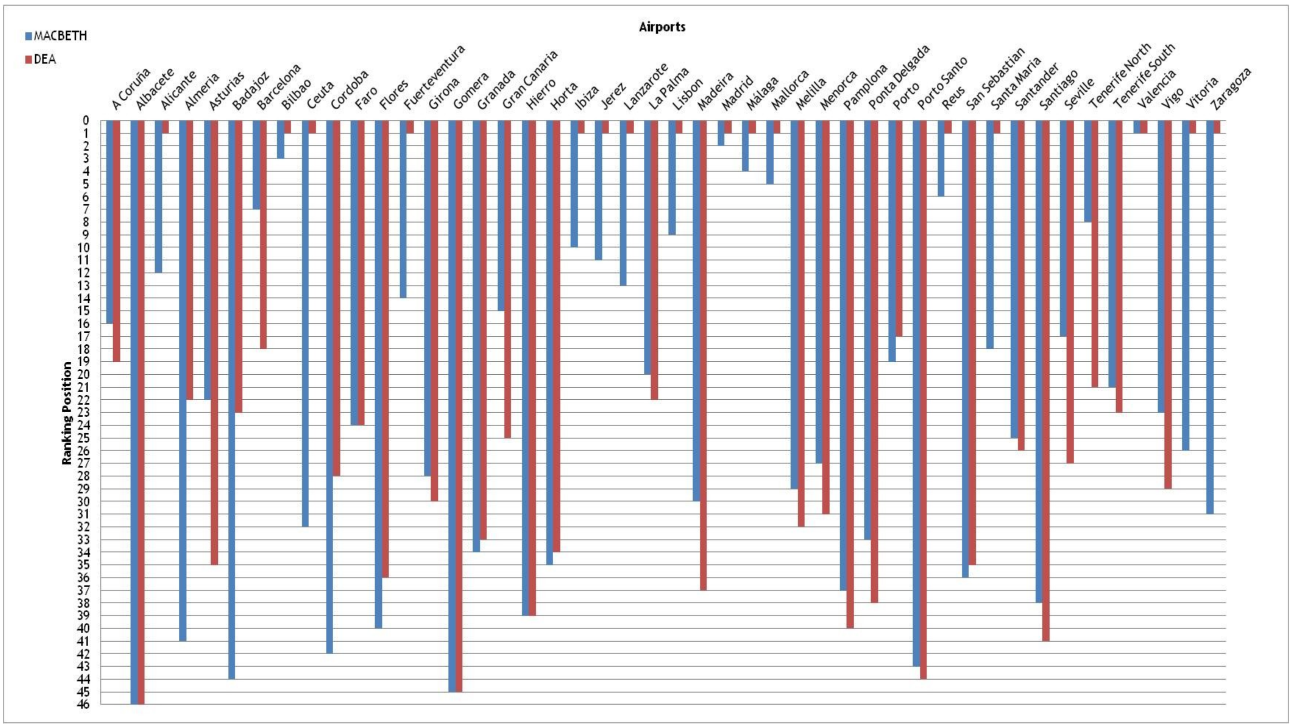

Figure 4.33: Balance Between MACBETH and DEA Rankings for Iberian Airports

In figure 4.33 is shown a comparison between MACBETH and DEA rankings, where the main differences were for Almeria, Badajoz, Barcelona, Ceuta, Cordoba, Fuerteventura, Ibiza, Jerez, Lanzarote, Lisbon, Madeira, Santa Maria, Vitoria and Zaragoza. Valencia airport had 1st position on both approaches and Albacete got last place, 46th. The airports which had not significant differences were Albacete, Faro, Gomera, Granada, Hierro, Horta, Madrid, Porto Santo, San Sebastian, Santander and Valencia.

In the case of the Portuguese airports, MACBETH and DEA rankings, as from table 20, were respectively for Lisbon airport 9th position and 1st position, Porto 19th and 17th, Faro maintained 24th position, Madeira 30th position and 37th position, Porto Santo 43rd and 44th, Ponta Delgada 33rd and 38th, Santa Maria 18th and 1st, Horta 35th and 34th,and Flores 40th and 36th.

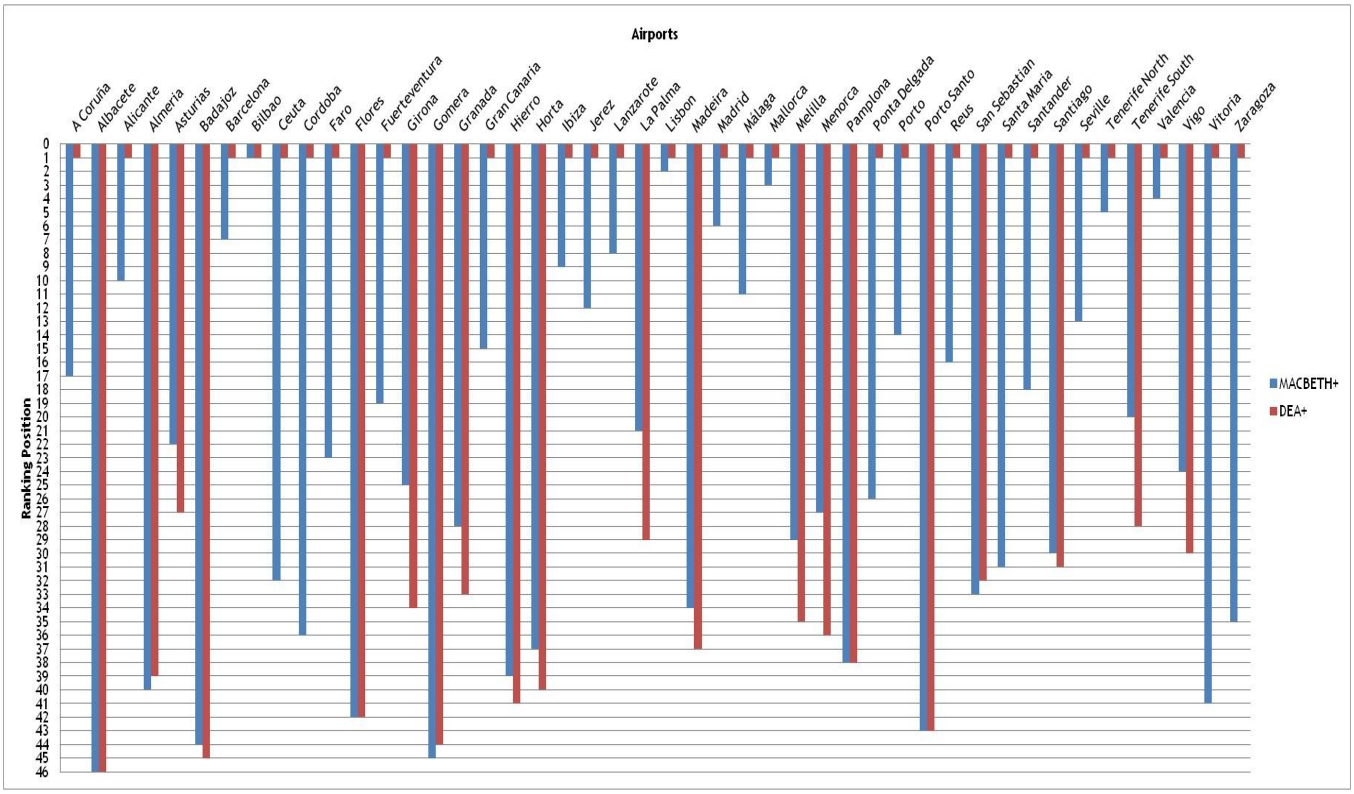

Figure 4.34: Balance between MACBETH+ and DEA+ Rankings for Iberian Airports

In figure 4.34 is shown a comparison between MACBETH+ and DEA+ rankings, where the main differences were for Coruña, Alicante, Ceuta, Cordoba, Faro, Fuerteventura, Girona, Gran Canaria, Ponta Delgada, Porto, Reus, Santa Maria, Santander, Seville, Vitoria and Zaragoza. Bilbao airport had 1st position on both approaches and Albacete got last place, 46th. The airports which had not significant differences were Albacete, Alemeria, Badajoz, Bilbao, Flores, Gomera, Lisbon, Pamplona and Porto Santo.

In the case of the Portuguese airports, MACBETH+ and DEA+ rankings, as from table 20, were respectively for Lisbon airport 2nd position and 1st position, Porto 14th and 1st, Faro 23th and 1st, Madeira 34th and 37th, Porto Santo maintained 43rd position, Ponta Delgada 26th position and 1st position, Santa Maria 31th and 1st, Horta 37th and 40th, and Flores maintained 42th place.

The ranking results obtained with MACBETH and DEA approaches are quite different. From figures 4.31 to 4.34, or from figure 4.35 and table 20 (direct comparison), it's possible to observe the variation on ranking places, due the use of those two different tools. Some airports have different values between approaches, and in general, DEA approach gives higher ranking positions than MACBETH.

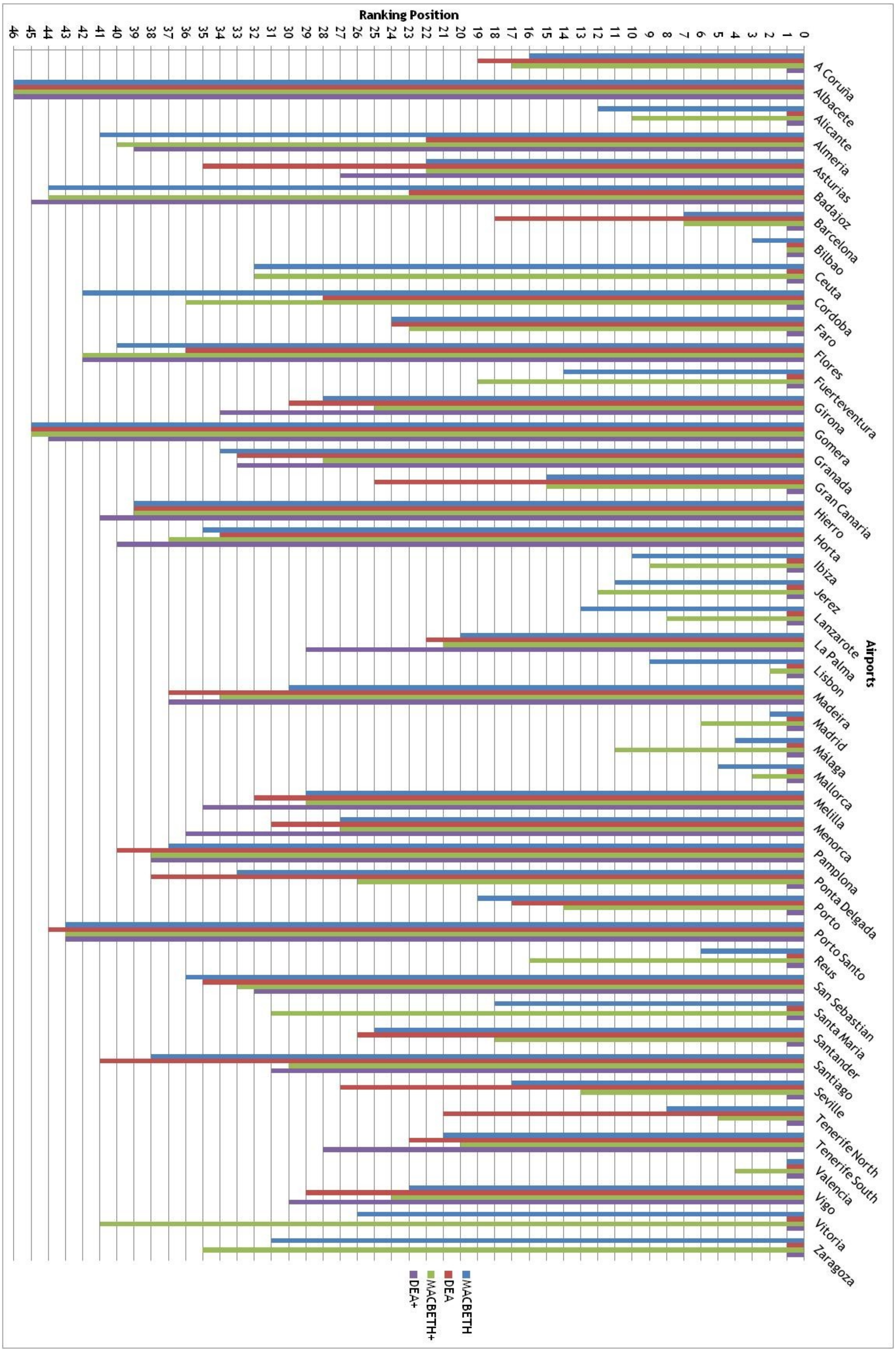

Figure 4.35: Iberian Airports Comparative Ranking for all Cases

As visible in tables 18 and 19, the maximum scores achieved within MACBETH and MACBETH+ analysis were: Valencia airport in MOVS/STANDS, Malaga airport in MOVS/RWS, Bilbao airport in PAX/PAX TA, Santa Maria airport in CARGO/CARGO TA, Santander airport in PAX/CHK-IN, Alicante airport in PAX/GATES, Cordoba airport in MOVS/GATES and Lisbon airport in MOVS/BELTS.

Despite being a little airport with relatively low traffic, passengers and cargo, Santa Maria had 100% in CARGO/CARGO TA in MACBETH and MACBETH+, because it could process 2688,9 tons of cargo in a 132,5 m^2 cargo terminal (despite much of the cargo was not stored and is distributed immediately when it arrives at the island, but it was not possible to take this factor into account.

4.2.4. CASE IV - Portuguese Airports Benchmarking Study

After a Worldwide, a European and Iberian case studies it was decided to take in account a Portuguese case study, as presented in figure 4.36. This is the last one for benchmarking analysis in this work, and includes the main Portuguese airports: in Portuguese mainland - Lisbon (LIS), Porto (OPO), Faro (FAO); in Madeira Archipelago - Madeira (FNC) and Porto Santo (PXO); and in Azores Archipelago - Ponta Delgada (PDL), Santa Maria (SMA), Horta (HOR) and Flores (FLW).

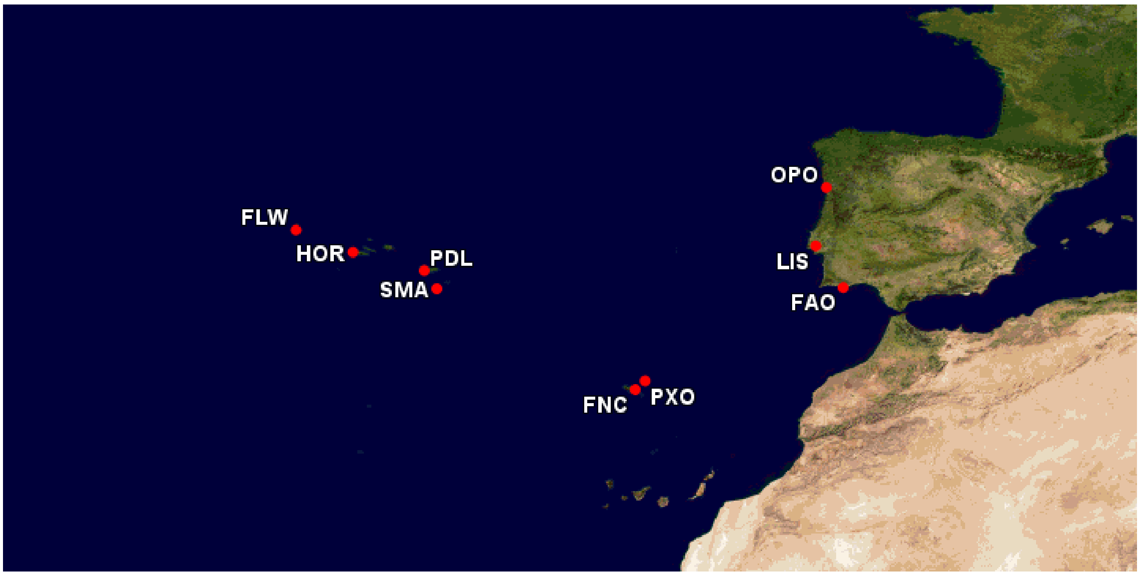

Figure 4.36: Map of the Portuguese Airports used in this Study (Great Circle Mapper, 2012)

As in the previous cases, it was necessary to get the same data for these airports to produce an efficiency ranking, as presented in table 21. We had already this data from the Iberian analysis, in which we had consulted several Master Plans and Statistical data, in this case for the year 2011, taking into account, when possible, changes in the infrastructures after the Master Plans publication.

Table 21: Portuguese Airports Data - from the list in the References

									STATISTICS 2011		
Airport	IATA	RWS	STANDS	PAX TA	CARGO TA	CHK-IN	GATES	BELTS	MOVS	PAX	CARGO
Faro	FAO	1	29	68500	1050	60	36	5	44879	5617786	224,3
Flores	FLW	1	1	1500	120	3	1	1	1439	45447	210,8
Horta	HOR	1	3	6605	270	6	2	1	4650	192064	755,5
Lisboa	LIS	2	58	236025	18625	128	50	7	143331	14805601	94355
Madeira	FNC	1	16	44590	4500	40	16	4	21346	2311380	5095
Ponta Delgada	PDL	1	14	13637	2200	14	3	3	12327	933763	5900,9
Porto	OPO	1	35	69112	19141	60	23	4	61647	6004589	34080,7
Porto Santo	PXO	1	7	9480	80	6	5	1	2816	106592	142,6
Santa Maria	SMA	1	6	3069	132,5	3	2	1	3353	93902	2688,9

In order to use the MACBETH analysis, it was necessary again to obtain the complex indicators of table 22 for each airport; the respective weights are again those of table 7.

Table 22: Complex Indicators for Portuguese Airports

Airport	IATA	MOVS/ STANDS	MOVS/ RWS	PAX/ PAX TA	CARGO/ CARGO TA	PAX/ CHK-IN	PAX/ GATES	MOVS/ GATES	MOVS/ BELTS
Faro	FAO	1547,55	44879,00	82,01	0,21	93629,77	156049,61	1246,64	8975,80
Flores	FLW	1439,00	1439,00	30,30	1,76	15149,00	45447,00	1439,00	1439,00
Horta	HOR	1550,00	4650,00	29,08	2,80	32010,67	96032,00	2325,00	4650,00
Lisboa	LIS	2471,22	71665,50	62,73	5,07	115668,76	296112,02	2866,62	20475,86
Madeira	FNC	1334,13	21346,00	51,84	1,13	57784,50	144461,25	1334,13	5336,50
Ponta Delgada	PDL	880,50	12327,00	68,47	2,68	66697,36	311254,33	4109,00	4109,00
Porto	OPO	1761,34	61647,00	86,88	1,78	100076,48	261069,09	2680,30	15411,75
Porto Santo	PXO	402,29	2816,00	11,24	1,78	17765,33	21318,40	563,20	2816,00
Santa Maria	SMA	558,83	3353,00	30,60	20,29	31300,67	46951,00	1676,50	3353,00

Then we use MACBETH and DEA tools to get airports efficiency ranking based on a combination of the above mentioned indicators, and its related weights (tables 23 to 25, and figures 4.37 to 4.46).

Table 23: Portuguese Airport Scores for MACBETH Study Case

	Global	MOVS/STANDS	MOVS/RWS	PAX/ PAX TA	CARGO/ CARGO TA
[tudo sup.]	100.00	100.00	100.00	100.00	100.00
LIS	74,28	100	100	72,2	24,9
OPO	67,37	71,27	86,02	100	8,81
FAO	55,61	62,62	62,62	94,39	1,03
SMA	39,98	22,61	4,68	35,22	100
FNC	36,74	53,99	29,79	59,66	5,56
PDL	36,09	35,63	17,2	78,81	13,19
HOR	27,4	62,72	6,49	33,47	13,78
FLW	24,28	58,23	2,01	34,88	8,66
PXO	10,11	16,28	3,93	12,94	8,76
[tudo inf.]	0.00	0.00	0.00	0.00	0.00
	Weights	0.2160	0.2790	0.2580	0.2470

Table 24: Portuguese Airport Scores for MACBETH+ Study Case

	Overall	MOVS/ STANDS	MOVS/ RWS	PAX/ PAX TA	CARGO/ CARGO TA	PAX/ CHK-IN	PAX/ GATES	MOVS/ GATES	MOVS/ BELTS
[tudo sup.]	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
LIS	82,1	100	100	72,2	24,95	100	95,14	69,76	100
OPO	72,99	71,27	86,02	100	8,76	86,52	83,88	65,23	75,27
FAO	56,23	62,62	62,62	94,39	1,03	80,95	50,14	30,34	43,84
PDL	51,76	35,63	17,2	78,81	13,19	57,66	100	100	20,07
FNC	39,78	53,99	29,79	59,67	5,56	49,96	46,41	32,47	26,06
SMA	33,32	22,61	4,68	35,22	100	27,06	15,08	40,8	16,38
HOR	32,56	62,72	6,49	33,47	13,78	27,67	30,85	56,58	22,71
FLW	24,02	58,23	2,01	34,86	8,66	13,1	14,6	35,02	7,03
PXO	11,58	16,28	3,93	12,94	8,76	15,36	6,85	13,71	13,75
[tudo inf.]	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Weights	0.1643	0.1288	0.1756	0.1284	0.1116	0.1034	0.0952	0.0927

Table 25: Efficiency Ranking for Portuguese Airports in the Four Cases

Airport	DEA	Rank DEA	DEA+	Rank DEA+	MACBETH	Rank MACBETH	MACBETH+	Rank MACBETH+
Faro	100,00	1	100,00	1	55,61	3	56,23	3
Flores	100,00	1	100,00	1	24,28	8	24,02	8
Horta	98,86	7	100,00	1	27,4	7	32,56	7
Lisboa	100,00	1	100,00	1	74,28	1	82,1	1
Madeira	70,00	9	70,00	9	36,74	5	39,78	5
Ponta Delgada	100,00	1	100,00	1	36,09	6	51,76	4
Porto	100,00	1	100,00	1	67,37	2	72,99	2
Porto Santo	85,60	8	85,60	8	10,11	9	11,58	9
Santa Maria	100,00	1	100,00	1	39,98	4	33,32	6

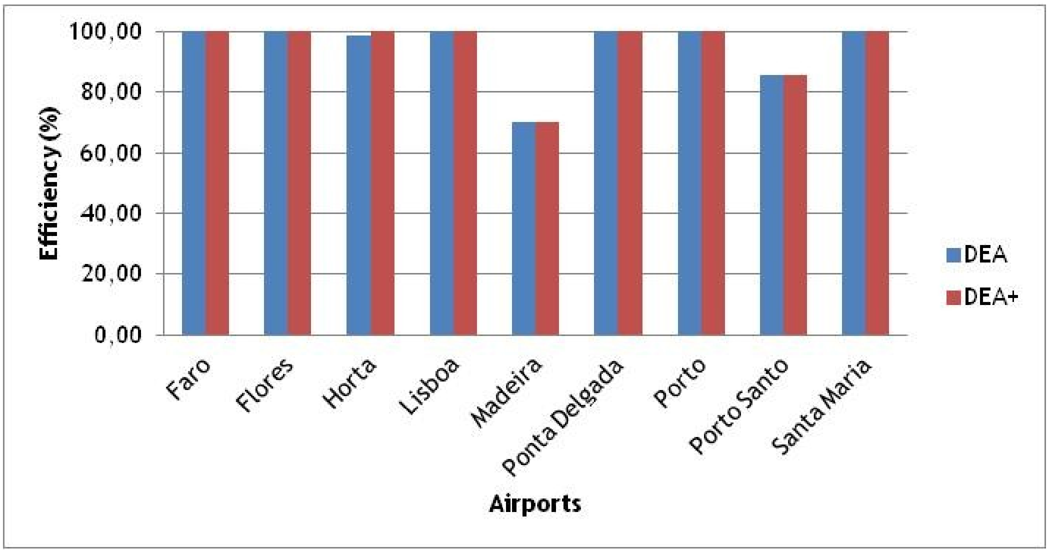

Figure 4.37: Comparative Efficiency between DEA and DEA+ for Portuguese Airports

As presented in figure 4.37, the addition of new performance indicators does not affect the efficiency for some airports as they continue with an efficiency value of 100%, i.e. Faro, Flores, Lisbon, Ponta Delgada, Porto and Santa Maria, except for Horta that changed from 98,86% to 100%, Madeira and Porto Santo airports that maintained its value on 70% and 85,60% respectively, as shown in table 25.

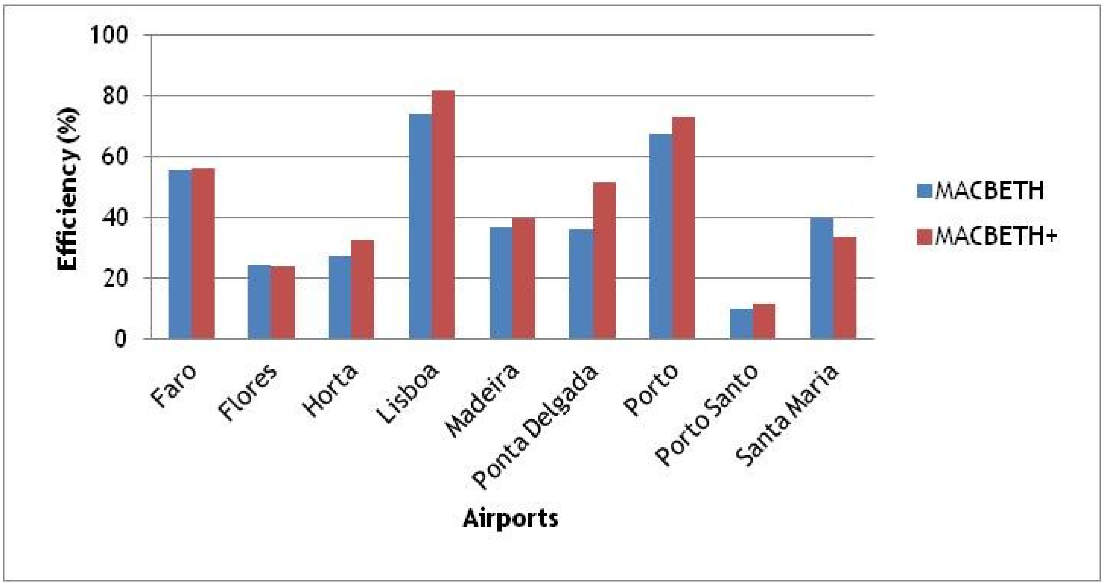

Figure 4.38: Comparative Efficiency between MACBETH and MACBETH+ for Portuguese Airports

As presented in figure 4.38, the addition of new performance indicators in MACBETH tool shows a relevant increase for Ponta Delgada changing from 36,09% to 51,76%, followed by Lisbon, Horta, Porto and Madeira. Flores and Santa Maria airports present a drop in the efficiency value. Lisbon airport got the best values and Porto Santo airport got the lower ones.

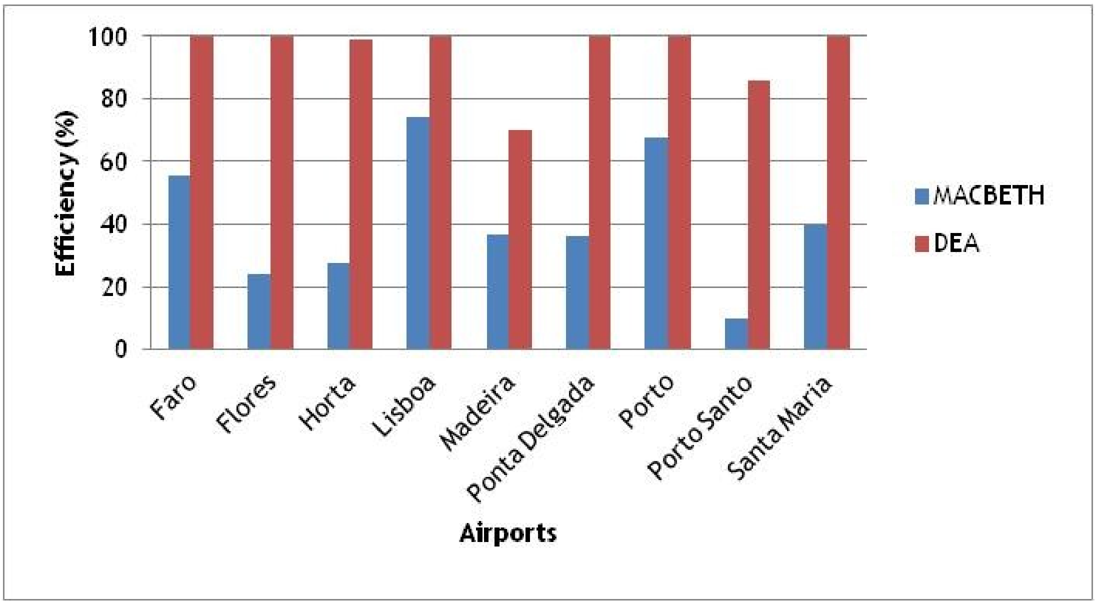

Figure 4.39: Comparative Efficiency Between MACBETH and DEA for Portuguese Airports

In figure 4.39 is shown a comparison between MACBETH and DEA efficiency values, where in general, DEA values are higher than MACBETH. The main differences are for Faro, Flores, Lisbon, Ponta Delgada, Porto and Santa Maria, which had respectively 100% efficiency for DEA but not so much for MACBETH. Lisbon airport had the best value in both approaches. Madeira got the lower efficiency in DEA, and Porto Santo in MACBETH.

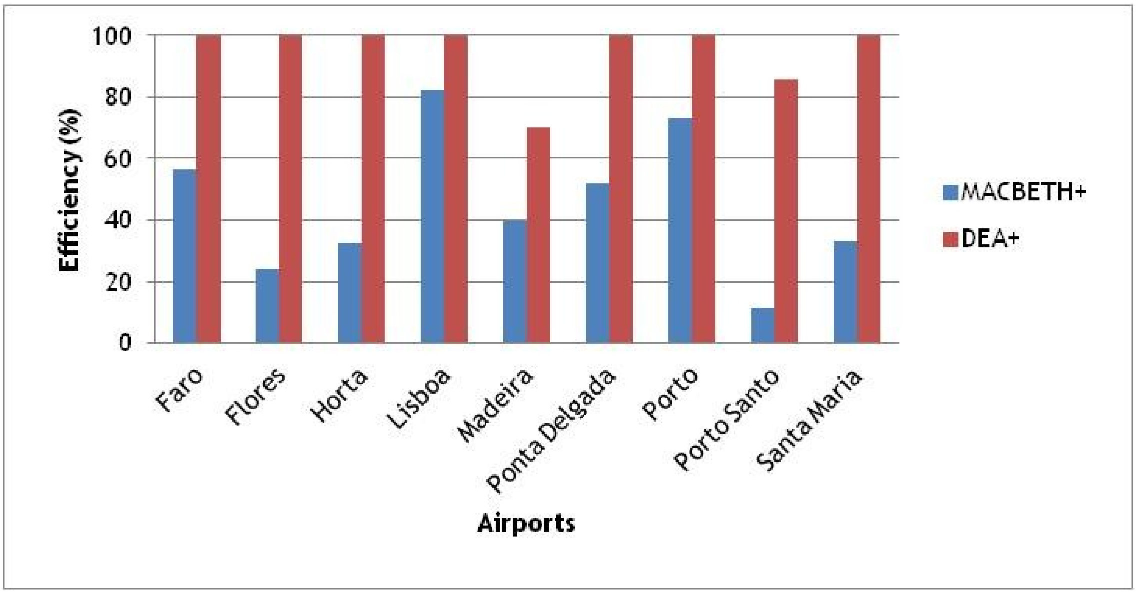

Figure 4.40: Comparative Efficiency between MACBETH+ and DEA+ for Portuguese Airports

In figure 4.40 is shown a comparison between MACBETH+ and DEA+ efficiency values, where in general and as in the previous analysis, DEA+ values are again higher than MACBETH+ ones. The main differences are to Faro, Flores, Horta and Santa Maria which had respectively 100% efficiency for DEA+ but not so much for MACBETH+. Lisbon airport had the best value in both approaches. Madeira got the lower efficiency in DEA+, and Porto Santo in MACBETH+.

The efficiency results obtained with MACBETH and DEA approaches are quite different. From figures 4.37 to 4.40, or from figure 4.41 and table 25 (direct comparison), it's possible to observe the variation on efficiency values, due the use of those two different tools. Some airports have different values between approaches, and in general, DEA approach gives higher efficiency values than MACBETH.

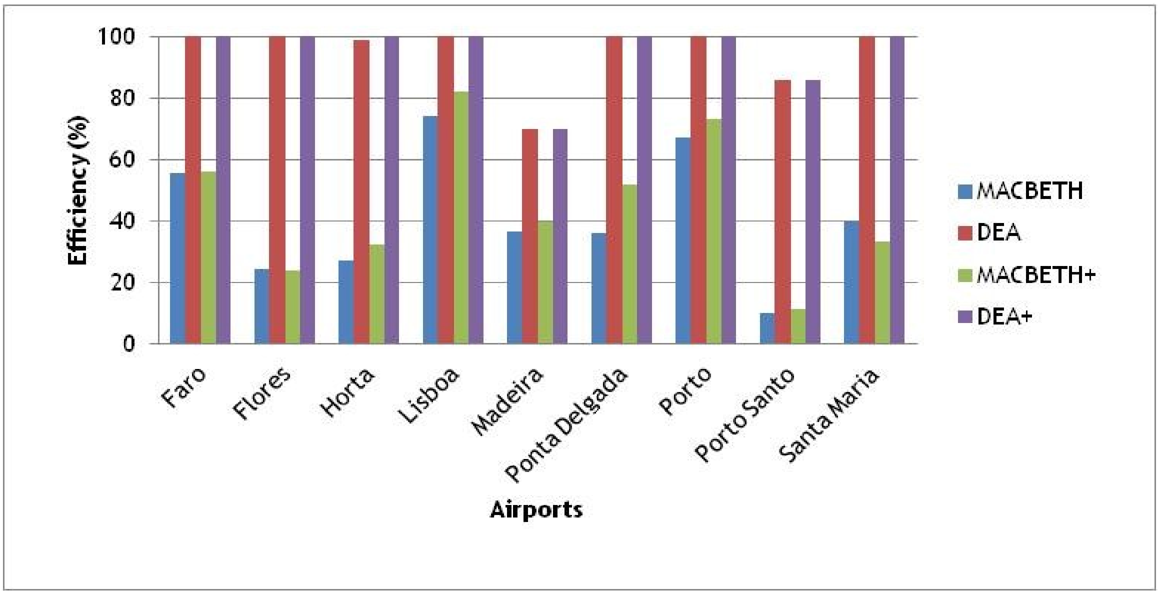

Figure 4.41: Portuguese Airports Comparative Efficiency for all Cases

Figures 4.42 to 4.45 permit another perspective, i.e. the efficiency ranking which is the main target of this study. The first two, present a comparison between rankings, before and after the addition of new indicators, and the last a comparison between tools, as in the previous analysis.

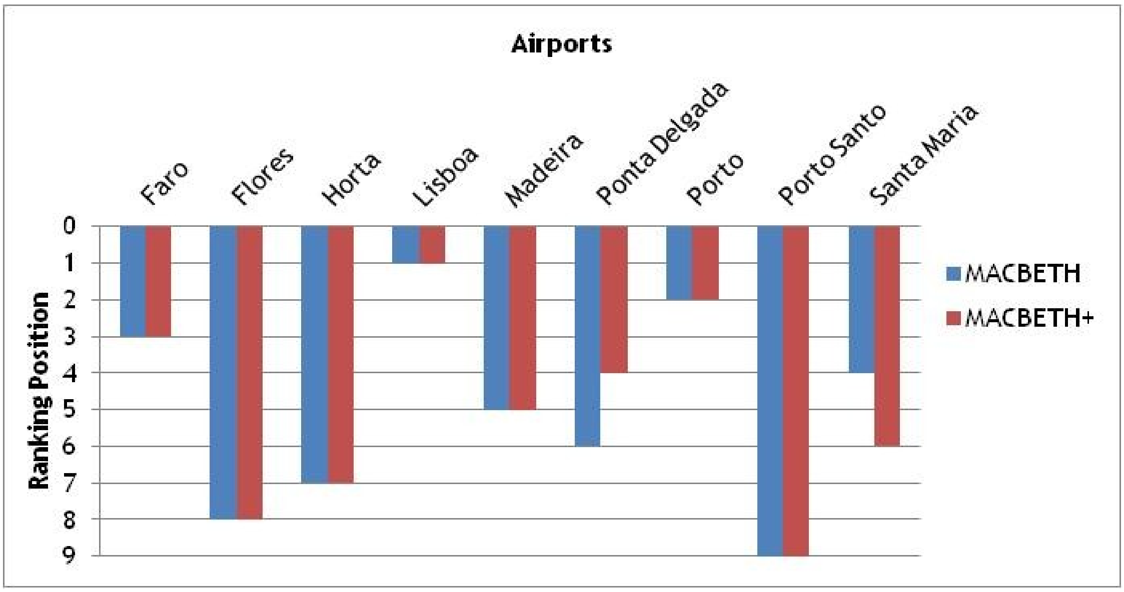

Figure 4.42: Balance between MACBETH and MACBETH+ Rankings for Portuguese Airports

Comparing the transition from MACBETH to MACBETH+, which represents the adding of new indicators in figure 4.42, it's possible to observe that there are some similarities in the ranking as for Faro, Flores, Horta, Lisbon, Madeira, Porto and Porto Santo but also that there some discrepancies as for Ponta Delgada (changes from 6th to 4th) and Santa Maria (4th to 6th). Lisbon airport got 1st place on both approaches and Porto Santo got 9th.

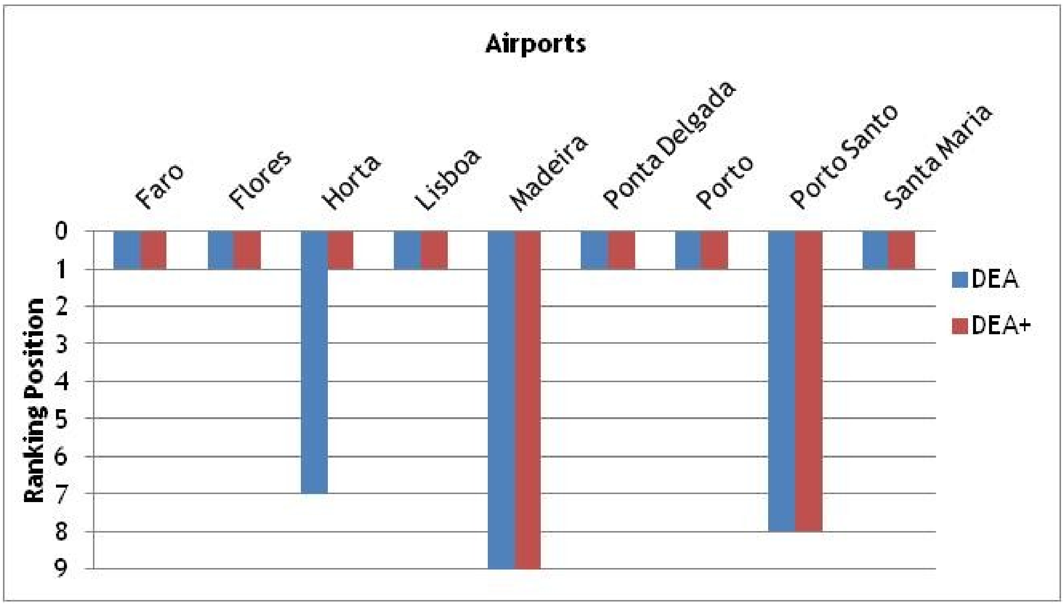

Figure 4.43: Balance between DEA and DEA+ Rankings for Portuguese Airports

Comparing the transition from DEA to DEA+ in figure 4.33, which represent again the adding of new indicators, it's possible to observe that all airports, except Horta (changing from 7th in DEA to 1st in DEA+), maintained its position in the ranking. Madeira airport got 9th and Porto Santo 8th.

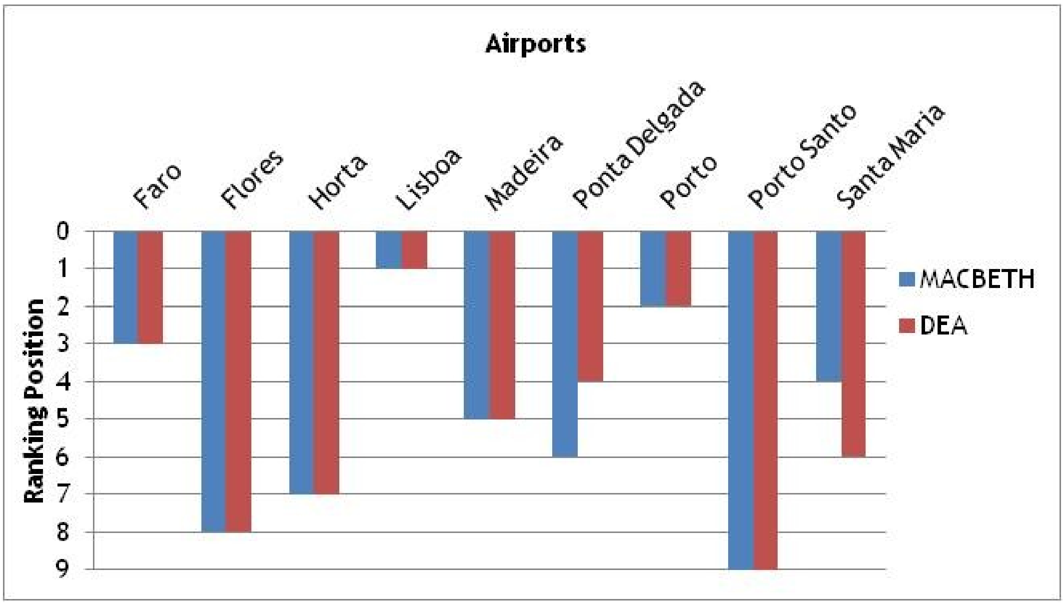

Figure 4.44: Balance between MACBETH and DEA Rankings for Portuguese Airports

In figure 4.44 is shown a comparison between MACBETH and DEA rankings, where the main differences were for Ponta Delgada and Santa Maria. Lisbon airport had 1st position on both approaches and Porto Santo got 9th.

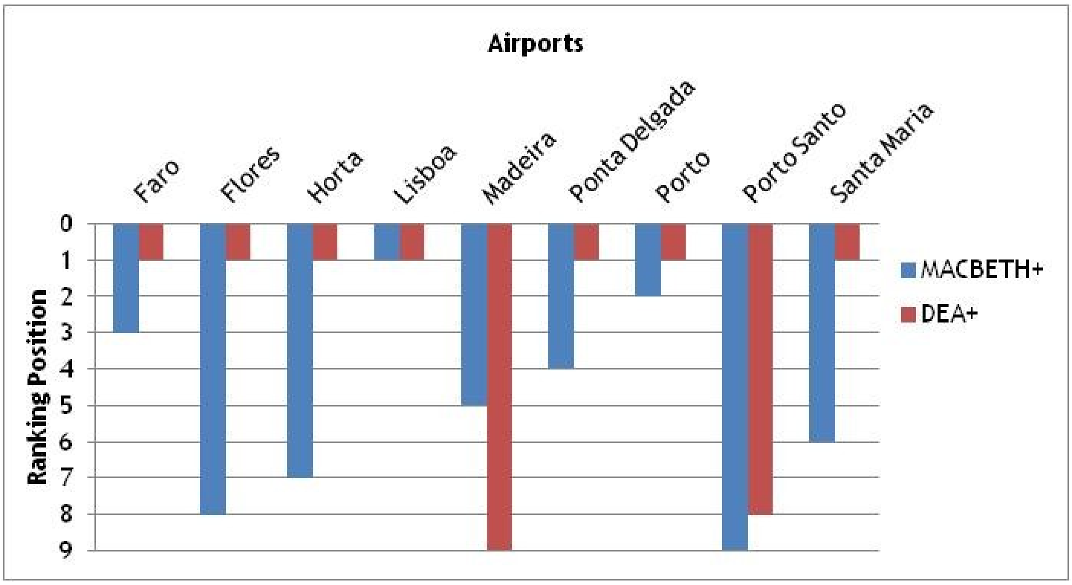

Figure 4.45: Balance between MACBETH+ and DEA+ Rankings for Portuguese Airports

In figure 4.45 is shown a comparison between MACBETH+ and DEA+ rankings, where the main differences were for Flores, Horta, Madeira and Santa Maria. Lisbon airport had 1st position on both approaches; Porto Santo got last position on MACBETH+ and Madeira on DEA+.

The ranking results obtained with MACBETH and DEA approaches are quite different. From figures 4.42 to 4.45, or from figure 4.46 and table 25 (direct comparison), it's possible to observe the variation on ranking places, due the use of those two different tools. Some airports have different values between approaches.

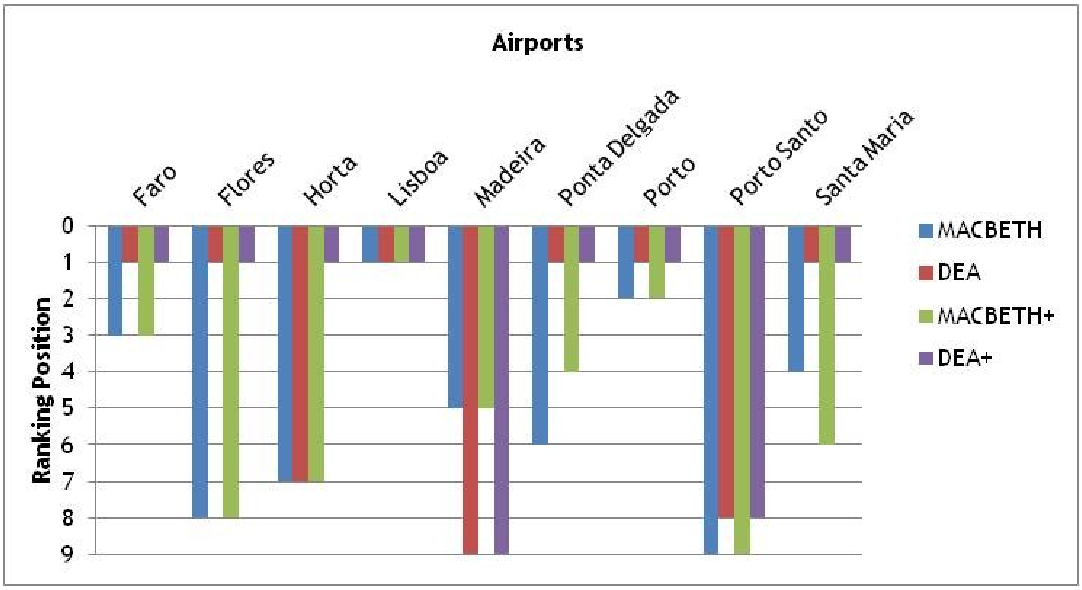

Figure 4.46: Portuguese Airports Comparative Ranking for all Cases

As visible in tables 23 and 24, the maximum scores within MACBETH and MACBETH+ analysis were: Lisbon airport in MOVS/STANDS, MOVS/RWS, PAX/CHK-IN and MOVS/BELTS; Porto airport in PAX/PAX TA; Santa Maria airport in CARGO/CARGO TA; and Ponta Delgada in PAX/GATES and MOVS/GATES.

As in the Iberian analysis, the fact that Santa Maria had 100% in CARGO/CARGO TA, despite being a little airport with relatively low traffic, passengers and cargo, was because it could process 2688,9 tons of cargo in a 132,5 m^2 cargo terminal.

4.2.5. CASE V - Iberian Airports 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. This feature is particularly interesting when observing the answer given by the airport whenever there are investments in such infrastructure. If there are no investments, it is always possible to see how effective the airport has become all over the years. Thus, this case study performs specifically the self-benchmarking of the main Iberian airports, as presented in figure 4.47: in the Portuguese side - Lisbon (LIS), Porto (OPO), Faro (FAO), Madeira (FNC) in Madeira Archipelago, and Ponta Delgada (PDL) in Azores Archipelago; and in the Spanish side - Madrid (MAD), Barcelona (BCN), Vigo (VGO) (to compare with Porto (OPO)), Gran Canaria (LPA) in Canary Archipelago, and Palma de Mallorca (PMI) in Baleares Archipelago.

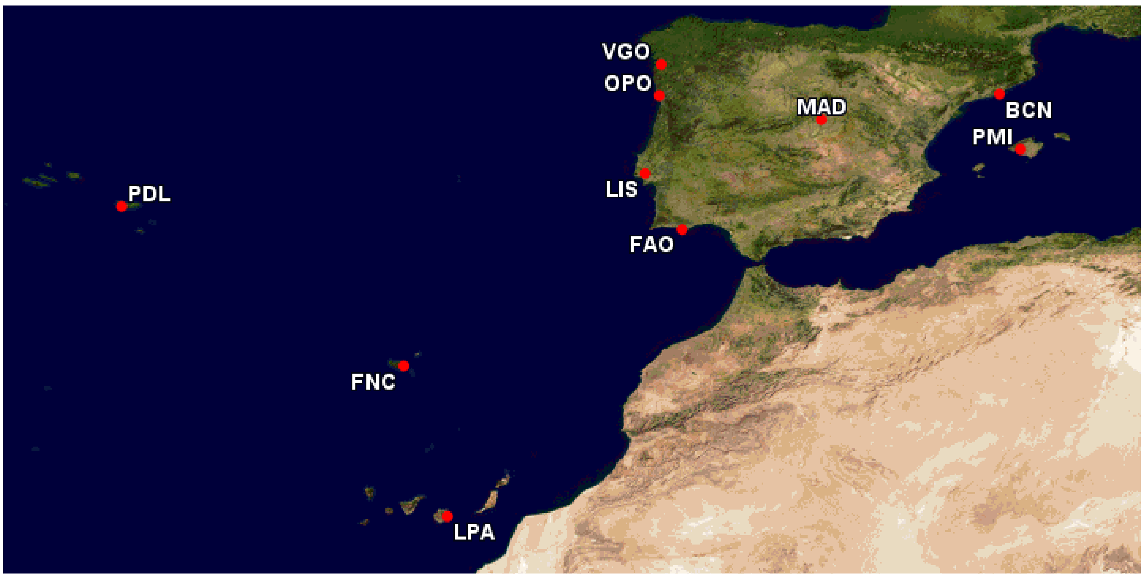

Figure 4.47: Map of the Iberian Airports used in this Study

4.2.5.1. Lisbon Airport (LIS)

Lisbon Airport, also known as Lisbon Portela Airport (IATA: LIS, ICAO: 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, as visible in figure 4.48, being one of the few airports in Europe located inside a major city. It is operated by ANA – Aeroportos de Portugal.

Figure 4.48: Lisbon Airport
(Piavani, 2012)

As in the previous cases, it was necessary to get the same data for this airport to produce an efficiency ranking, as presented in table 26. We had already the 2011 data from the Iberian analysis, but now it was necessary taking into account other years and possible changes in the infrastructures. As visible, 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 and a new pier in Terminal 1; the Cargo Terminal Area (CARGO TA) since it was rebuilt and expanded; and the Number of Check-In Desks (CHK-IN) and the Number of Boarding Gates (GATES) due to the addition of Terminal 2.

Table 26: Lisbon Airport Data - from the list in the References

									STATISTICS		
	YEARS	RWS	STANDS	PAX TA	CARGO TA	CHK-IN	GATES	BELTS	PAX	MOVS	CARGO
LISBON	LIS2006	2	51	204216	13000	106	25	7	12314314	137109	99483
	LIS2007	2	51	204216	13000	106	25	7	13239756	139516	94515
	LIS2008	2	51	208216	13000	128	37	7	13626358	144771	101161
	LIS2009	2	58	208216	13000	128	37	7	13277960	136287	95612
	LIS2010	2	58	236025	18625	128	50	7	14088956	142683	105340
	LIS2011	2	58	236025	18625	128	50	7	14805601	143331	94355

In order to use the MACBETH analysis, it was necessary again to obtain the complex indicators of table 27 for each year; the respective weights are again those of table 7.

Table 27: Complex Indicators for Lisbon Airport

YEARS	PAX/ PAX TA	PAX/ GATES	PAX/ CHK-IN	CARGO/ CARGO TA	MOVS/ STANDS	MOVS/ GATES	MOVS/ RWS	MOVS/ BELTS
LIS2006	60,30	492572,56	116172,77	7,65	2688,41	5484,36	68554,50	19587,00
LIS2007	64,83	529590,24	124903,36	7,27	2735,61	5580,64	69758,00	19930,86
LIS2008	65,44	368279,95	106455,92	7,78	2838,65	3912,73	72385,50	20681,57
LIS2009	63,77	358863,78	103734,06	7,35	2349,78	3683,43	68143,50	19469,57
LIS2010	59,69	281779,12	110069,97	5,66	2460,05	2853,66	71341,50	20383,29
LIS2011	62,73	296112,02	115668,76	5,07	2471,22	2866,62	71665,50	20475,86

Then we use MACBETH and DEA tools to get the airport efficiency ranking based on a combination of the above mentioned indicators, and its related weights (tables 28 to 30, and figures 4.49 to 4.58).

Table 28: Lisbon Airport Scores for MACBETH Study Case

	Global	MOVS/STANDS	MOVS/RWS	PAX/ PAX TA	CARGO/ CARGO TA
[tudo sup.]	100	100	100	100	100
LIS2008	100	100.00	100.00	100.00	100.00
LIS2007	96,34	96.37	96.37	99.07	93.43
LIS2006	94,94	94.71	94.71	92.15	98.32
LIS2009	92,62	82.78	94.14	97.45	94.46
LIS2010	87,7	86.66	98.56	91.21	72.68
LIS2011	87,23	87.06	99.01	95.84	65.08
[tudo inf.]	**0**	0	0	0	0
	Weights	0,216	0,279	0,258	0,247

Table 29: Lisbon Airport Scores for MACBETH+ Study Case

	Global	MOVS/ STANDS	MOVS/ RWS	PAX/ PAX TA	CARGO/ CARGO TA	PAX/ CHK-IN	PAX/ GATES	MOVS/ GATES	MOVS/ BELTS
[tudo sup.]	100	100	100	100	100	100	100	100	100
LIS2007	97,59	96,37	96,37	99,07	93,43	100	100	100	96,37
LIS2006	94,7	94,71	94,71	92,15	98,32	93,01	93,01	98,27	94,71
LIS2008	92,36	100	100	100	100	85,23	69,54	70,11	100
LIS2009	86,25	82,78	94,14	97,45	94,46	83,05	67,76	66	94,14
LIS2011	82,43	87,06	99,01	95,86	65,08	92,61	55,91	51,37	99,01
LIS2010	81,63	86,66	98,56	91,21	72,68	88,12	53,21	51,13	98,59
[tudo inf.]	0	0	0	0	0	0	0	0	0
	Weights	0,1643	0,1288	0,1756	0,1284	0,1116	0,1034	0,0952	0,0927

Table 30: Efficiency Ranking for Lisbon Airport in the Four Cases

YEARS	DEA	Rank DEA	DEA+	Rank DEA+	MACBETH	Rank MACBETH	MACBETH+	Rank MACBETH+
LIS2006	100,00	1	100,00	1	94,94	3	94,7	2
LIS2007	100,00	1	99,066	5	96,34	2	97,59	1
LIS2008	100,00	1	100,00	1	100,00	1	92,36	3
LIS2009	97,4432	6	97,4432	6	92,62	4	86,25	4
LIS2010	100,00	1	100,00	1	87,7	5	81,63	6
LIS2011	100,00	1	100,00	1	87,23	6	82,43	5

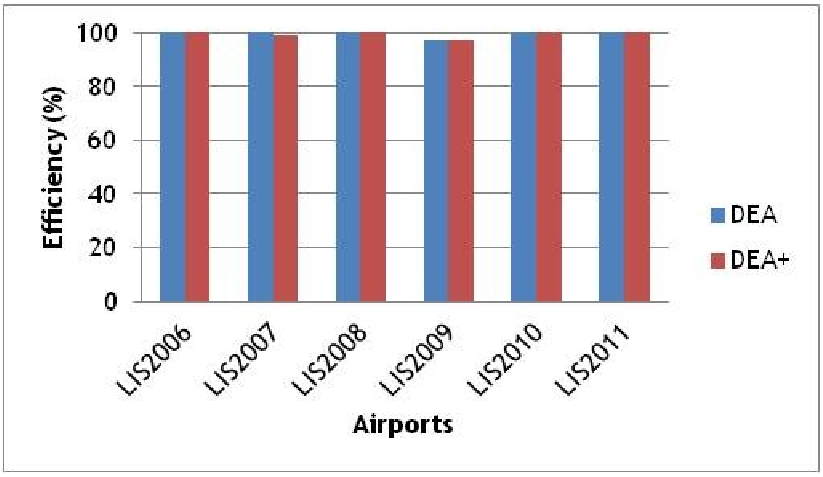

Figure 4.49: Comparative Efficiency Between DEA and DEA+ for Lisbon Airport

As presented in figure 4.49, the addition of new performance indicators does not affect the efficiency of Lisbon airport in DEA analysis. It continues with an efficiency value of 100% in all years, except for 2007 and that is a bit lower for DEA+ (99,06% in table 30), and 2009 (97,44%), in both approaches.

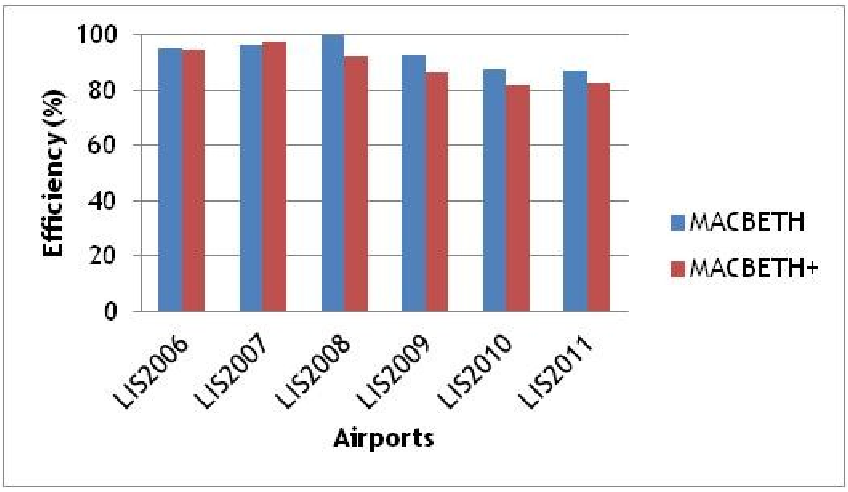

Figure 4.50: Comparative Efficiency between MACBETH and MACBETH+ for Lisbon Airport

As presented in figure 4.50, the addition of new performance indicators in MACBETH tool shows a decrease in the efficiency for all years, except for 2007, that increased from 96,34% to 97,59%.

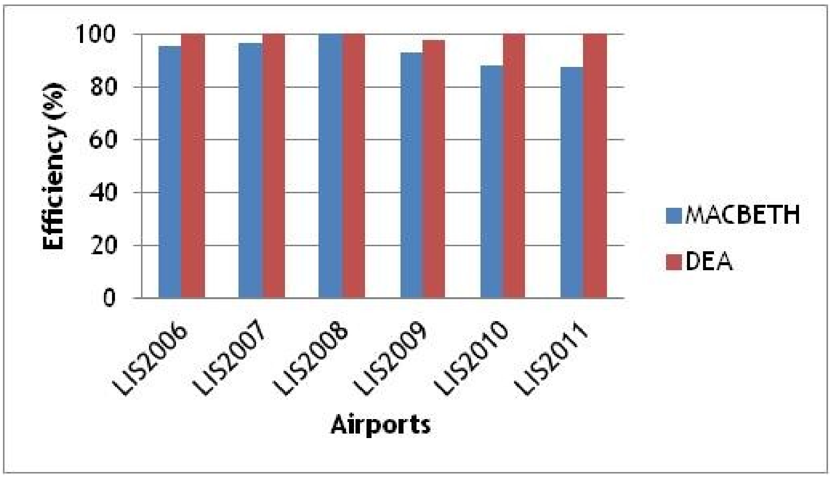

Figure 4.51: Comparative Efficiency Between MACBETH and DEA for Lisbon Airport

In figure 4.51 is shown a comparison between MACBETH and DEA efficiency values, where in general, DEA values are higher than MACBETH. The main differences are for 2010 and 2011 which had respectively 100% efficiency for DEA but not so much for MACBETH. Lisbon airport had the best value in both approaches in 2008.

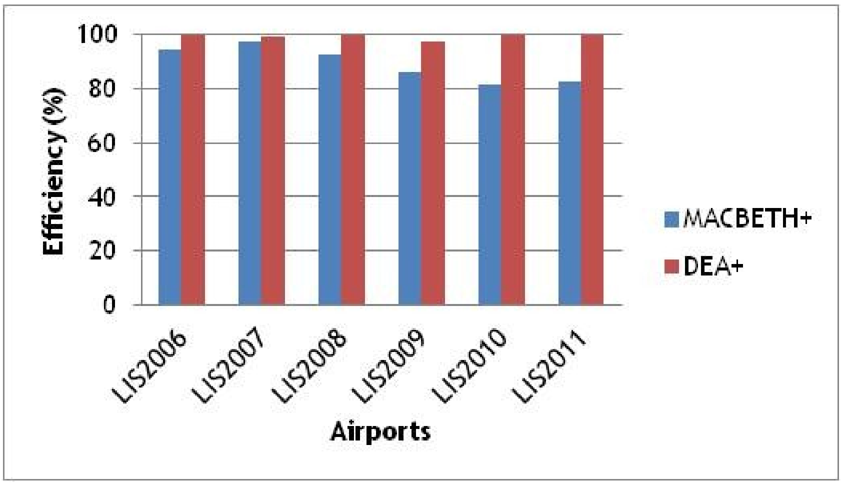

Figure 4.52: Comparative Efficiency Between MACBETH+ and DEA+ for Lisbon Airport

In figure 4.52 is shown a comparison between MACBETH+ and DEA+ efficiency values, where in general and as in the previous analysis, DEA+ values are again higher than MACBETH+ ones. The main differences are again on 2010 and 2011 which had respectively 100% efficiency for DEA+ but not so much for MACBETH+. Lisbon airport had the best value in both approaches in the year of 2007.

The efficiency results obtained with MACBETH and DEA approaches are quite different. From figure 4.49 to 4.52, or from figure 4.53 and table 30 (direct comparison), it's possible to observe the variation on efficiency values, due the use of those two different tools. Some airports have different values between approaches, and in general, DEA approach gives higher efficiency values than MACBETH.

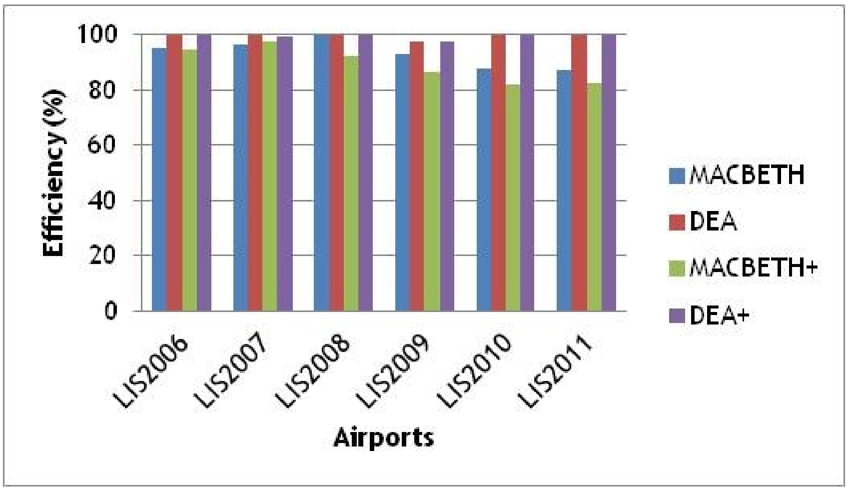

Figure 4.53: Lisbon Airport Comparative Efficiency for all Cases

Figures 4.54 to 4.55 permit another perspective, i.e. the efficiency ranking which is the goal of this study. The first two, present a comparison between rankings, before and after the addition of new indicators, and the last a comparison between tools, as in the previous analysis.

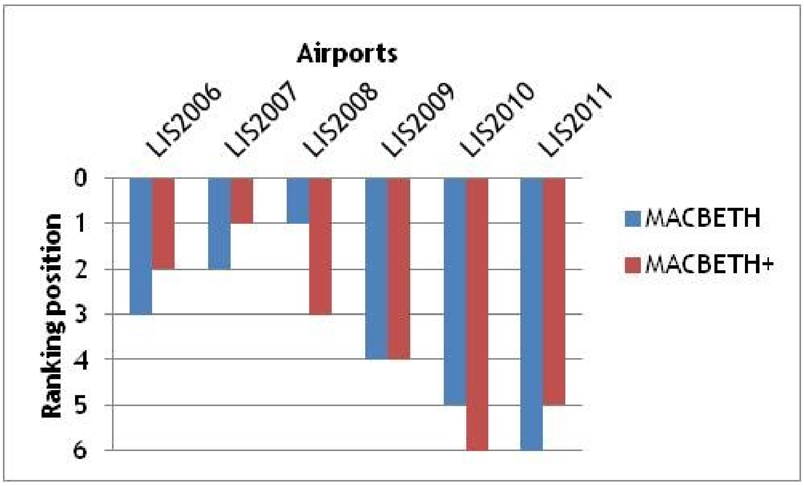

Figure 4.54: Balance between MACBETH and MACBETH+ Rankings for Lisbon Airport

Comparing the transition from MACBETH to MACBETH+, which represents the adding of new indicators in figure 4.54, it's possible to observe that there are some similarities in the ranking for 2009, but also that there are some discrepancies as for 2008, changing from 1st to 3rd. Lisbon airport got 1st place on MACBETH and MACBETH+ for 2008 and 2007 respectively, and last position on 2011 for MACBETH and 2010 for MACBETH+.

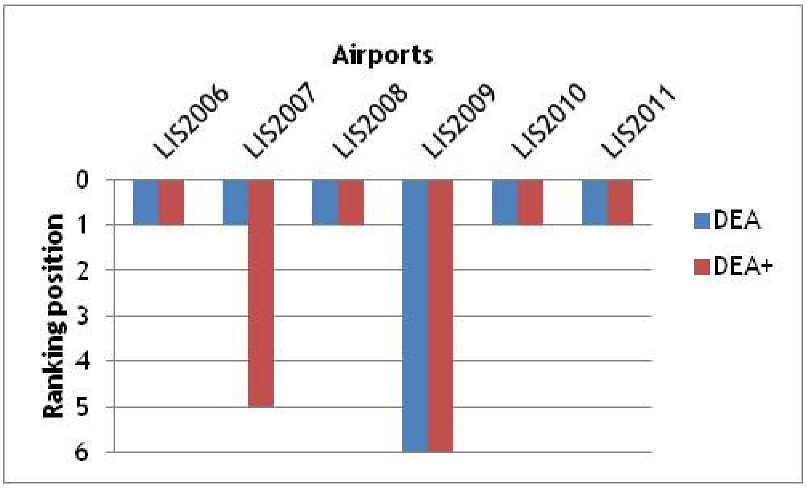

Figure 4.55: Balance between DEA and DEA+ Rankings for Lisbon Airport

Comparing the transition from DEA to DEA+ in figure 4.55, which represent again the adding of new indicators, it's possible to observe that during all years, except for 2007 (from 1st to 5th) and 2009 (6th place on both approaches) Lisbon maintained its position in the ranking, the 1st place.

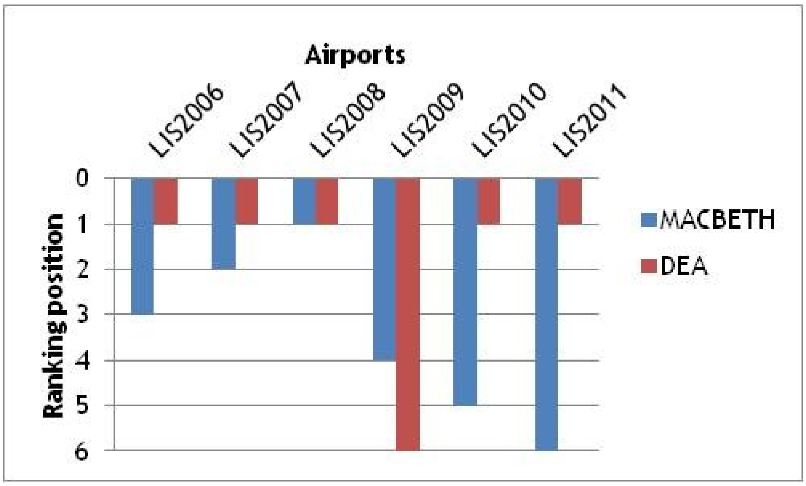

Figure 4.56: Balance between MACBETH and DEA Rankings for Lisbon Airport

In figure 4.56 is shown a comparison between MACBETH and DEA rankings, where the main differences are for 2010 and 2011. Lisbon airport had 1st position on both approaches in 2008, but the less efficient years are for MACBETH and DEA, 2011 and 2009 respectively.

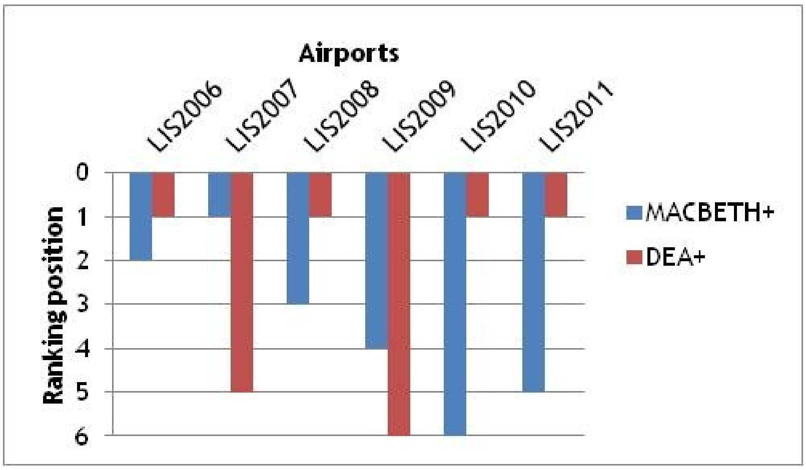

Figure 4.57: Balance between MACBETH+ and DEA+ Rankings for Lisbon Airport

In figure 4.57 is shown a comparison between MACBETH+ and DEA+ rankings, where the main differences are again for 2010 and 2011. Lisbon airport had 1st position on 2007 for MACBETH+ and on 2006, 2008, 2010 and 2011 for DEA+. The less efficient years are for MACBETH+ and DEA+, 2010 and 2009, respectively.

The ranking results obtained with MACBETH and DEA approaches are quite different. From figure 4.54 to 4.57, or from figure 4.58 and table 30 (direct comparison), it's possible to observe the variation on ranking places, due to the use of those two different tools. Some years have different values between approaches.

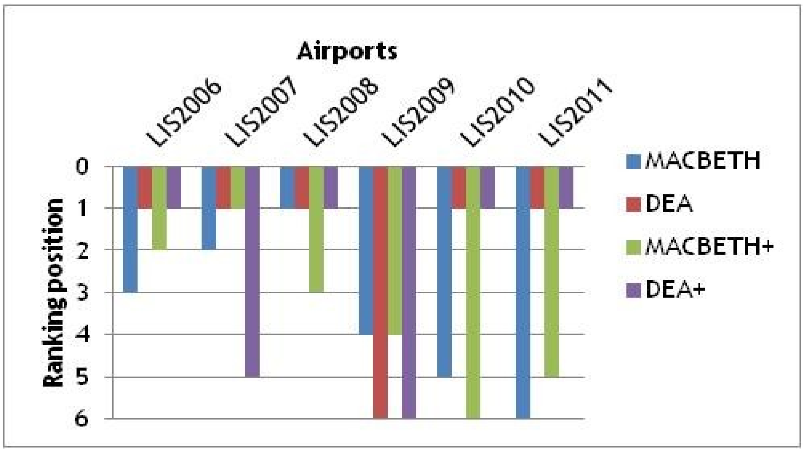

Figure 4.58: Lisbon Airport Comparative Ranking for all Cases

As visible in tables 28 and 29, the maximum scores into MACBETH and MACBETH+ analysis for Lisbon Airport were: 2008 for MOVS/STANDS, MOVS/RWS, PAX/PAX TA, CARGO/CARGO TA and MOVS/BELTS; 2007 for, PAX/CHK-IN, PAX/GATES and MOVS/GATES.

4.2.5.2. Porto Airport (OPO)

Porto Airport (IATA: OPO, ICAO: LPPR) or Francisco Sá Carneiro Airport is an international airport near Porto, Portugal. It is located 11 km (6.8 mi) northwest of the centre of Porto, and has a relatively new terminal, as a result of recent expansion (figure 4.59). The airport is currently the second busiest in the country based on aircraft operations and the second busiest in passengers, based on official traffic statistics, after Lisbon Portela Airport and before Faro Airport, and reached six millions passengers in 2011. It is operated by ANA – Aeroportos de Portugal.

Figure 4.59: Porto Airport
(Resendes, 2012)

As in the previous cases, it was necessary to get the same data for this airport as in the previous one to produce an efficiency ranking, as presented in table 31. We had already the 2011 data from the Iberian analysis, but now it was necessary taking into account other years.

Table 31: Porto airport Data - from the list in the References

									STATISTICS		
	YEARS	RWS	STANDS	PAX TA	CARGO TA	CHK-IN	GATES	BELTS	PAX	MOVS	CARGO
PORTO	OPO2006	1	35	69112	19141	60	23	4	3402816	49205	34444
	OPO2007	1	35	69112	19141	60	23	4	3988388	53441	36147
	OPO2008	1	35	69112	19141	60	23	4	4535813	58135	36647
	OPO2009	1	35	69112	19141	60	23	4	4509350	54107	32393
	OPO2010	1	35	69112	19141	60	23	4	5283361	57290	35284
	OPO2011	1	35	69112	19141	60	23	4	6004589	61647	34080,7

In order to use the MACBETH analysis, it was necessary again to obtain the complex indicators of table 32 for each year; the respective weights are again those of table 7.

Table 32: Complex Indicators for Porto Airport

YEARS	PAX/ PAX TA	PAX/ GATES	PAX/ CHK-IN	CARGO/ CARGO TA	MOVS/ STANDS	MOVS/ GATES	MOVS/ RWS	MOVS/ BELTS
OPO2006	49,24	147948,52	56713,60	1,80	1405,86	2139,35	49205,00	12301,25
OPO2007	57,71	173408,17	66473,13	1,89	1526,89	2323,52	53441,00	13360,25
OPO2008	65,63	197209,26	75596,88	1,91	1661,00	2527,61	58135,00	14533,75
OPO2009	65,25	196058,70	75155,83	1,69	1545,91	2352,48	54107,00	13526,75
OPO2010	76,45	229711,35	88056,02	1,84	1636,86	2490,87	57290,00	14322,50
OPO2011	86,88	261069,09	100076,48	1,78	1761,34	2680,30	61647,00	15411,75

Then we use MACBETH and DEA tools to get the airport efficiency ranking based on a combination of the above mentioned indicators, and its related weights (tables 33 to 35, and figures 4.60 to 4.69).

Table 33: Porto Airport Scores for MACBETH Study Case

	Global	MOVS/STANDS	MOVS/RWS	PAX/ PAX TA	CARGO/ CARGO TA
[tudo sup.]	100	100	100	100	100
OPO2011	98,29	100	100	100	93,09
OPO2010	92,48	92,93	92,93	87,99	96,28
OPO2008	90,87	94,3	94,3	75,54	100
OPO2009	84,63	87,77	87,77	75,1	88,3
OPO2007	84,49	86,69	86,69	66,42	98,94
OPO2006	77,26	79,82	79,82	56,68	93,62
[tudo inf.]	**0**	0	0	0	0
	Weights	0,216	0,279	0,258	0,247

Table 34: Porto Airport Scores for MACBETH+ Study Case

	Global	MOVS/ STANDS	MOVS/ RWS	PAX/ PAX TA	CARGO/ CARGO TA	PAX/ CHK-IN	PAX/ GATES	MOVS/ GATES	MOVS/ BELTS
[tudo sup.]	100	100	100	100	100	100	100	100	100
OPO2011	99,11	100	100	100	93,09	100	100	100	100
OPO2010	91,43	92,93	92,93	87,99	96,28	87,99	87,99	92,93	92,93
OPO2008	87,71	94,3	94,3	75,54	100	75,54	75,54	94,3	94,3
OPO2009	82,89	87,77	87,77	75,1	88,3	75,1	75,1	87,77	87,77
OPO2007	80,35	86,69	86,69	66,42	98,94	66,42	66,42	86,69	86,69
OPO2006	72,55	79,82	79,82	56,68	93,62	56,67	56,67	79,82	79,82
[tudo inf.]	0	0	0	0	0	0	0	0	0
	Weights	0,1643	0,1288	0,1756	0,1284	0,1116	0,1034	0,0952	0,0927

Table 35: Efficiency Ranking for Porto Airport in the Four Cases

YEARS	DEA	Rank DEA	DEA+	Rank DEA+	MACBETH	Rank MACBETH	MACBETH+	Rank MACBETH+
OPO2006	95,29	5	95,29	6	77,26	6	72,55	6
OPO2007	100,00	1	100,00	1	84,49	5	80,35	5
OPO2008	100,00	1	100,00	1	90,87	3	87,71	3
OPO2009	90,90	6	90,90	5	84,63	4	82,89	4
OPO2010	98,87	4	99,87	4	92,48	2	91,43	2
OPO2011	100,00	1	100,00	1	98,29	1	99,11	1

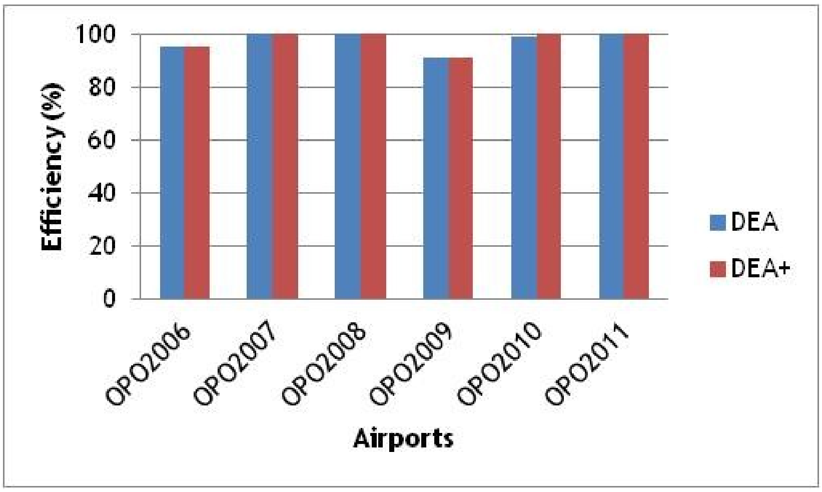

Figure 4.60: Comparative Efficiency between DEA and DEA+ for Porto Airport

As presented in figure 4.60, the addition of new performance indicators does not affect the efficiency of Porto airport in DEA analysis. It continues with an efficiency value of 100% in all years, except for 2006 and 2009.

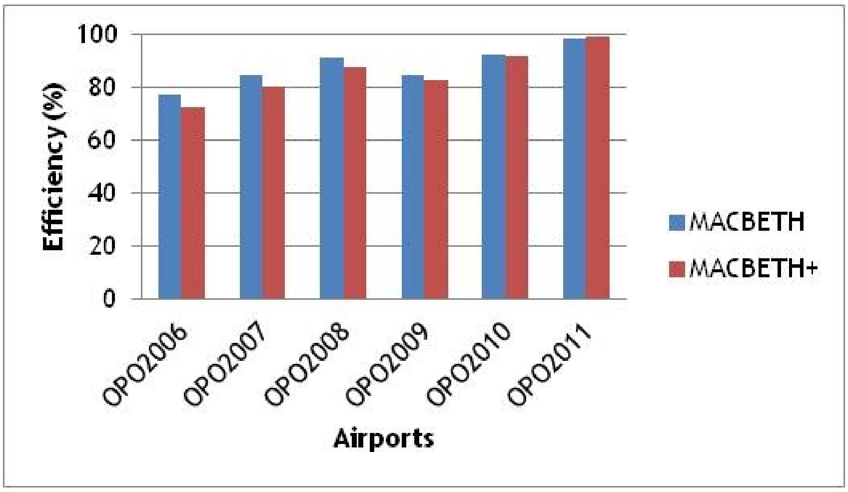

Figure 4.61: Comparative Efficiency between MACBETH and MACBETH+ for Porto Airport

As presented in figure 4.61, the addition of new performance indicators in MACBETH tool shows a decrease in the efficiency for all years, except for 2011, when increased from 98,29% to 99,11%.

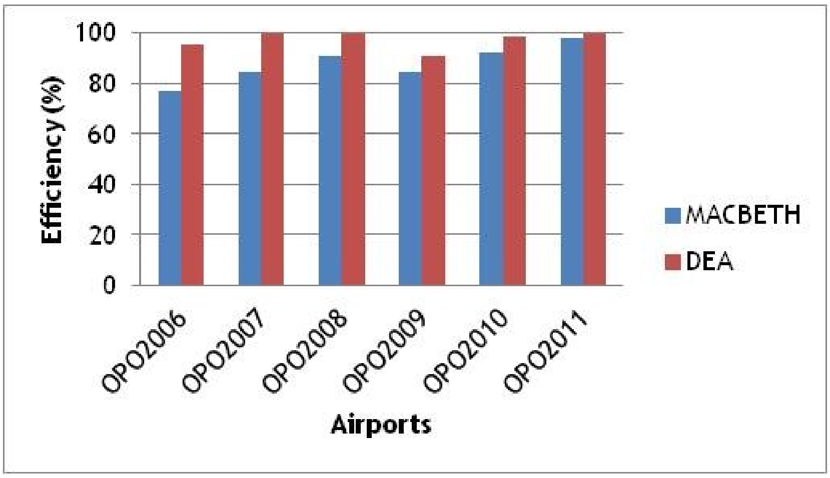

Figure 4.62: Comparative Efficiency between MACBETH and DEA for Porto Airport

In figure 4.62 is shown a comparison between MACBETH and DEA efficiency values, where DEA values are higher than MACBETH. The main differences are for 2006 and 2007. Porto airport had the best value in both approaches in 2011. The less efficient years were 2006 for MACBETH and 2009 for DEA.

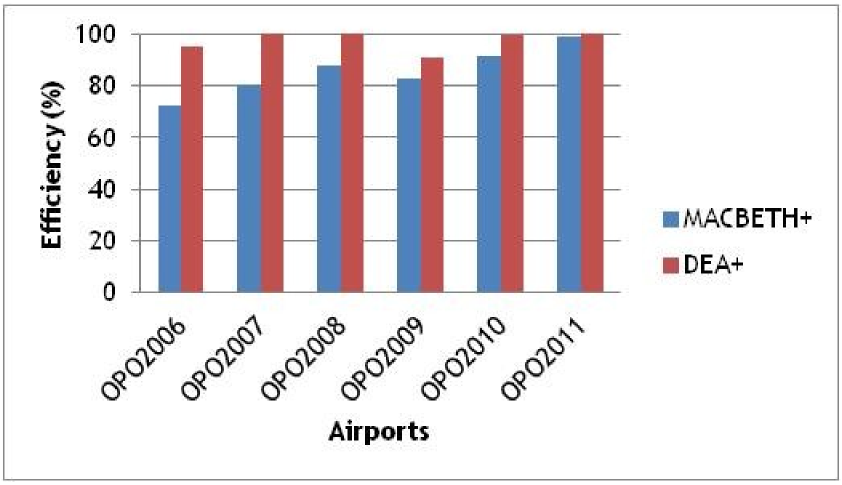

Figure 4.63: Comparative Efficiency between MACBETH+ and DEA+ for Porto Airport

In figure 4.63 is shown a comparison between MACBETH+ and DEA+ efficiency values, where in general and as in the previous analysis, DEA+ values are again higher than MACBETH+. The main differences are again for 2006 and 2007. Porto airport had the best value in both approaches in the year 2011. The less efficient years were 2006 for MACBETH+ and 2009 for DEA+.

The efficiency results obtained with MACBETH and DEA approaches are quite different. From figure 4.60 to 4.63, or from figure 4.64 and table 35 (direct comparison), it's possible to observe the variation on efficiency values, due to the use of those two different tools.

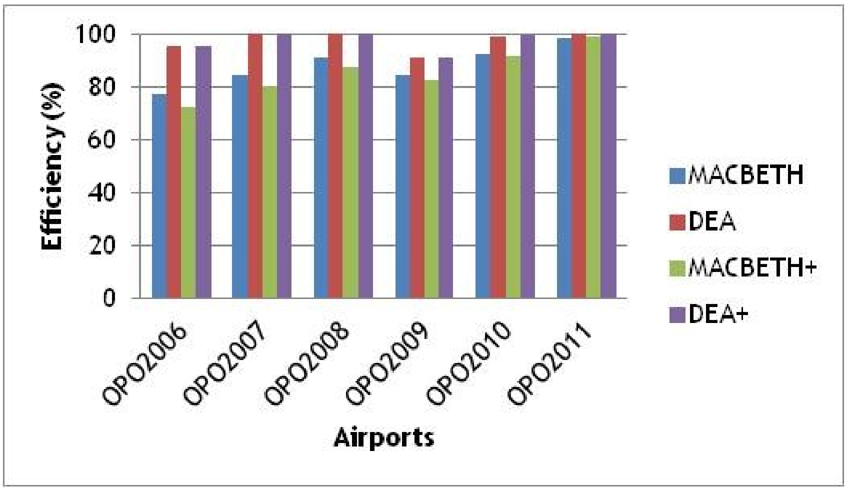

Figure 4.64: Porto Airport Comparative Efficiency for all Cases

Figures 4.65 to 4.69 permit another perspective, i.e. the efficiency ranking which is the target of this study. The first two, present a comparison between rankings, before and after the addition of new indicators, and the last a comparison between tools, as in the previous analysis.

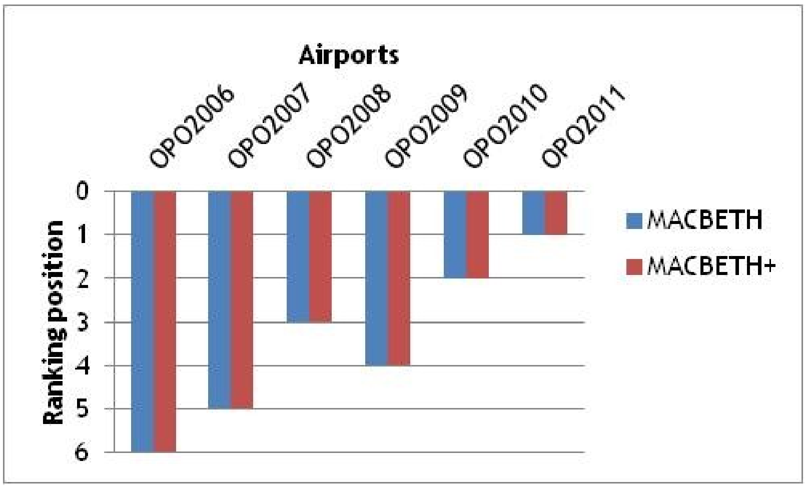

Figure 4.65: Balance between MACBETH and MACBETH+ Rankings for Porto Airport

Comparing the transition from MACBETH to MACBETH+, in figure 4.65, it's possible to observe that there is no changes in the rankings due to the addition of new indicators. Porto airport got 1st place on MACBETH and MACBETH+ for 2011, and last position on 2006, and in a general view, the efficiency of this airport grew in the last years.

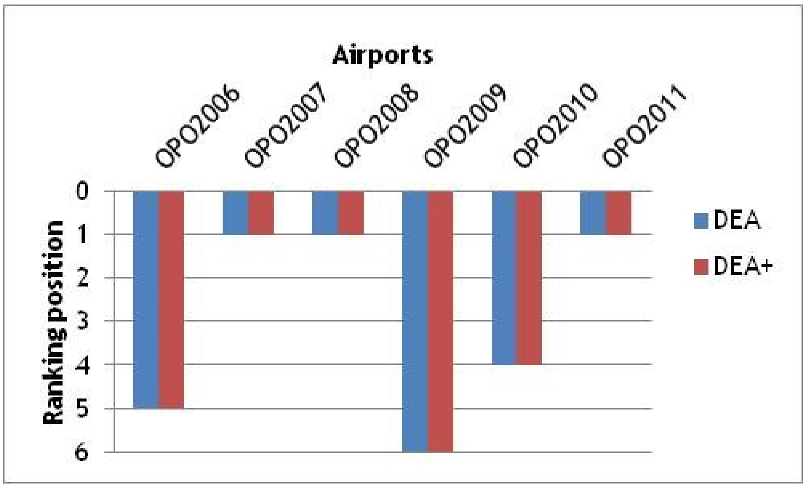

Figure 4.66: Balance between DEA and DEA+ Rankings for Porto Airport

Comparing the transition from DEA to DEA+ in figure 4.66, which represent again the adding of new indicators, it's possible to observe that all years maintained its position in the ranking, with a 1st place, except for 2006 (5th), 2009 (6th) and 2010 (4th).

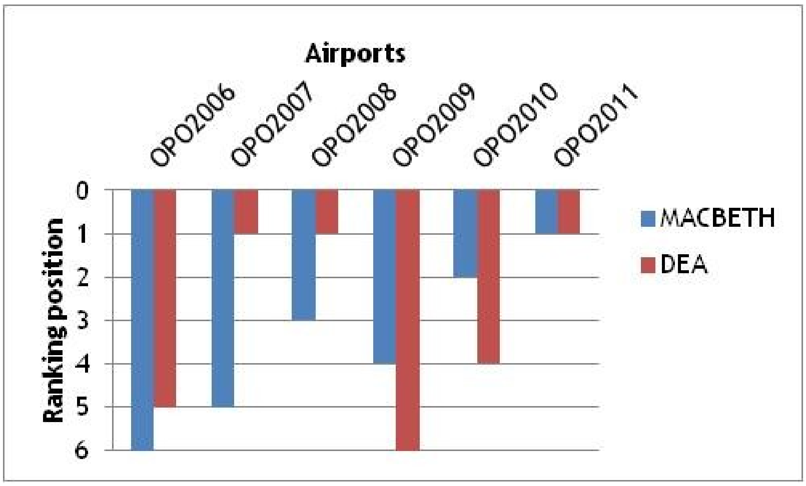

Figure 4.67: Balance between MACBETH and DEA Rankings for Porto Airport

In figure 4.67 is shown a comparison between MACBETH and DEA rankings, where the main differences are for 2007 and 2008. Porto airport had the 1st position on both approaches in 2011, and the less efficient years are for MACBETH and DEA, 2006 and 2009, respectively.

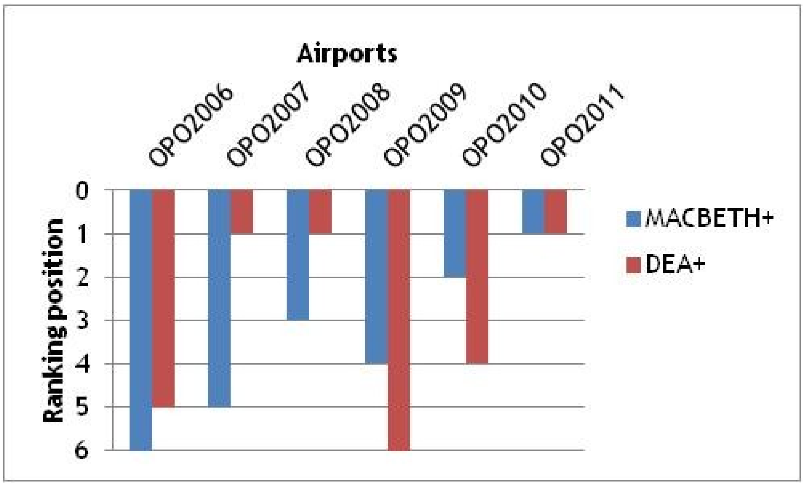

Figure 4.68: Balance between MACBETH+ and DEA+ Rankings for Porto Airport

In figure 4.68 is shown a comparison between MACBETH+ and DEA+ rankings, where the main differences are again for 2007 and 2008. Porto airport had the 1st position on both approaches in 2011, and the less efficient year for MACBETH+ and DEA+ was 2006 and 2009, respectively.

The ranking results obtained with MACBETH and DEA approaches are quite different. From figures 4.65 to 4.68, or from figure 4.69 and table 35 (direct comparison), it's possible to observe the variation on ranking places, due the use of those two different tools. Some years have different values between approaches.

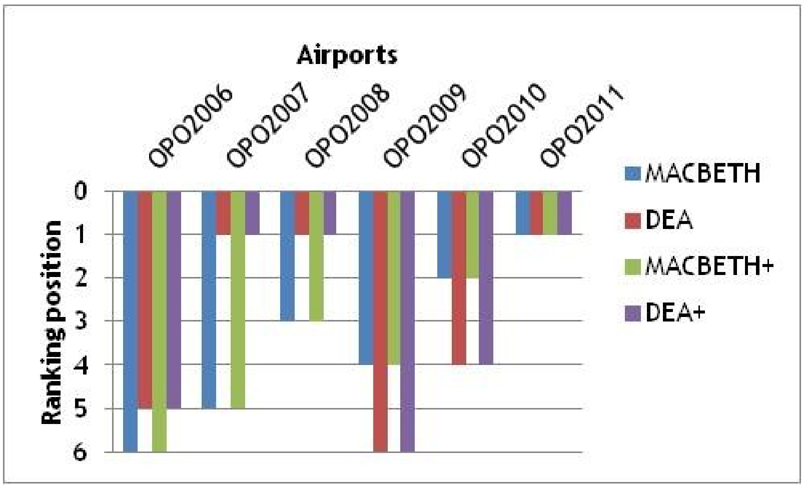

Figure 4.69: Porto Airport Comparative Ranking for all Cases

As visible in tables 33 and 34, the maximum scores within MACBETH and MACBETH+ analysis for Porto Airport were: 2011 for MOVS/STANDS, MOVS/RWS; PAX/PAX TA, PAX/CHK-IN, PAX/GATES, MOVS/GATES and MOVS/BELTS; and 2008 for CARGO/CARGO TA.

4.2.5.3. Faro Airport (FAO)

Faro Airport (IATA: FAO, ICAO: LPFR), also known as Algarve Airport, is located 4 km (2.5 mi) to the west of Faro, Portugal (see figure 4.70). The airport is usually very busy during the summer months, namely from March to October – IATA Summer, and became an important hub for the first time in March 2010, when Ryanair decided to base some of its aircrafts there. It is operated by ANA – Aeroportos de Portugal.

4.70: Faro Airport
(Zagope, 2012)

So, it was necessary to get data for this airport to produce an efficiency ranking, as presented in table 36. We had already the 2011 data from the Iberian analysis, but now it was necessary taking into account other years.

Table 36: Faro airport Data - from the list in the References

									STATISTICS		
	YEARS	RWS	STANDS	PAX TA	CARGO TA	CHK-IN	GATES	BELTS	PAX	MOVS	CARGO
FARO	FAO2006	1	29	68500	1050	60	36	5	5089672	42494	953
	FAO2007	1	29	68500	1050	60	36	5	5472791	45428	717,6
	FAO2008	1	29	68500	1050	60	36	5	5449683	45804	543
	FAO2009	1	29	68500	1050	60	36	5	5063774	44012	634,7
	FAO2010	1	29	68500	1050	60	36	5	5345394	44582	289,3
	FAO2011	1	29	68500	1050	60	36	5	5617786	44879	224,3

In order to use the MACBETH analysis, it was necessary again to obtain the complex indicators of table 36 for each year; the respective weights are those of table 7.

Table 37: Complex Indicators for Faro Airport

YEARS	PAX/ PAX TA	PAX/ GATES	PAX/ CHK-IN	CARGO/ CARGO TA	MOVS/ STANDS	MOVS/ GATES	MOVS/ RWS	MOVS/ BELTS
FAO2006	74,30	141379,78	84827,87	0,91	1465,31	1180,39	42494,00	8498,80
FAO2007	79,89	152021,97	91213,18	0,68	1566,48	1261,89	45428,00	9085,60
FAO2008	79,56	151380,08	90828,05	0,52	1579,45	1272,33	45804,00	9160,80
FAO2009	73,92	140660,39	84396,23	0,60	1517,66	1222,56	44012,00	8802,40
FAO2010	78,03	148483,17	89089,90	0,28	1537,31	1238,39	44582,00	8916,40
FAO2011	82,01	156049,61	93629,77	0,21	1547,55	1246,64	44879,00	8975,80

Then we use MACBETH and DEA tools to get the airport efficiency ranking based on a combination of the above mentioned indicators, and its related weights (tables 38 to 40, and figures 4.71 to 4.80).

Table 38: Faro Airport Scores for MACBETH Study Case

	Global	MOVS/STANDS	MOVS/RWS	PAX/ PAX TA	CARGO/ CARGO TA
[tudo sup.]	100	100	100	100	100
FAO2006	94	92,77	92,77	90,6	100
FAO2007	92,75	99,18	99,18	97,41	75
FAO2008	88,76	100	100	97	57,61
FAO2009	87,2	96,09	96,09	90,13	66,3
FAO2010	80,51	97,33	97,33	95,15	31,52
FAO2011	80,19	97,98	97,98	100	23,86
[tudo inf.]	**0**	0	0	0	0
	Weights	0,216	0,279	0,258	0,247

Table 39: Faro Airport Scores for MACBETH+ Study Case

	Global	MOVS/ STANDS	MOVS/ RWS	PAX/ PAX TA	CARGO/ CARGO TA	PAX/ CHK-IN	PAX/ GATES	MOVS/ GATES	MOVS/ BELTS
[tudo sup.]	100	100	100	100	100	100	100	100	100
FAO2007	95,39	99,18	99,18	97,41	75	97,42	97,42	99,18	99,18
FAO2008	93,39	100	100	97,01	57,61	97,01	97,01	100	100
FAO2006	92,1	92,77	92,77	90,6	100	90,6	90,6	84,91	92,77
FAO2009	89,94	96,09	96,09	90,13	66,3	90,14	90,14	96,09	96,09
FAO2011	89,25	97,98	97,98	100	23,86	100	100	97,98	97,98
FAO2010	88,03	97,33	97,33	95,15	31,52	95,15	95,15	97,33	97,33
[tudo inf.]	0	0	0	0	0	0	0	0	0
	Weights	0,1643	0,1288	0,1756	0,1284	0,1116	0,1034	0,0952	0,0927

Table 40: Efficiency Ranking for Faro Airport in the Four Cases

YEARS	DEA	Rank DEA	DEA+	Rank DEA+	MACBETH	Rank MACBETH	MACBETH+	Rank MACBETH+
FAO2006	100,00	1	100,00	1	94	1	92,1	3
FAO2007	100,00	1	100,00	1	92,75	2	95,39	1
FAO2008	100,00	1	100,00	1	88,76	3	93,39	2
FAO2009	96,6055	6	96,6055	6	87,2	4	89,94	4
FAO2010	97,6305	5	97,6305	5	80,51	5	88,03	6
FAO2011	100,00	1	100,00	1	80,19	6	89,25	5

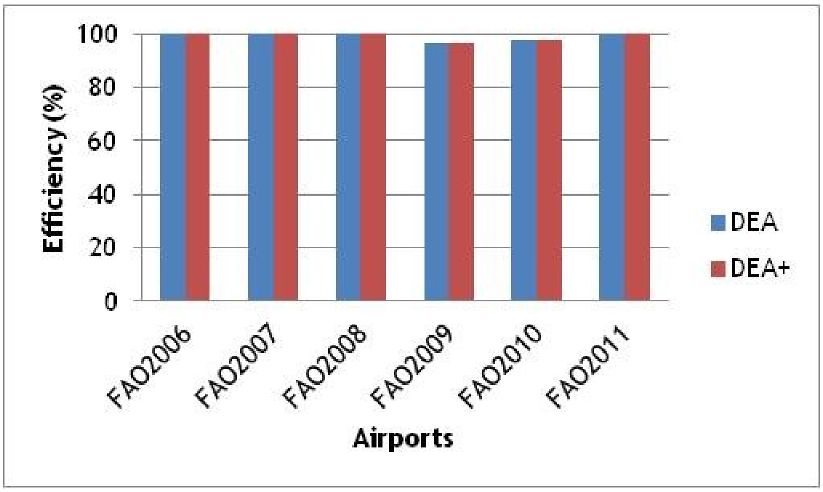

Figure 4.71: Comparative Efficiency between DEA and DEA+ for Faro Airport

As presented in figure 4.71, the addition of new performance indicators does not affect the efficiency of Faro airport in DEA analysis. It continues with an efficiency value of 100% in all years, except for 2009 and 2010, but not changing between the two cases.

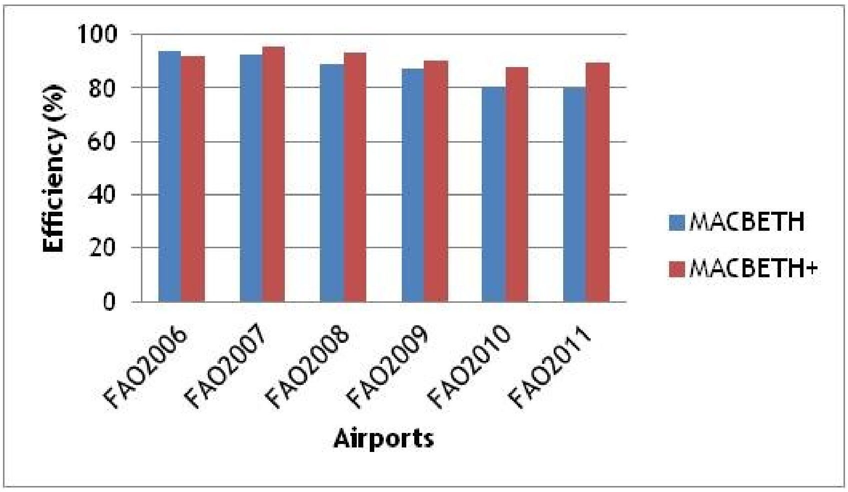

Figure 4.72: Comparative Efficiency Between MACBETH and MACBETH+ for Faro Airport

As presented in figure 4.72, the addition of new performance indicators in MACBETH tool shows an increase in the efficiency for all years, except for 2006, that decreased from 94% to 92,1% (table 40). The main difference was for 2011.

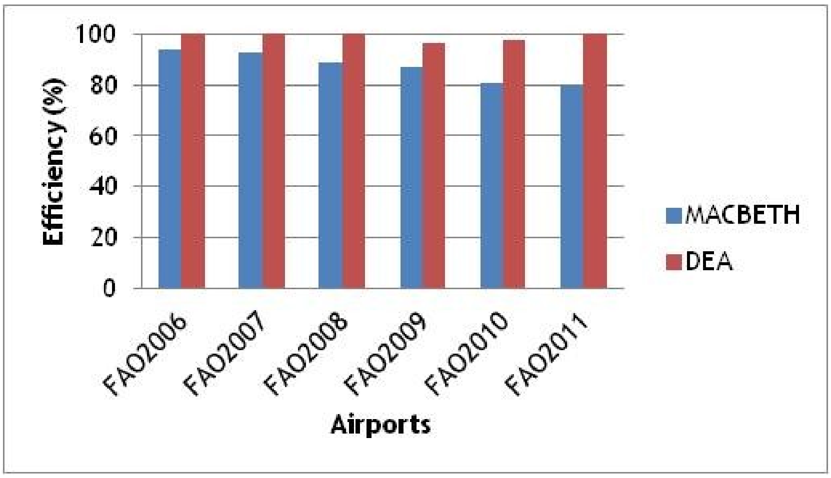

Figure 4.73: Comparative Efficiency between MACBETH and DEA for Faro Airport

In figure 4.73 is shown a comparison between MACBETH and DEA efficiency values, where DEA values are higher than MACBETH. The main differences are for 2010 and 2011. Faro airport had the best value in both approaches in 2006. The less efficient years were 2011 for MACBETH and 2009 for DEA.

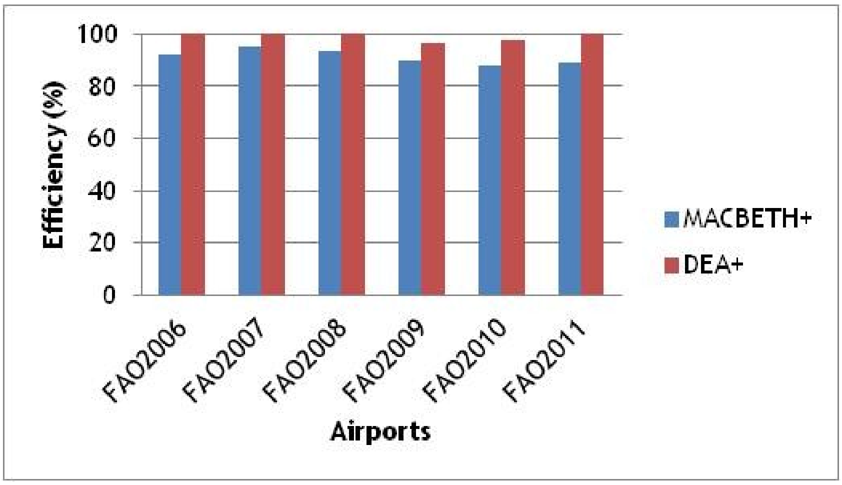

Figure 4.74: Comparative Efficiency between MACBETH+ and DEA+ for Faro Airport

In figure 4.63 is shown a comparison between MACBETH+ and DEA+ efficiency values, where in general and as in the previous analysis, DEA+ values are again higher than MACBETH+. Faro airport had the best value in both approaches in the year 2007. The less efficient years were 2010 for MACBETH+ and 2009 for DEA+.

The efficiency results obtained with MACBETH and DEA approaches are quite different. From figure 4.71 to 4.74, or from figure 4.75 and table 40 (direct comparison), it's possible to observe the variation on efficiency values, due to the use of those two different tools.

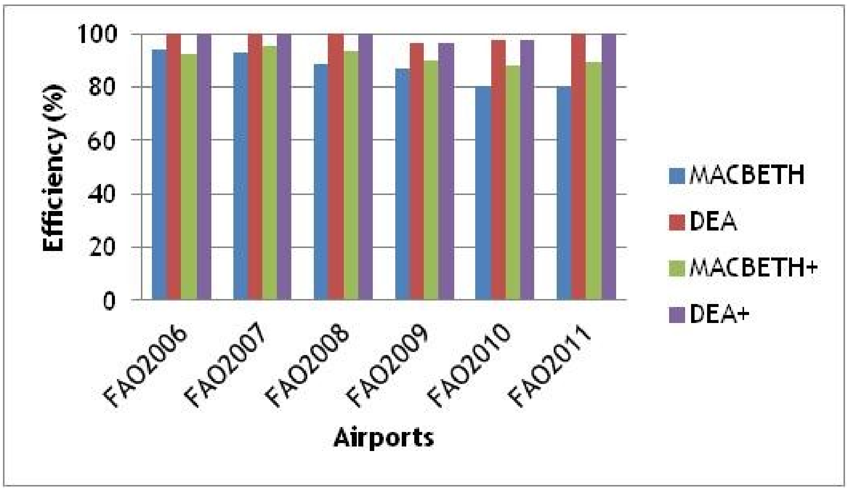

Figure 4.75: Faro Airport Comparative Efficiency for all Cases

Figures 4.76 to 4.79 permit another perspective, i.e. the efficiency ranking which is the goal of this study. The first two, present a comparison between rankings, before and after the addition of new indicators, and the last a comparison between tools, as in the previous analysis.

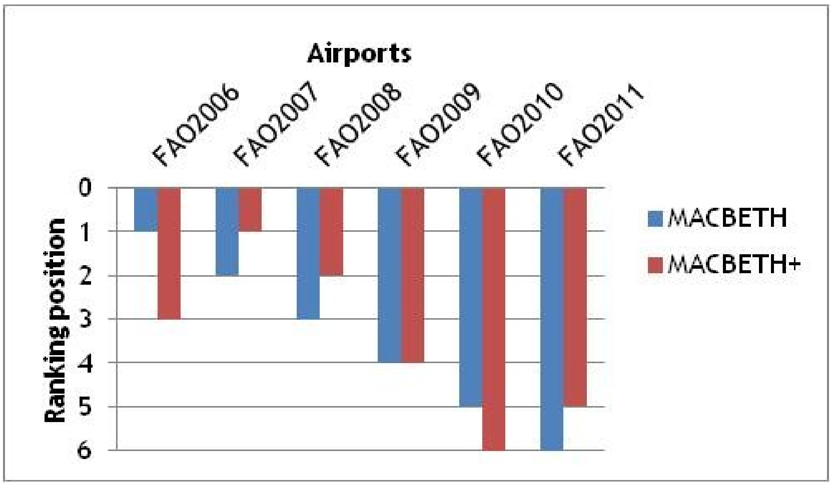

Figure 4.76: Balance between MACBETH and MACBETH+ Rankings for Faro Airport

Comparing the transition from MACBETH to MACBETH+, in figure 4.76, it's possible to observe that there is no changing in the rankings due to the addition of new indicators in 2009. Faro airport got 1st place on MACBETH and MACBETH+ for 2006 and 2007 respectively, and last position on 2011 for MACBETH and 2010 for MACBETH+, and in a general view, the efficiency of this airport decreased in the last years.

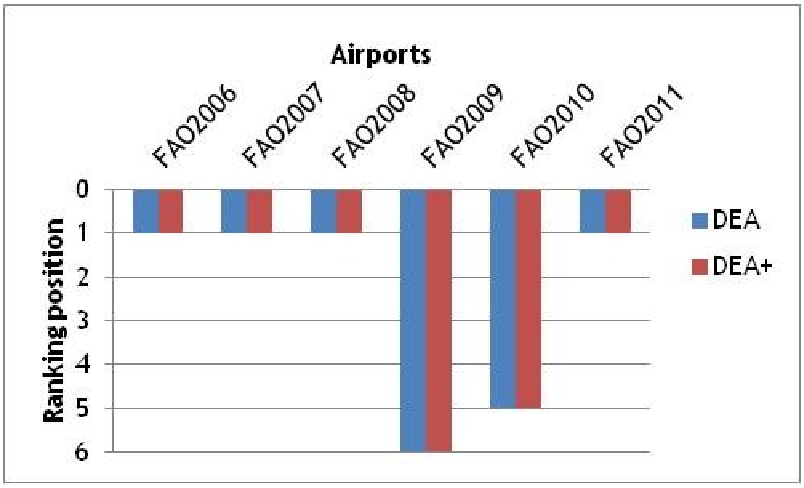

Figure 4.77: Balance between DEA and DEA+ Rankings for Faro Airport

Comparing the transition from DEA to DEA+ in figure 4.77, which represent again the adding of new indicators, it's possible to observe that in all years, except 2009 (6th) and 2010 (5th), the airport maintained its position in the ranking, the 1st place.

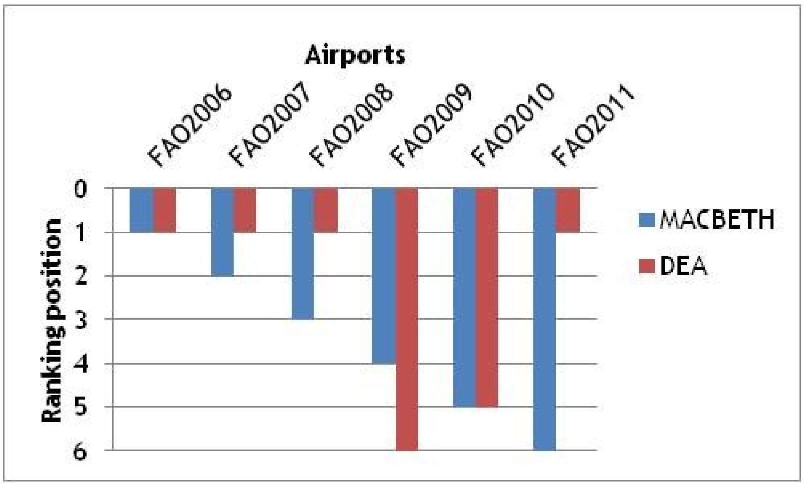

Figure 4.78: Balance between MACBETH and DEA Rankings for Faro Airport

In figure 4.78 is shown a comparison between MACBETH and DEA rankings, where the main difference is for 2011. Faro airport had 1st position on both approaches in 2006, and the less efficient years are for MACBETH and DEA, 2011 and 2009 respectively.

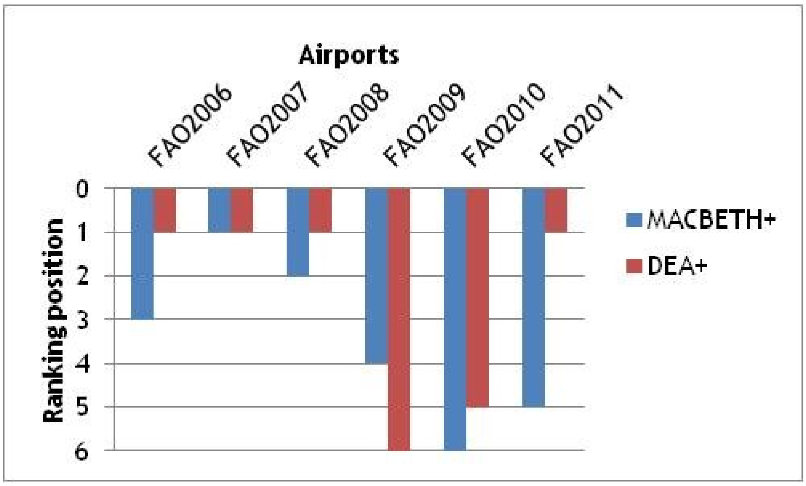

Figure 4.79: Balance between MACBETH+ and DEA+ Rankings for Faro Airport

In figure 4.79 is shown a comparison between MACBETH+ and DEA+ rankings, where the main difference is again for 2011. Faro airport had 1st position on both approaches in 2007, and the less efficient year for MACBETH+ and DEA+ was 2010 and 2009 respectively.

The ranking results obtained with MACBETH and DEA approaches are quite different. From figures 4.76 to 4.79, or from figure 4.80 and table 40 (direct comparison), it's possible to observe the variation on ranking places, due the use of those two different tools. Some years have different values between approaches.

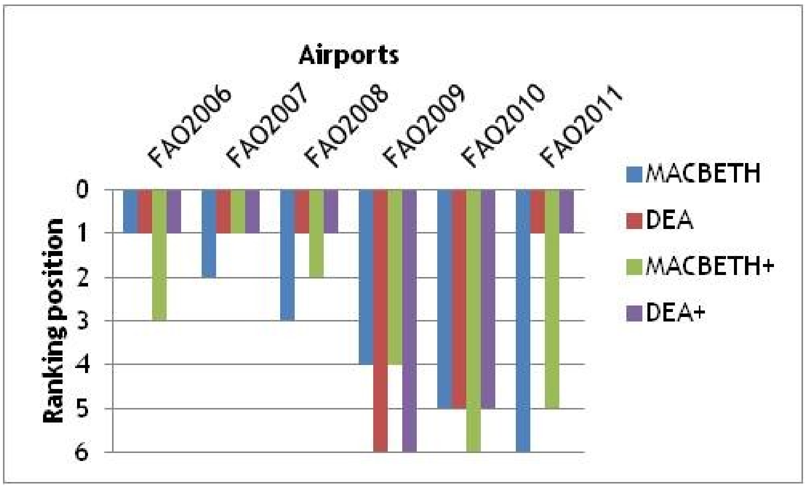

Figure 4.80: Faro Airport Comparative Ranking for all Cases

As visible in tables 38 and 39, the maximum scores within MACBETH and MACBETH+ analysis for Faro Airport were: 2008 for MOVS/STANDS, MOVS/RWS, MOVS/GATES and MOVS/BELTS; 2011 for PAX/PAX TA, PAX/CHK-IN, PAX/GATES; and 2006 for CARGO/CARGO TA.

4.2.5.4. Madeira Airport (FNC)

Madeira Airport (IATA: FNC, ICAO: LPMA), informally known as Funchal Airport, is an international airport located in Santa Cruz. It is located 13.2 km (8.2 mi) east northeast of the Funchal city centre, Madeira Island, Portugal. It is operated by ANAM – Aeroportos da Madeira, managing national and international air traffic for the island and it is constructed between high terrain and the sea, as visible in figure 4.81. Part of the runway is constructed above an inert landfill, as part of the airport expansion works, in which all the airport infrastructures were rebuilt, with exception of the air traffic control tower. Is one of the most important airports in Portugal in what concerns touristic activity; the last airline starting connections with it was Deutsche Lufthansa, on September 8th 2012.

Figure 4.81: Madeira Airport
(Couceiro, 2012)

So, it was necessary to get the same data for this airport to produce an efficiency ranking, as presented in table 41. We had already the 2011 data from the Iberian analysis, but now it was necessary to taking into account other years.

Table 41: Madeira Airport Data - from the list in the References

									STATISTICS		
	YEARS	RWS	STANDS	PAX TA	CARGO TA	CHK-IN	GATES	BELTS	PAX	MOVS	CARGO
MADEIRA	FNC2006	1	16	44590	4500	40	16	4	2360857	25828	9200
	FNC2007	1	16	44590	4500	40	16	4	2418489	21954	6774,6
	FNC2008	1	16	44590	4500	40	16	4	2446924	22799	6637,6
	FNC2009	1	16	44590	4500	40	16	4	2346649	21955	6228,4
	FNC2010	1	16	44590	4500	40	16	4	2233524	22094	6069,5
	FNC2011	1	16	44590	4500	40	16	4	2311380	21346	5095

In order to use the MACBETH analysis, it was necessary again to obtain the complex indicators of table 42 for each year; the respective weights are those of table 7.

Table 42: Complex Indicators for Madeira Airport

YEARS	PAX/ PAX TA	PAX/ GATES	PAX/ CHK-IN	CARGO/ CARGO TA	MOVS/ STANDS	MOVS/ GATES	MOVS/ RWS	MOVS/ BELTS
FNC2006	52,95	147553,56	59021,43	2,04	1614,25	1614,25	25828,00	6457,00
FNC2007	54,24	151155,56	60462,23	1,51	1372,13	1372,13	21954,00	5488,50
FNC2008	54,88	152932,75	61173,10	1,48	1424,94	1424,94	22799,00	5699,75
FNC2009	52,63	146665,56	58666,23	1,38	1372,19	1372,19	21955,00	5488,75
FNC2010	50,09	139595,25	55838,10	1,35	1380,88	1380,88	22094,00	5523,50
FNC2011	51,84	144461,25	57784,50	1,13	1334,13	1334,13	21346,00	5336,50

Then we use MACBETH and DEA tools to get the airport efficiency ranking based on a combination of the above mentioned indicators, and its related weights (tables 43 to 45, and figures 4.82 to 4.91).

Table 43: Madeira Airport Scores for MACBETH Study Case

	Global	MOVS/STANDS	MOVS/RWS	PAX/ PAX TA	CARGO/ CARGO TA
[tudo sup.]	100	100	100	100	100
FNC2006	99,09	99,97	100	96,5	100
FNC2008	87,42	88,26	88,27	100	72,55
FNC2007	85,86	84,99	85	98,85	74,02
FNC2009	83,53	84,99	85	95,92	67,65
FNC2010	82,24	85,53	85,54	91,28	66,18
FNC2011	78,96	82,64	82,65	94,47	55,39
[tudo inf.]	**0**	0	0	0	0
	Weights	0,216	0,279	0,258	0,247

Table 44: Madeira Airport Scores for MACBETH+ Study Case

	Global	MOVS/ STANDS	MOVS/ RWS	PAX/ PAX TA	CARGO/ CARGO TA	PAX/ CHK-IN	PAX/ GATES	MOVS/ GATES	MOVS/ BELTS
[tudo sup.]	100	100	100	100	100	100	100	100	100
FNC2006	98,63	100	100	96,5	100	96,48	96,48	100	100
FNC2008	90,84	88,27	88,27	100	72,55	100	100	88,27	88,27
FNC2007	89	85	85	98,85	74,02	98,84	98,84	85	85
FNC2009	87,03	85	85	95,92	67,65	95,9	95,9	85	85
FNC2010	85,3	85,54	85,54	91,28	66,18	91,28	91,28	85,54	85,54
FNC2011	83,76	82,65	82,65	94,47	55,39	94,46	94,46	82,65	82,65
[tudo inf.]	0	0	0	0	0	0	0	0	0
	Weights	0,1643	0,1288	0,1756	0,1284	0,1116	0,1034	0,0952	0,0927

Table 45: Efficiency Ranking for Madeira Airport in the Four Cases

YEARS	DEA	Rank DEA	DEA+	Rank DEA+	MACBETH	Rank MACBETH	MACBETH+	Rank MACBETH+
FNC2006	100,00	1	100,00	1	99,09	1	98,63	1
FNC2007	99,1073	3	99,1073	3	85,86	3	89	3
FNC2008	100,00	1	100,00	1	87,42	2	90,84	2
FNC2009	95,9849	4	95,9849	4	83,53	4	87,03	4
FNC2010	92,4571	6	92,4571	6	82,24	5	85,3	5
FNC2011	94,4606	5	94,4606	5	78,96	6	83,76	6

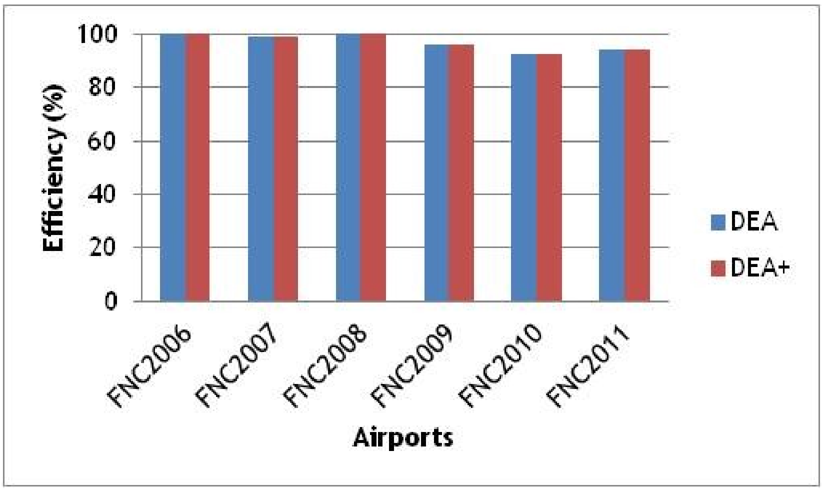

Figure 4.82: Comparative Efficiency Between DEA and DEA+ for Madeira Airport

As presented in figure 4.82, the addition of new performance indicators does not affect the efficiency of Madeira airport in DEA analysis. Each year maintain its efficiency value in both cases. The most efficient years were 2006 and 2008, and the less efficient 2010.

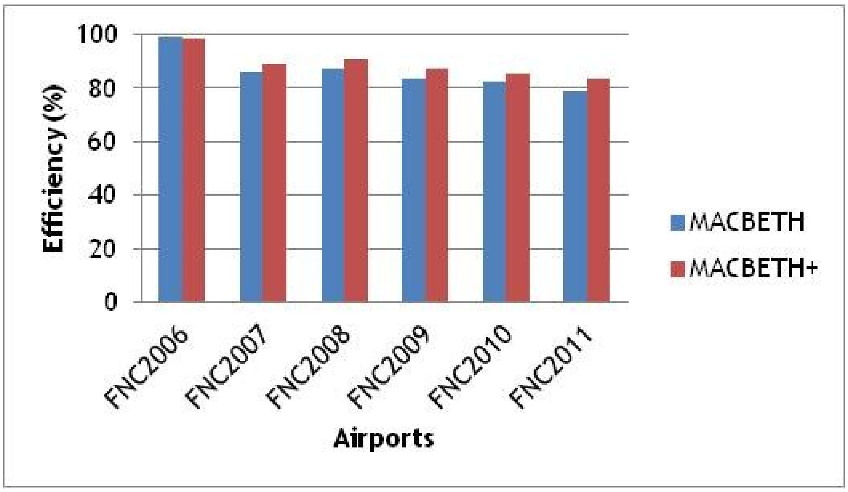

Figure 4.83: Comparative Efficiency between MACBETH and MACBETH+ for Madeira Airport

As presented in figure 4.83, the addition of new performance indicators in MACBETH tool shows an increase in the efficiency for all years, except for 2006, that decreased from 99,09% to 98,63% (table 45). The main difference was for 2011.

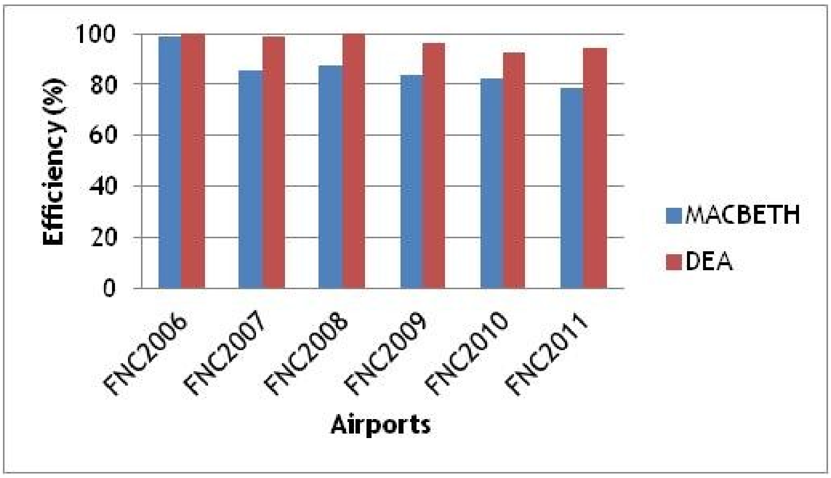

Figure 4.84: Comparative Efficiency between MACBETH and DEA for Madeira Airport

In figure 4.84 is shown a comparison between MACBETH and DEA efficiency values, where DEA values are higher than MACBETH. The main difference was for 2011. Madeira airport had the best value in both approaches in 2006. The less efficient years were 2011 for MACBETH and 2010 for DEA.

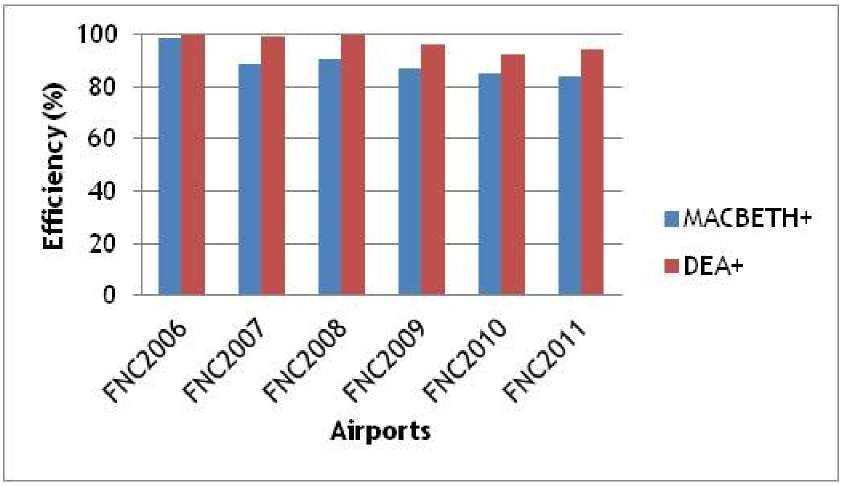

Figure 4.85: Comparative Efficiency between MACBETH+ and DEA+ for Madeira Airport

In figure 4.85 is shown a comparison between MACBETH+ and DEA+ efficiency values, where in general and as in the previous analysis, DEA+ values are again higher than MACBETH+. Madeira airport had the best value in both approaches in the year 2006. The less efficient years were 2011 for MACBETH+ and 2010 for DEA+.

The efficiency results obtained with MACBETH and DEA approaches are quite different. From figures 4.82 to 4.85, or from figure 4.86 and table 45 (direct comparison), it's possible to observe the variation on efficiency values, due to the use of those two different tools.

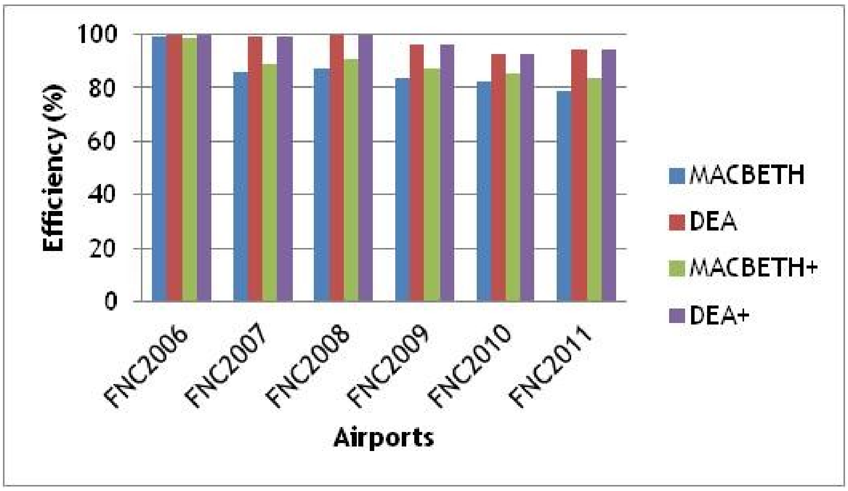

Figure 4.86: Madeira Airport Comparative Efficiency for all Cases

Figures 4.87 to 4.91 permit another perspective, i.e. the efficiency ranking which is the target of this study. The first two, present a comparison between rankings, before and after the addition of new indicators, and the last a comparison between tools, as in the previous analysis.

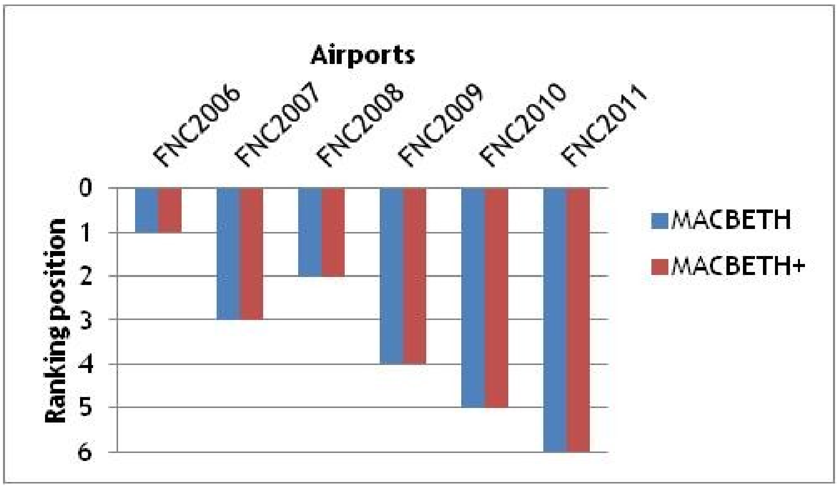

Figure 4.87: Balance between MACBETH and MACBETH+ Rankings for Madeira Airport

Comparing the transition from MACBETH to MACBETH+, in figure 4.87, it's possible to observe that there is no changes in the rankings due to the addition of new indicators. Madeira airport got 1st place on MACBETH and MACBETH+ for 2006, and last position on 2011 for MACBETH and MACBETH+. In a general view, the efficiency of this airport decreased in the last years, mainly due to a high decrease in traffic statistics.

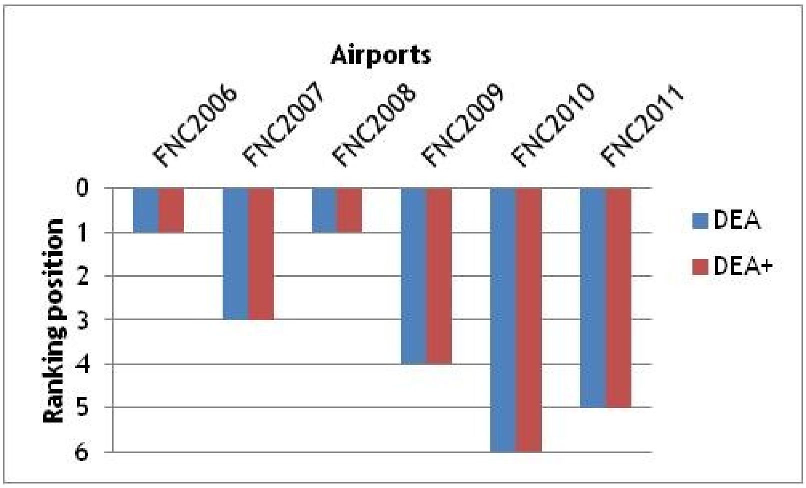

Figure 4.88: Balance between DEA and DEA+ Rankings for Madeira Airport

Comparing the transition from DEA to DEA+ in figure 4.88, which represent again the adding of new indicators, it's possible to observe that there is no changing in the rankings due to the addition of new indicators. Madeira airport got 1st place on DEA and DEA+ for 2006 and 2008, and last position on 2010 for DEA and DEA+.

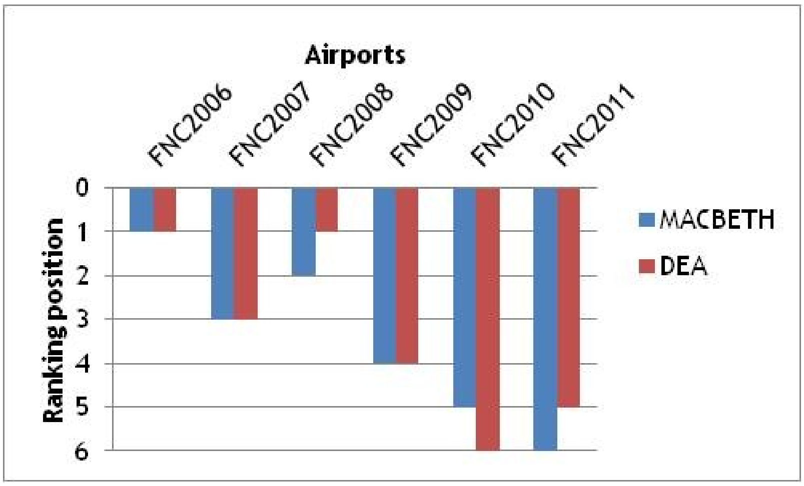

Figure 4.89: Balance between MACBETH and DEA Rankings for Madeira Airport

In figure 4.89 is shown a comparison between MACBETH and DEA rankings, where the difference were in 2008, 2010 and 2011. Madeira airport had 1st position on both approaches in 2006, and the less efficient years are for MACBETH and DEA, 2011 and 2010 respectively.

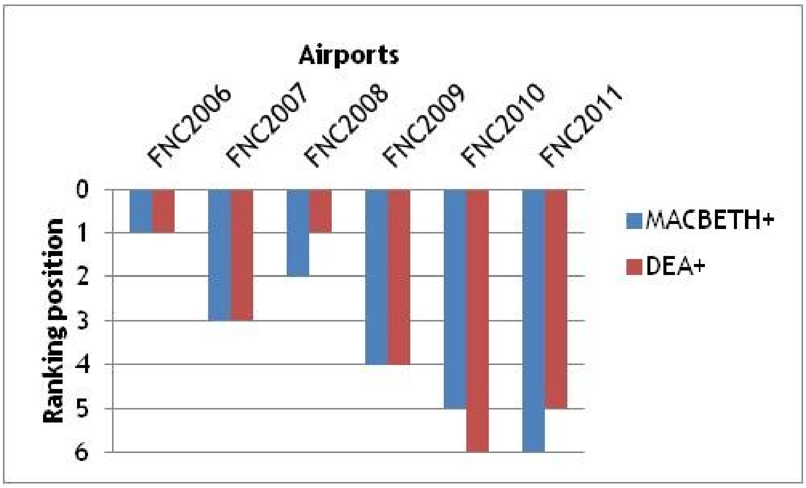

Figure 4.90: Balance between MACBETH+ and DEA+ Rankings for Madeira Airport

In figure 4.90 is shown a comparison between MACBETH+ and DEA+ rankings, where the difference were again for 2008, 2010 and 2011. Madeira airport had 1st position on both approaches in 2006, and the less efficient year for MACBETH+ and DEA+ was 2011 and 2010 respectively.

The ranking results obtained with MACBETH and DEA approaches are quite different. From figure 4.87 to 4.90, or from figure 4.91 and table 45 (direct comparison), it's possible to observe the variation on ranking places, due the use of those two different tools. Some years have different values between approaches.

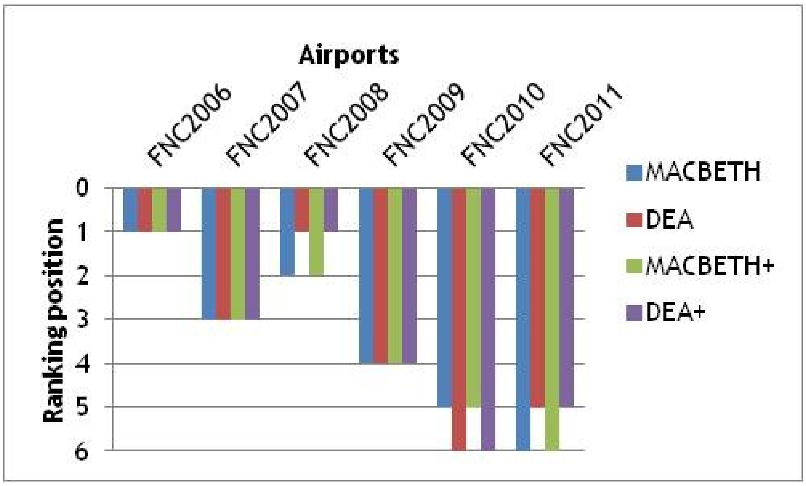

Figure 4.91: Madeira Airport Comparative Ranking for all Cases

As visible in tables 43 and 44, the maximum scores within MACBETH and MACBETH+ analysis for Madeira Airport were: 2006 for MOVS/STANDS, MOVS/RWS, CARGO/CARGO TA, MOVS/GATES and MOVS/BELTS; 2008 for PAX/PAX TA, PAX/CHK-IN and PAX/GATES.

4.2.5.5. Ponta Delgada Airport (PDL)

João Paulo II Airport (IATA: PDL, ICAO: LPPD), named Pope John Paul II, is an 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 (see figure 4.92). The airport is a hub for the Azorian airline SATA Air Açores and SATA International.

Figure 4.92: Ponta Delgada Airport
(Sousa, 2012)

Thus, it was necessary to get data for this airport to produce an efficiency ranking, as presented in 4able 46. We had already the 2011 data from the Iberian analysis, but now it was necessary to take into account other years.

Table 46: Ponta Delgada Airport Data - from the list in the References

									STATISTICS		
	YEARS	RWS	STANDS	PAX TA	CARGO TA	CHK-IN	GATES	BELTS	PAX	MOVS	CARGO
PONTA DELGADA	PDL2006	1	9	13637	2200	14	3	3	909609	12165	8593
	PDL2007	1	9	13637	2200	14	3	3	944904	12604	6678,6
	PDL2008	1	9	13637	2200	14	3	3	925766	12875	6430,6
	PDL2009	1	9	13637	2200	14	3	3	899266	13449	6245
	PDL2010	1	14	13637	2200	14	3	3	935207	13115	5994,7
	PDL2011	1	14	13637	2200	14	3	3	933763	12327	5900,9

In order to use the MACBETH analysis, it was necessary again to obtain the complex indicators of table 47 for each year; the respective weights are those of table 7.

Table 47: Complex Indicators for Ponta Delgada Airport

YEARS	PAX/ PAX TA	PAX/ GATES	PAX/ CHK-IN	CARGO/ CARGO TA	MOVS/ STANDS	MOVS/ GATES	MOVS/ RWS	MOVS/ BELTS
PDL2006	66,70	303203,00	64972,07	3,91	1351,67	4055,00	12165,00	4055,00
PDL2007	69,29	314968,00	67493,14	3,04	1400,44	4201,33	12604,00	4201,33
PDL2008	67,89	308588,67	66126,14	2,92	1430,56	4291,67	12875,00	4291,67
PDL2009	65,94	299755,33	64233,29	2,84	1494,33	4483,00	13449,00	4483,00
PDL2010	68,58	311735,67	66800,50	2,72	936,79	4371,67	13115,00	4371,67
PDL2011	68,47	311254,33	66697,36	2,68	880,50	4109,00	12327,00	4109,00

Then we use MACBETH and DEA tools to get the airport efficiency ranking based on a combination of the above mentioned indicators, and its related weights (tables 48 to 50, and figures 4.93 to 4.102).

Table 48: Ponta Delgada Airport Scores for MACBETH Study Case

	Global	MOVS/STANDS	MOVS/RWS	PAX/ PAX TA	CARGO/ CARGO TA
[tudo sup.]	100	100	100	100	100
PDL2006	94,31	90,45	90,45	96,26	100
PDL2009	91,95	100	100	95,16	72,45
PDL2007	91,41	93,72	93,72	100	77,81
PDL2008	91,13	95,73	95,73	97,98	74,74
PDL2010	83,49	62,69	97,52	98,98	69,64
PDL2011	80,74	58,92	91,66	98,82	68,62
[tudo inf.]	**0**	0	0	0	0
	Weights	0,216	0,279	0,258	0,247

Table 49: Ponta Delgada Airport Scores for MACBETH+ Study Case

	Global	MOVS/ STANDS	MOVS/ RWS	PAX/ PAX TA	CARGO/ CARGO TA	PAX/ CHK-IN	PAX/ GATES	MOVS/ GATES	MOVS/ BELTS
[tudo sup.]	100	100	100	100	100	100	100	100	100
PDL2009	94,57	100	100	95,16	72,45	95,17	95,17	100	100
PDL2007	94,13	93,72	93,72	100	77,81	100	100	93,72	93,72
PDL2006	93,95	90,45	90,45	96,26	100	96,26	96,26	90,45	90,45
PDL2008	93,91	95,73	95,73	97,98	74,74	97,97	97,97	95,73	95,73
PDL2010	88,78	62,69	97,52	98,98	69,64	98,97	98,97	97,52	97,52
PDL2011	86,12	58,92	91,66	98,82	68,62	98,82	98,82	91,66	91,66
[tudo inf.]	0	0	0	0	0	0	0	0	0
	Weights	0,1643	0,1288	0,1756	0,1284	0,1116	0,1034	0,0952	0,0927

Table 50: Efficiency Ranking for Ponta Delgada Airport in the Four Cases

YEARS	DEA	Rank DEA	DEA+	Rank DEA+	MACBETH	Rank MACBETH	MACBETH+	Rank MACBETH+
PDL2006	100,00	1	100,00	1	94,31	1	93,95	3
PDL2007	100,00	1	100,00	1	91,41	2	94,13	2
PDL2008	99,72	5	99,72	5	91,13	4	93,91	4
PDL2009	100,00	1	100,00	1	91,95	3	94,57	1
PDL2010	100,00	1	100,00	1	83,49	5	88,78	5
PDL2011	98,82	6	98,82	6	80,74	6	86,12	6

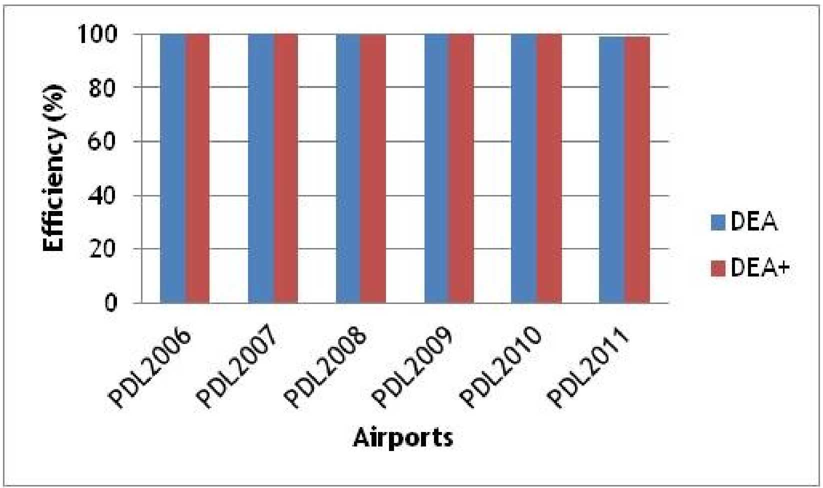

Figure 4.93: Comparative Efficiency between DEA and DEA+ for Ponta Delgada Airport

As presented in figure 4.93, the addition of new performance indicators does not affect the efficiency of Ponta Delgada airport in DEA analysis. Each year maintain its efficiency value in both cases. The less efficient year was 2011.

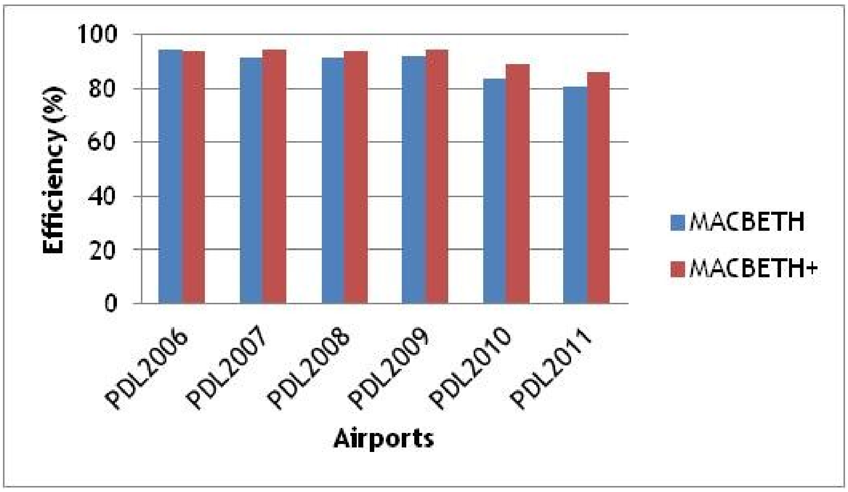

Figure 4.94: Comparative Efficiency between MACBETH and MACBETH+ for Ponta Delgada Airport

As presented in figure 4.94, the addition of new performance indicators in MACBETH tool shows an increase in the efficiency for all years, except for 2006, that decreased from 94,31% to 93,95% (table 50). The main differences were for 2010 and 2011.

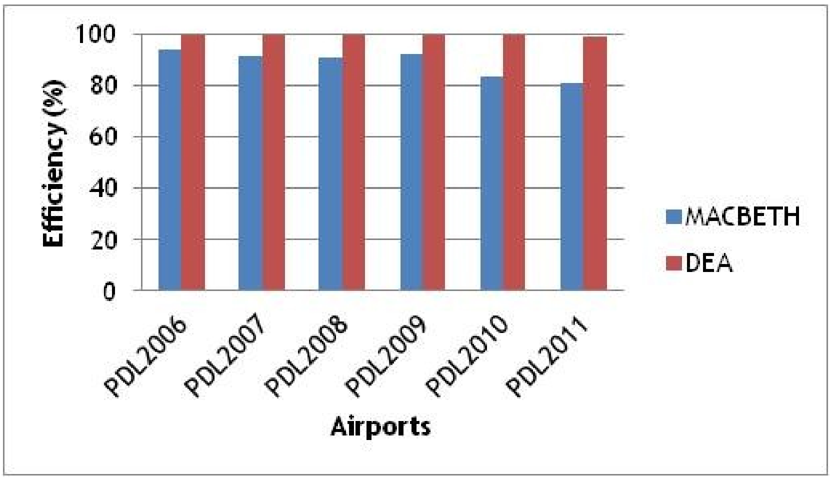

Figure 4.95: Comparative Efficiency Between MACBETH and DEA for Ponta Delgada Airport

In figure 4.95 is shown a comparison between MACBETH and DEA efficiency values, where DEA values are higher than MACBETH ones. The main differences were for 2010 and 2011. Ponta Delgada airport had the best value in both approaches in 2006. The less efficient years were 2011 for MACBETH and DEA.

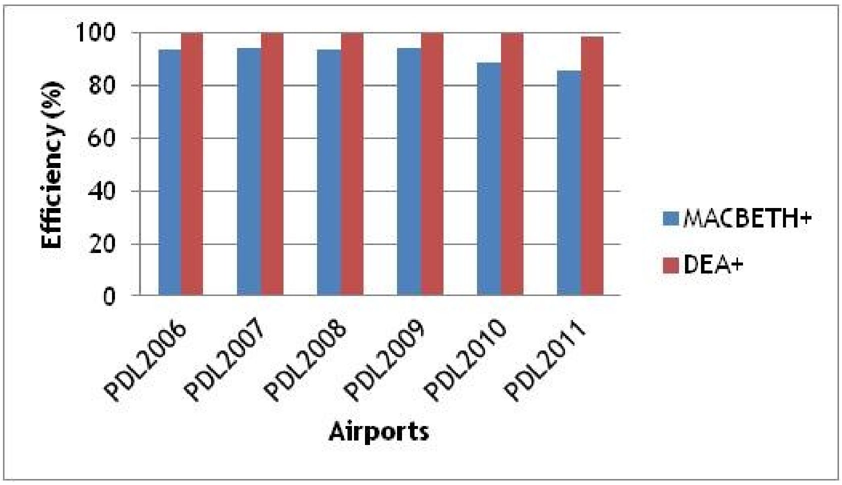

Figure 4.96: Comparative Efficiency Between MACBETH+ and DEA+ for Ponta Delgada Airport

In figure 4.96 is shown a comparison between MACBETH+ and DEA+ efficiency values, where in general and as in the previous analysis, DEA+ values are again higher than MACBETH+. Ponta Delgada airport had the best value in both approaches in the year 2009. The less efficient year was 2011 for MACBETH+ and DEA+.

The efficiency results obtained with MACBETH and DEA approaches are quite different. From figure 4.93 to 4.96, or from figure 4.97 and table 50 (direct comparison), it's possible to observe the variation on efficiency values, due to the use of those two different tools.

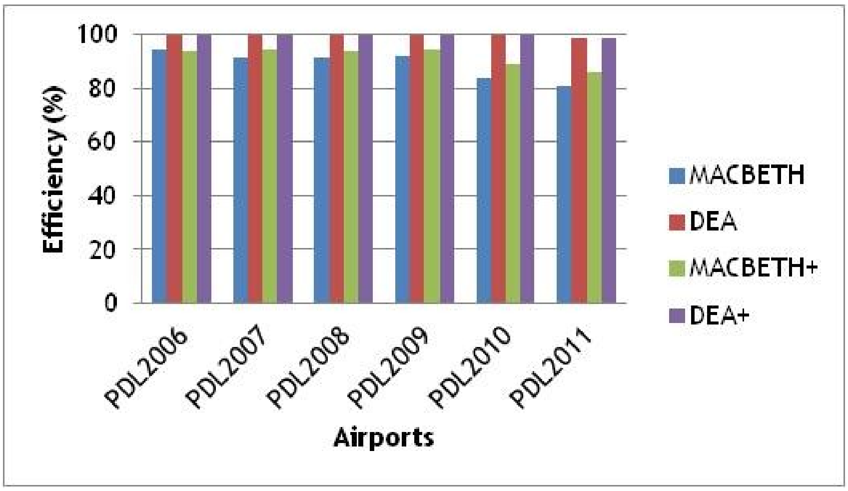

Figure 4.97: Ponta Delgada Airport Comparative Efficiency for all Cases

Figures 4.98 to 4.102 permit another perspective, i.e. the efficiency ranking which is the core of this study. The first two, present a comparison between rankings, before and after the addition of new indicators, and the last a comparison between tools, as in the previous analysis.

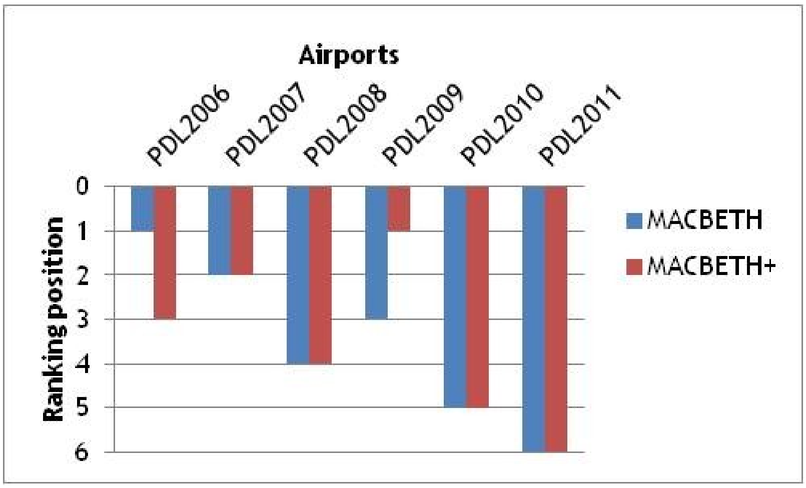

Figure 4.98: Balance between MACBETH and MACBETH+ Rankings for Ponta Delgada Airport

Comparing the transition from MACBETH to MACBETH+, in figure 4.98, it's possible to observe that there is no changes in the rankings due to the addition of new indicators for 2007, 2008, 2010 and 2011, however in 2006 it changes from 1st to 3rd and in 2009 from 3rd to 1st. Ponta Delgada airport got 1st place on MACBETH and MACBETH+ for 2006 and 2009 respectively, and last position on 2011 for both cases. In a general view, the efficiency of this airport decreased equally in the last years.

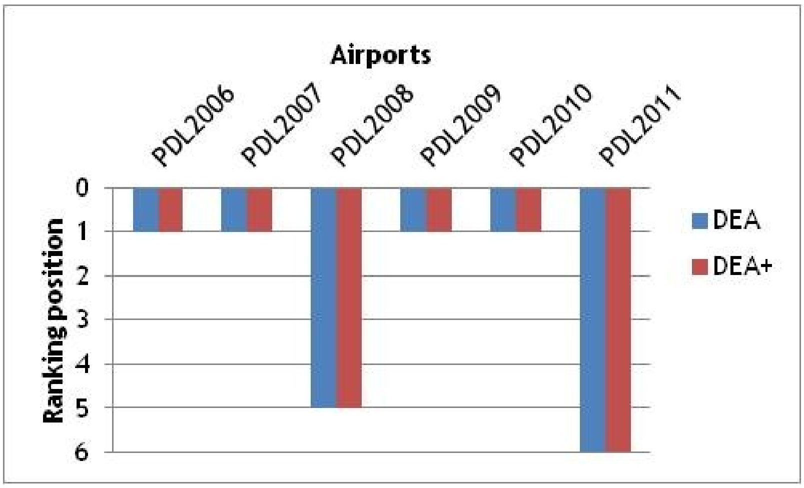

Figure 4.99: Balance between DEA and DEA+ Rankings for Ponta Delgada Airport

Comparing the transition from DEA to DEA+ in figure 4.99, which represent again the adding of new indicators, it's possible to observe that there is no changes in the rankings due to the addition of new indicators. Ponta Delgada airport got 1st place on DEA and DEA+ on 2006, 2007, 2009 and 2010 and last position on 2011.

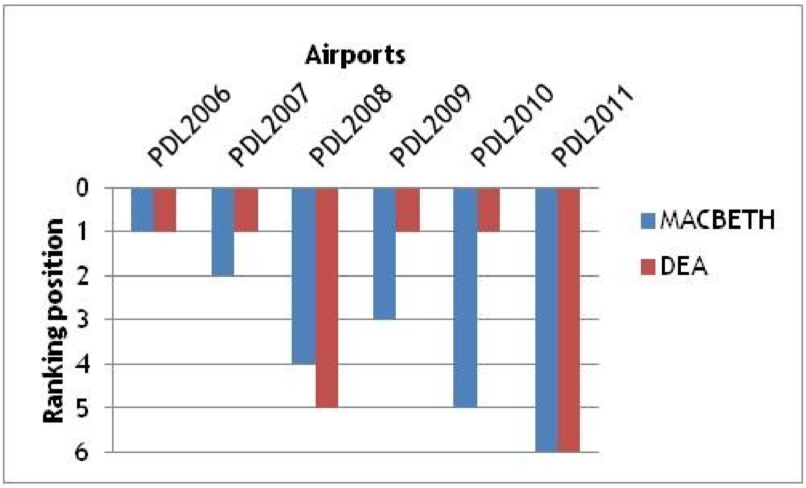

Figure 4.100: Balance between MACBETH and DEA Rankings for Ponta Delgada Airport

In figure 4.100 is shown a comparison between MACBETH and DEA rankings, where the main differences were for 2007, 2008, 2009 and 2010. Ponta Delgada airport had 1st position on both approaches in 2006, and the less efficient year for MACBETH and DEA, was 2011.

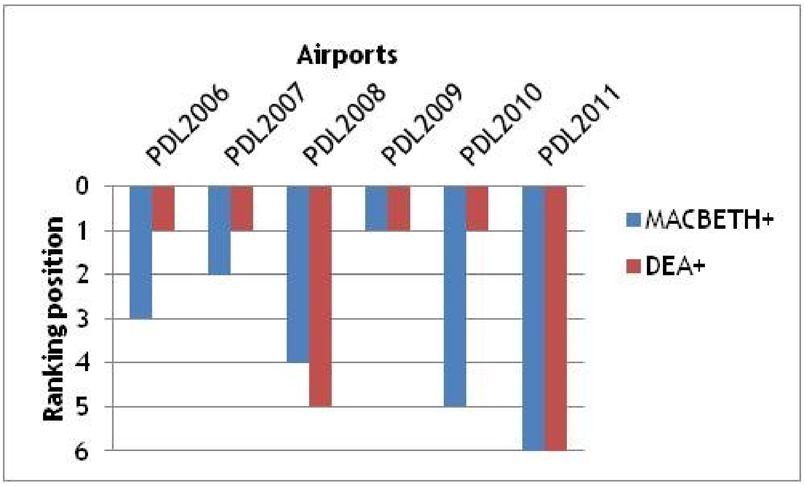

Figure 4.101: Balance between MACBETH+ and DEA+ Rankings for Ponta Delgada Airport

In figure 4.101 is shown a comparison between MACBETH+ and DEA+ rankings, where the difference were again for 2006, 2007, 2008 and 2010. The airport had the 1st position on both approaches in 2009, and the less efficient year for MACBETH+ and DEA+ was 2011.

The ranking results obtained with MACBETH and DEA approaches are quite different. From figures 4.98 to 4.101, or from figure 4.102 and table 50 (direct comparison), it's possible to observe the variation on ranking places, due the use of those two different tools. Some years have different values between approaches.

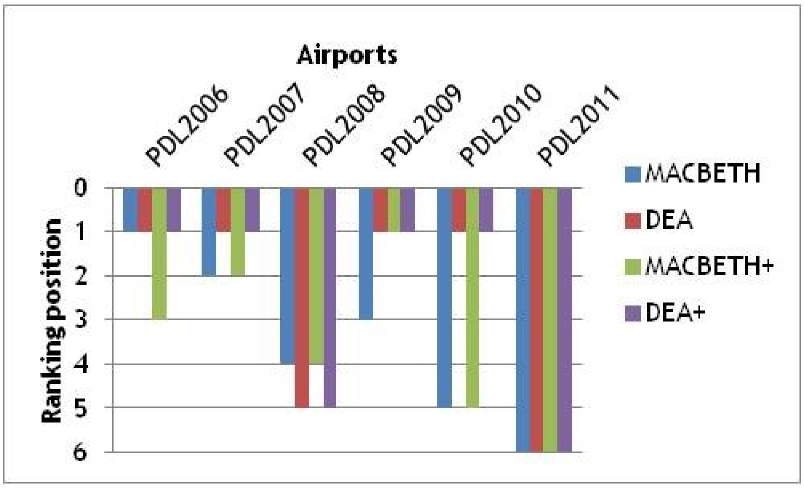

Figure 4.102: Ponta Delgada Airport Comparative Ranking for all Cases

As visible in tables 48 and 49, the maximum scores into MACBETH and MACBETH+ analysis for Ponta Delgada Airport were: 2009 for MOVS/STANDS, MOVS/RWS, MOVS/GATES and MOVS/BELTS; 2007 for PAX/PAX TA, PAX/CHK-IN and PAX/GATES; and 2006 for CARGO/CARGO TA.

4.2.5.6. Madrid Airport (MAD)

Madrid-Barajas Airport, in Spanish *Aeropuerto Internacional de Madrid-Barajas,* (IATA: MAD, ICAO: LEMD), is the main international airport serving Madrid, in Spain (figure 4.103). Localized within the city limits of Madrid, just 9 km (5.6 mi) from the city's financial district and 13 km (8.1 mi) northeast of the Puerta del Sol, Madrid's historic centre. It is operated by *AENA Aeropuertos*, whose headquarters are precisely in this airport.

Figure 4.103: Madrid Barajas Airport Terminal 4 (AENA, 2012a)

Thus, it was necessary to get data for this airport to produce an efficiency ranking, as presented in table 51. We had already the 2011 data from the Iberian analysis, but now it was necessary taking into account other years.

Table 51: Madrid Airport Data - from the list in the References

									STATISTICS		
	YEARS	RWS	STANDS	PAX TA	CARGO TA	CHK-IN	GATES	BELTS	PAX	MOVS	CARGO
MADRID	MAD2006	4	180	940000	15356	272	212	53	45501168	435018	350,758
	MAD2007	4	180	940000	15356	272	212	53	52110787	483292	325201,1
	MAD2008	4	180	940000	15356	272	212	53	50846494	469746	329186,6
	MAD2009	4	180	940000	15356	272	212	53	48437147	435187	302863,3
	MAD2010	4	180	940000	15356	272	212	53	49866113	433706	373911,1
	MAD2011	4	180	940000	15356	272	212	53	49671270	429390	394154,1

In order to use the MACBETH analysis, it was necessary again to obtain the complex indicators of table 52 for each year; the respective weights are those of table 7.

Table 52: Complex Indicators for Madrid Airport

YEARS	PAX/ PAX TA	PAX/ GATES	PAX/ CHK-IN	CARGO/ CARGO TA	MOVS/ STANDS	MOVS/ GATES	MOVS/ RWS	MOVS/ BELTS
MAD2006	48,41	214628,15	167283,71	22,84	2416,77	2051,97	108754,50	8207,89
MAD2007	55,44	245805,60	191583,78	21,18	2684,96	2279,68	120823,00	9118,72
MAD2008	54,09	239841,95	186935,64	21,44	2609,70	2215,78	117436,50	8863,13
MAD2009	51,53	228477,11	178077,75	19,72	2417,71	2052,77	108796,75	8211,08
MAD2010	53,05	235217,51	183331,30	24,35	2409,48	2045,78	108426,50	8183,13
MAD2011	52,84	234298,44	182614,96	25,67	2385,50	2025,42	107347,50	8101,70

Then we use MACBETH and DEA tools to get the airport efficiency ranking based on a combination of the above mentioned indicators, and its related weights (tables 53 to 55, and figures 4.104 to 4.113).

Table 53: Madrid Airport Scores for MACBETH Study Case

	Global	MOVS/STANDS	MOVS/RWS	PAX/ PAX TA	CARGO/ CARGO TA
[tudo sup.]	100	100	100	100	100
MAD2007	95,68	100	100	100	82,53
MAD2008	93,92	97,2	97,2	97,56	83,54
MAD2011	93,28	88,85	88,85	95,31	100
MAD2010	92,55	89,74	89,74	95,69	94,89
MAD2006	89,07	90,01	90,01	87,32	89
MAD2009	87,53	90,05	90,05	92,93	76,83
[tudo inf.]	**0**	0	0	0	0
	Weights	0,216	0,279	0,258	0,247

Table 54: Madrid Airport Scores for MACBETH+ Study Case

	Global	MOVS/ STANDS	MOVS/ RWS	PAX/ PAX TA	CARGO/ CARGO TA	PAX/ CHK-IN	PAX/ GATES	MOVS/ GATES	MOVS/ BELTS
[tudo sup.]	100	100	100	100	100	100	100	100	100
MAD2007	97,75	100	100	100	82,53	100	100	100	100
MAD2008	95,58	97,2	97,2	97,56	83,54	97,57	97,57	97,19	97,2
MAD2011	92,81	88,85	88,85	95,31	100	95,32	95,32	88,85	88,85
MAD2010	92,73	89,74	89,74	95,69	94,89	95,69	95,69	89,74	89,74
MAD2009	89,48	90,05	90,05	92,93	76,83	92,95	92,95	90,05	90,05
MAD2006	88,83	90,01	90,01	87,32	89	87,32	87,32	90,01	90,01
[tudo inf.]	0	0	0	0	0	0	0	0	0
	Weights	0,1643	0,1288	0,1756	0,1284	0,1116	0,1034	0,0952	0,0927

Table 55: Efficiency Ranking for Madrid Airport in the Four Cases

YEARS	DEA	Rank DEA	DEA+	Rank DEA+	MACBETH	Rank MACBETH	MACBETH+	Rank MACBETH+
MAD2006	90,0114	6	90,0114	6	89,07	5	88,83	6
MAD2007	100,00	1	100,00	1	95,68	1	97,75	1
MAD2008	98,5857	4	98,5857	4	93,92	2	95,58	2
MAD2009	92,983	5	92,983	5	87,53	6	89,48	5
MAD2010	99,1805	3	99,1805	3	92,55	4	92,73	4
MAD2011	100,00	1	100,00	1	93,28	3	92,81	3

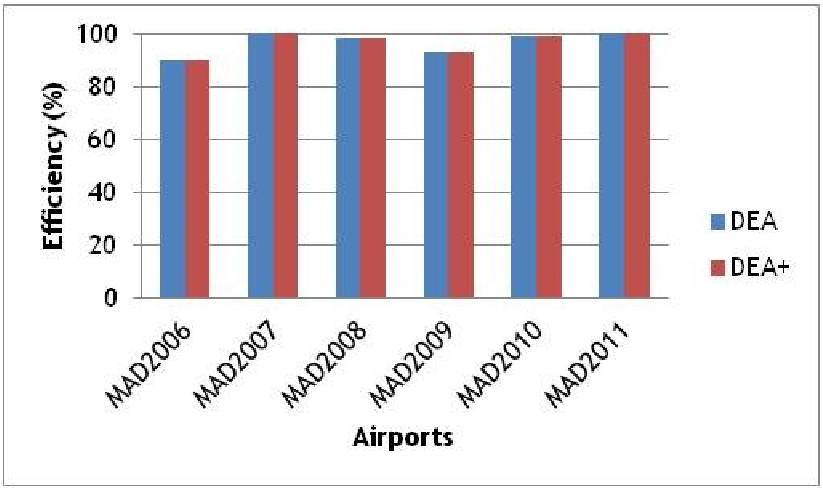

Figure 4.104: Comparative Efficiency between DEA and DEA+ for Madrid Airport

As presented in figure 4.104, the addition of new performance indicators does not affect the efficiency of Madrid airport in DEA analysis, i.e. each year maintain its efficiency value in both cases. The less efficient year was 2006, and the most were 2007 and 2011.

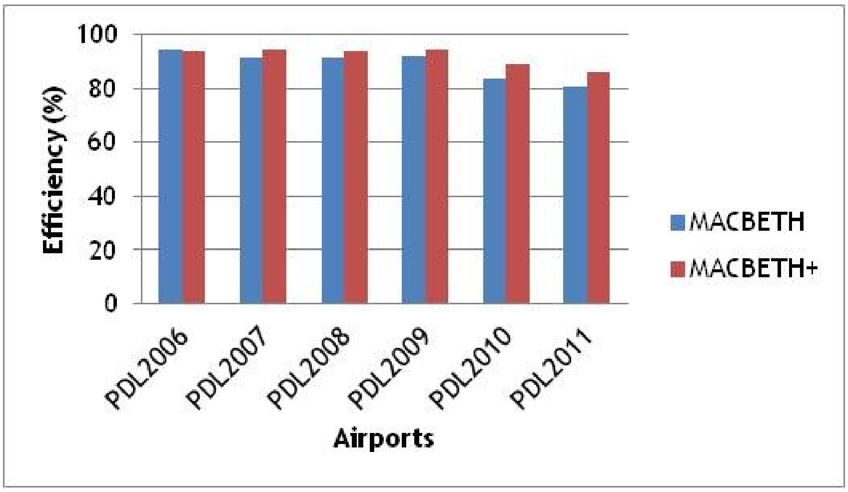

Figure 4.105: Comparative Efficiency between MACBETH and MACBETH+ for Madrid Airport

As presented in figure 4.105, the addition of new performance indicators in MACBETH tool show an increase in the efficiency for all years, except for 2006, that decreased from 89,07% to 88,83% (table 55). The main differences were for 2010 and 2011.

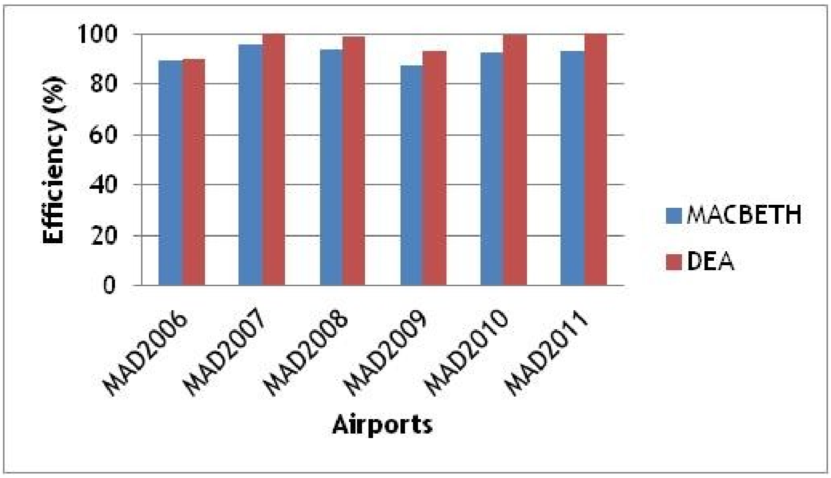

Figure 4.106: Comparative Efficiency between MACBETH and DEA for Madrid Airport

In figure 4.106 is shown a comparison between MACBETH and DEA efficiency values, where DEA values are higher than MACBETH. The main differences were for 2010 and 2011. Madrid airport had the best value in both approaches in 2007, and the less efficient years were 2009 for MACBETH and 2006 for DEA.

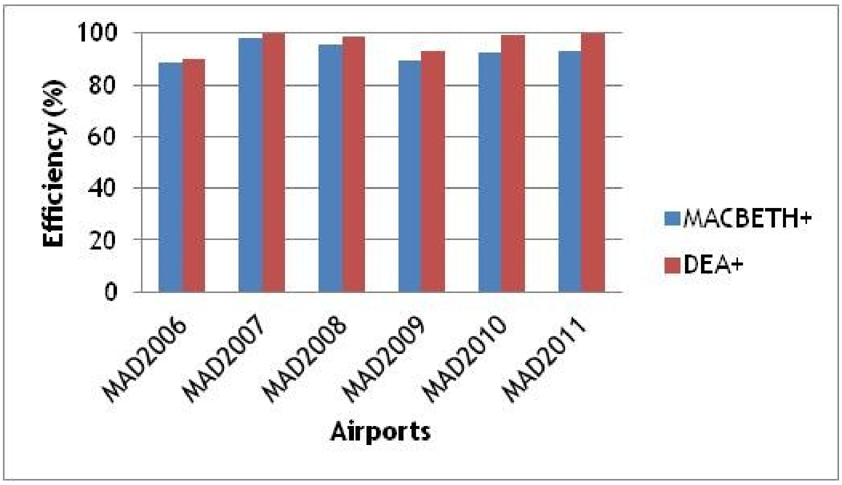

Figure 4.107: Comparative Efficiency between MACBETH+ and DEA+ for Madrid Airport

In figure 4.107 is shown a comparison between MACBETH+ and DEA+ efficiency values, where in general and as in the previous analysis, DEA+ values are again higher than MACBETH+. Madrid airport had the best value in both approaches in the year 2007. The less efficient year was 2006 for MACBETH+ and DEA+.

The efficiency results obtained with MACBETH and DEA approaches are quite different. From figure 4.104 to 4.107, or from figure 4.108 and table 55 (direct comparison), it's possible to observe the variation on efficiency values, due the use of those two different tools.

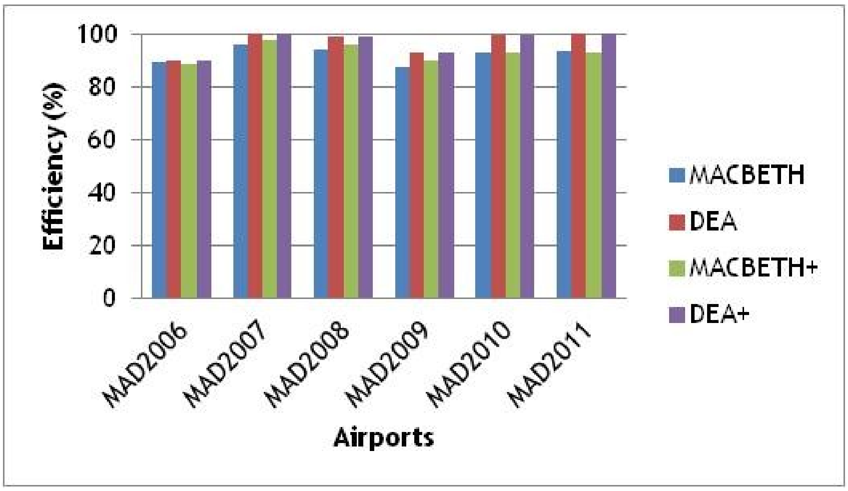

Figure 4.108: Madrid Airport Comparative Efficiency for all Cases

Figures 4.109 to 4.112 permit another perspective, i.e. the efficiency ranking which is the core of this study. The first two, present a comparison between rankings, before and after the addition of new indicators, and the last a comparison between tools, as in the previous analysis.

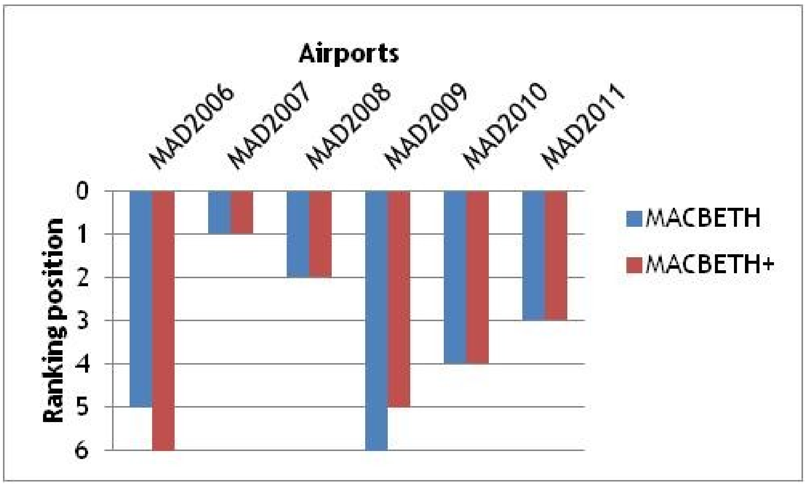

Figure 4.109: Balance between MACBETH and MACBETH+ Rankings for Madrid Airport

Comparing the transition from MACBETH to MACBETH+, in figure 4.109, it's possible to observe that there is no changes in the rankings due to the addition of new indicators for 2007, 2008, 2010 and 2011; however in 2006 it changes from 5th to 6th and in 2009 from 6th to 5th. Madrid airport got 1st place on MACBETH and MACBETH+ for 2007, and last position on 2009 and 2006, respectively.

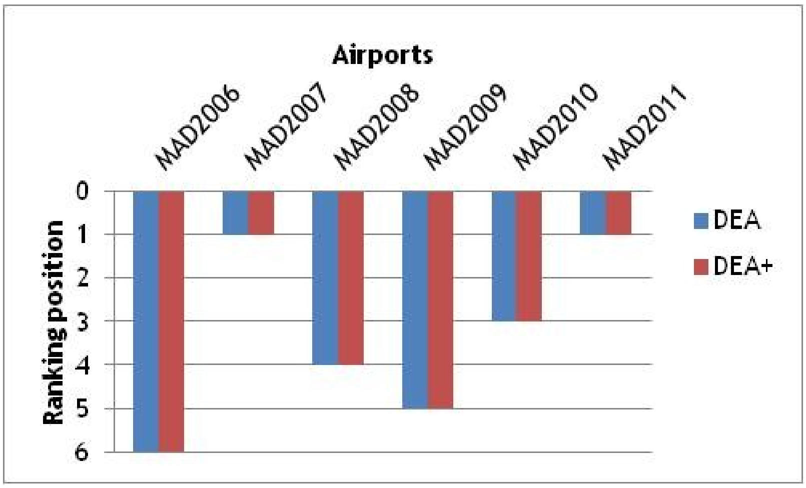

Figure 4.110: Balance between DEA and DEA+ Rankings for Madrid Airport

Comparing the transition from DEA to DEA+ in figure 4.110, which represent again the adding of new indicators, it's possible to observe that there is no changing in the rankings in the same year due to the addition of new indicators. Madrid airport got 1st place on DEA and DEA+ for 2007 and 2011 and the last position on 2006.

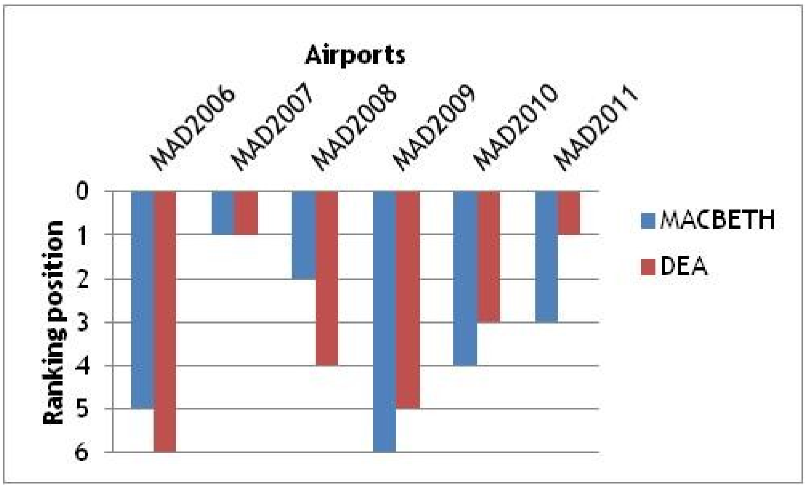

Figure 4.111: Balance between MACBETH and DEA Rankings for Madrid Airport

In figure 4.111 is shown a comparison between MACBETH and DEA rankings, where there were differences in all years except for 2007; the main changes were in 2008 (from 2nd to 4th) and in 2011 (from 3rd to 1st). Madrid airport had 1st position on both approaches in 2007, and the less efficient years for MACBETH and DEA, were 2009 and 2006 respectively.

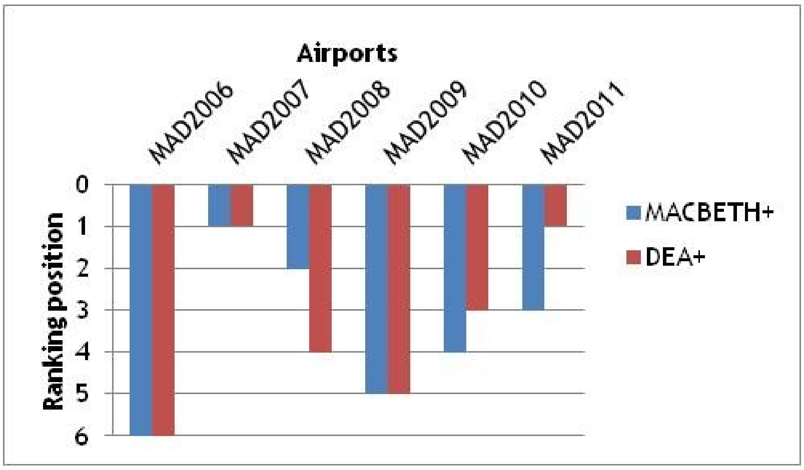

Figure 4.112: Balance between MACBETH+ and DEA+ Rankings for Madrid Airport

In figure 4.112 is shown a comparison between MACBETH+ and DEA+ rankings, where the main differences were for 2008, 2010 and mainly for 2011 (from 3rd to 1st). The airport had 1st position on both approaches in 2007, and the less efficient year for MACBETH+ and DEA+ was 2006.

The ranking results obtained with MACBETH and DEA approaches are quite different. From figure 4.109 to 4.112, or from figure 4.113 and table 55 (direct comparison), it's possible to observe the variation on ranking places, due the use of those two different tools. Some years have different values between approaches.

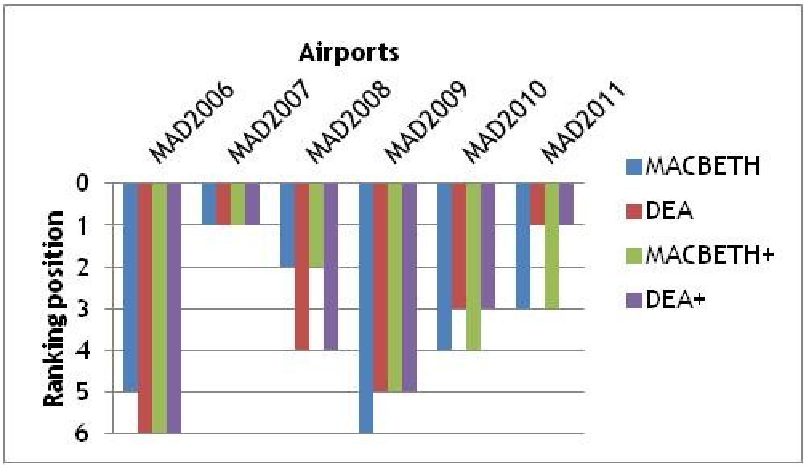

Figure 4.113: Madrid Airport Comparative Ranking for all Cases

As visible in tables 53 and 54, the maximum scores within MACBETH and MACBETH+ analysis for Madrid Airport were: 2007 for MOVS/STANDS, MOVS/RWS, PAX/PAX TA, PAX/CHK-IN PAX/GATES, MOVS/GATES and MOVS/BELTS; 2011 for CARGO/CARGO TA.

4.2.5.7. Barcelona Airport (BCN)

Barcelona - El Prat Airport (IATA: BCN, ICAO: LEBL), in Spanish *Aeropuerto de Barcelona - El Prat*, or just Barcelona Airport, is located 12 km (7.5 mi) southwest of the city centre of Barcelona, Catalonia, Spain. It is also operated by *AENA Aeropuertos*, being and important hub in this region.

Figure 4.114: Barcelona Airport (Brackx, 2012)

As in the previous cases, it was necessary to get data for this airport to produce an efficiency ranking, as presented in table 56. We had already the 2011 data from the Iberian analysis, but now it was necessary taking into account other years and possible changes in the infrastructures. As observed, there were expansion works at the airport during last year's: in the Number of Parking Stands (STANDS), the Passenger Terminal Area (PAX TA), the Number of Check-In Desks (CHK-IN), the Number of Boarding Gates (GATES), and the Number of Baggage Claim Belts (BELTS), due to the construction of the new Terminal 1, as showed in figure 4.114 - on the left side between runways. Also the old Terminal 2 (now low-cost) is visible on the right side, and a new runway was constructed as well (left side in the image).

Table 56: Barcelona Airport Data - from the list in the References

									STATISTICS		
	YEARS	RWS	STANDS	PAX TA	CARGO TA	CHK-IN	GATES	BELTS	PAX	MOVS	CARGO
BAFRCELONA	BCN2006	2	65	149359	31000	90	48	14	30000601	327636	99046
	BCN2007	2	65	149359	31000	90	48	14	32898249	352501	96785,978
	BCN2008	2	65	149359	31000	90	48	14	30272084	321693	103996,489
	BCN2009	3	65	149359	31000	90	48	14	27421682	278981	89815,384
	BCN2010	3	134	694359	31000	258	149	28	29209536	277832	104280,309
	BCN2011	3	134	694359	31000	258	149	28	34398226	303054	96572,859

In order to use the MACBETH analysis, it was necessary again to obtain the complex indicators of table 57 for each year; the respective weights are those of table 7.

Table 57: Complex Indicators for Barcelona Airport

YEARS	PAX/ PAX TA	PAX/ GATES	PAX/ CHK-IN	CARGO/ CARGO TA	MOVS/ STANDS	MOVS/ GATES	MOVS/ RWS	MOVS/ BELTS
BCN2006	200,86	625012,52	333340,01	3,20	5040,55	6825,75	163818,00	23402,57
BCN2007	220,26	685380,19	365536,10	3,12	5423,09	7343,77	176250,50	25178,64
BCN2008	202,68	630668,42	336356,49	3,35	4949,12	6701,94	160846,50	22978,07
BCN2009	183,60	571285,04	304685,36	2,90	4292,02	5812,10	92993,67	19927,21
BCN2010	42,07	196037,15	113215,26	3,36	2073,37	1864,64	92610,67	9922,57
BCN2011	49,54	230860,58	133326,46	3,12	2261,60	2033,92	101018,00	10823,36

Then we use MACBETH and DEA tools to get the airport efficiency ranking based on a combination of the above mentioned indicators, and its related weights (tables 58 to 60, and figures 4.115 to 4.124).

Table 58: Barcelona Airport Scores for MACBETH Study Case

	Global	MOVS/STANDS	MOVS/RWS	PAX/ PAX TA	CARGO/ CARGO TA
[tudo sup.]	100	100	100	100	100
BCN2007	98,24	100	100	100	92,86
BCN2008	93,54	91,26	91,26	92,02	99,7
BCN2006	92,99	92,95	92,95	91,19	94,94
BCN2009	74,57	79,14	52,76	83,35	86,01
BCN2011	53,74	41,7	57,32	22,5	92,86
BCN2010	52,55	38,23	52,54	19,11	100
[tudo inf.]	**0**	0	0	0	0
	Weights	0,216	0,279	0,258	0,247

Table 59: Barcelona Airport Scores for MACBETH+ Study Case

	Global	MOVS/ STANDS	MOVS/ RWS	PAX/ PAX TA	CARGO/ CARGO TA	PAX/ CHK-IN	PAX/ GATES	MOVS/ GATES	MOVS/ BELTS
[tudo sup.]	100	100	100	100	100	100	100	100	100
BCN2007	99,08	100	100	100	92,86	100	100	100	100
BCN2008	92,64	91,26	91,26	92,02	99,7	92,02	92,02	91,26	91,26
BCN2006	92,52	92,95	92,95	91,19	94,94	91,19	91,19	92,95	92,95
BCN2009	78,27	79,14	52,76	83,35	86,01	83,35	83,35	79,14	79,14
BCN2011	44,28	41,7	57,32	22,5	92,86	36,47	33,68	27,7	42,99
BCN2010	41,73	38,23	52,54	19,11	100	30,97	28,6	25,39	39,41
[tudo inf.]	0	0	0	0	0	0	0	0	0
	Weights	0,1643	0,1288	0,1756	0,1284	0,1116	0,1034	0,0952	0,0927

Table 60: Efficiency Ranking for Barcelona Airport in the Four Cases

YEARS	DEA	Rank DEA	DEA+	Rank DEA+	MACBETH	Rank MACBETH	MACBETH+	Rank MACBETH+
BCN2006	98,01	5	98,01	5	92,99	3	92,52	3
BCN2007	100,00	1	100,00	1	98,24	1	99,08	1
BCN2008	100,00	1	100,00	1	93,54	2	92,64	2
BCN2009	88,24	6	88,24	6	74,57	4	78,27	4
BCN2010	100,00	1	100,00	1	52,55	6	41,73	6
BCN2011	100,00	1	100,00	1	53,74	5	44,28	5

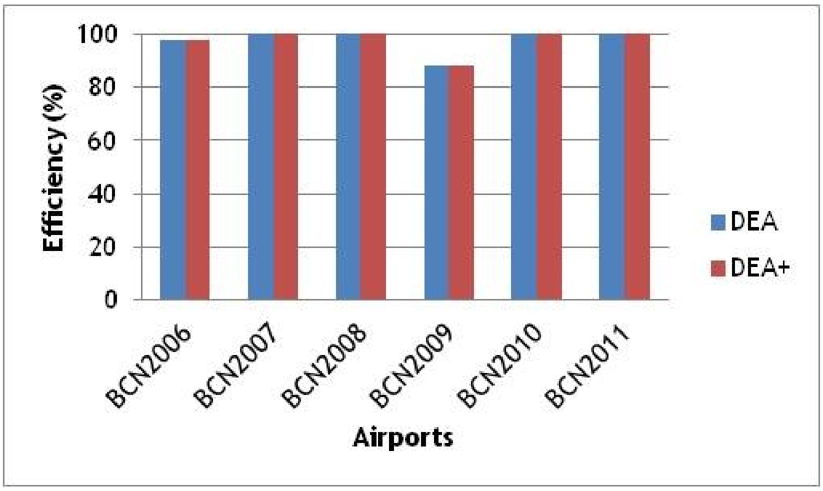

Figure 4.115: Comparative Efficiency between DEA and DEA+ for Barcelona Airport

As presented in figure 4.115, the addition of new performance indicators does not affect the efficiency of Barcelona airport in DEA analysis, i.e. each year maintain its efficiency value in both cases. The less efficient year was 2009, and the most were 2007, 2008, 2010 and 2011.

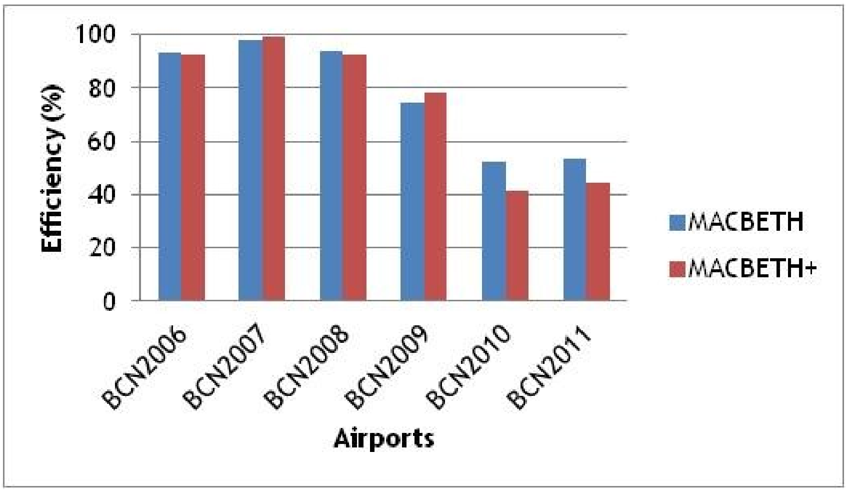

Figure 4.116: Comparative Efficiency between MACBETH and MACBETH+ for Barcelona Airport

As presented in figure 4.116, the addition of new performance indicators in MACBETH tool shows an increase in the efficiency for all years, but also evidences a decrease for 2006, 2010 and 2011, being the main differences for these last two years.

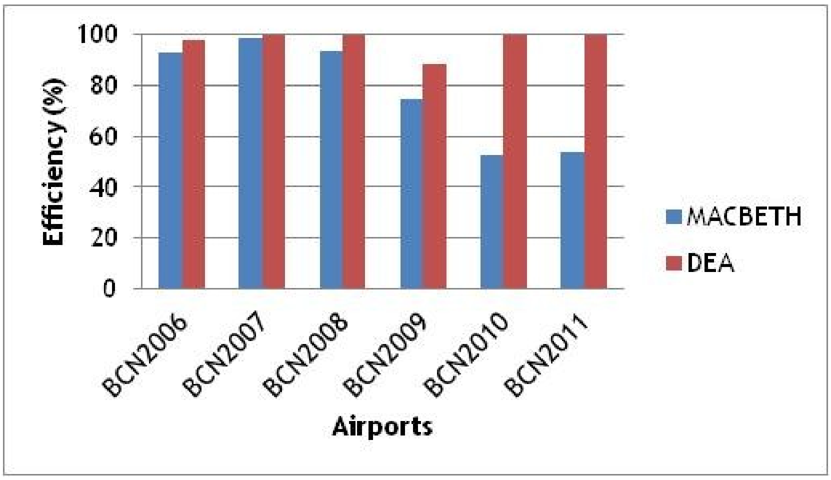

Figure 4.117: Comparative Efficiency between MACBETH and DEA for Barcelona Airport

In figure 4.117 is shown a comparison between MACBETH and DEA efficiency values, where DEA values are higher than MACBETH. The main differences were for 2010 and 2011. Barcelona airport had the best value in both approaches in 2007, and the less efficient years were 2010 for MACBETH and 2009 for DEA.

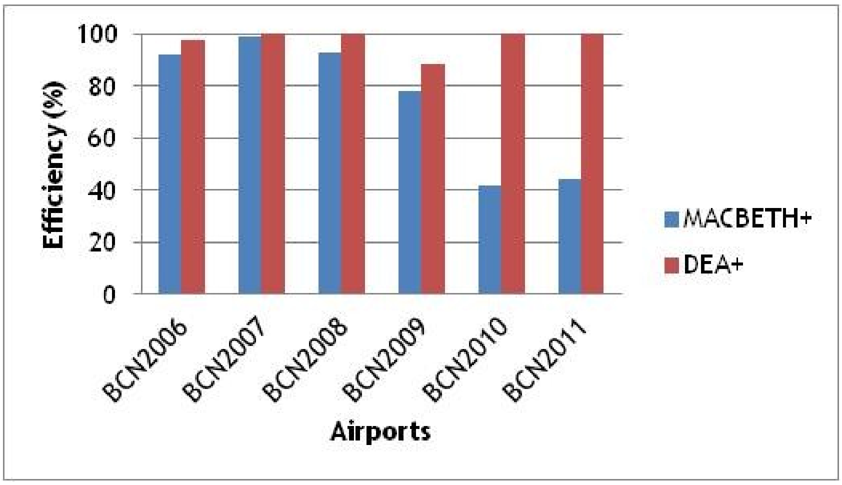

Figure 4.118: Comparative Efficiency between MACBETH+ and DEA+ for Barcelona Airport

In figure 4.118 is shown a comparison between MACBETH+ and DEA+ efficiency values, where in general and as in the previous analysis, DEA+ values are again higher than MACBETH+. Barcelona airport had the best value in both approaches in the year 2007, and the less efficient year was 2010 for MACBETH+ and 2009 for DEA+. The major differences in the values were again for 2010 and 2011.

The efficiency results obtained with MACBETH and DEA approaches are quite different. From figures 4.115 to 4.118, or from figure 4.119 and table 60 (direct comparison), it's possible to observe the variation on efficiency values, due the use of those two different tools.

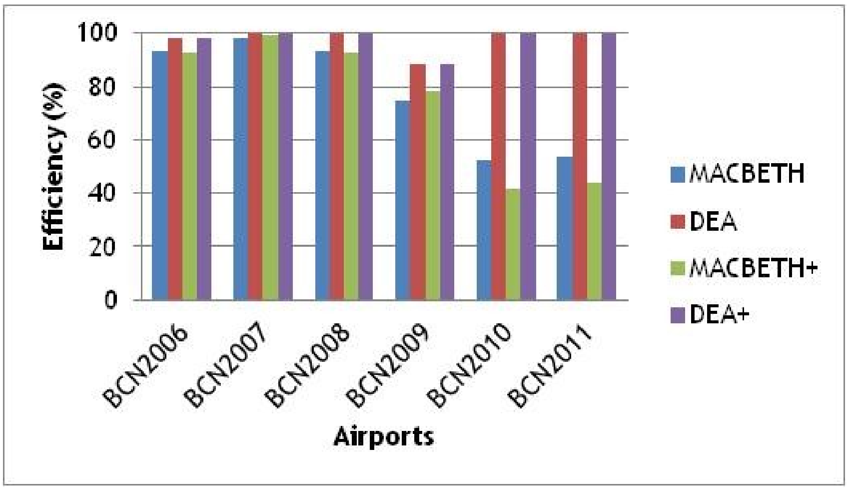

Figure 4.119: Barcelona Airport Comparative Efficiency for all Cases

Figures 4.120 to 4.123 permit another perspective, i.e. the efficiency ranking which is the target of this study. The first two, present a comparison between rankings, before and after the addition of new indicators, and the last a comparison between tools, as in the previous analysis.

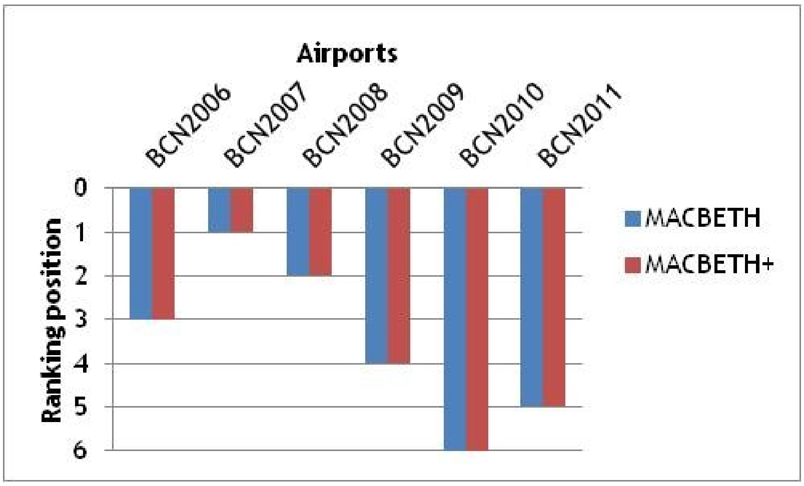

Figure 4.120: Balance between MACBETH and MACBETH+ Rankings for Barcelona Airport

Comparing the transition from MACBETH to MACBETH+, in figure 4.120, it's possible to observe that there is no changes in the rankings due to the addition of new indicators for Barcelona airport in this analysis. It achieves the 1st place on MACBETH and MACBETH+ for 2007, and the last position on 2010.

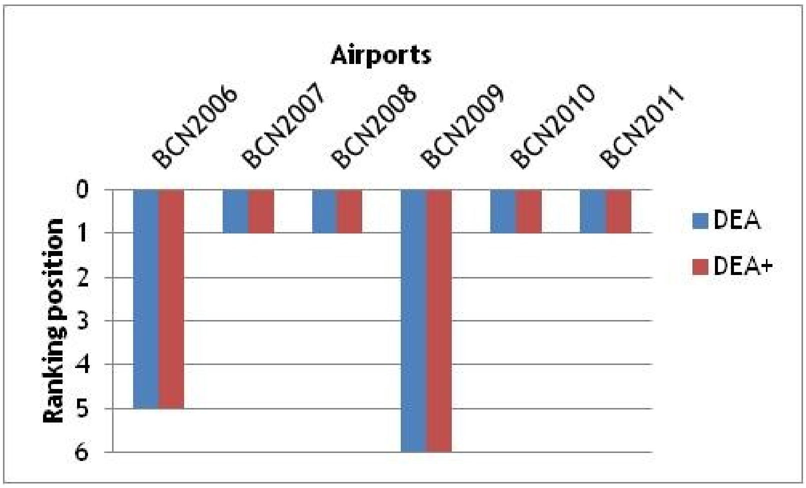

Figure 4.121: Balance between DEA and DEA+ Rankings for Barcelona Airport

Comparing the transition from DEA to DEA+ in figure 4.121, which represent again the adding of new indicators, it's possible to observe that there is no changing in the rankings (for the same year) due to the addition of new indicators. Madrid airport got 1st place on DEA and DEA+ for 2007, 2008, 2010 and 2011 and last position in 2009.

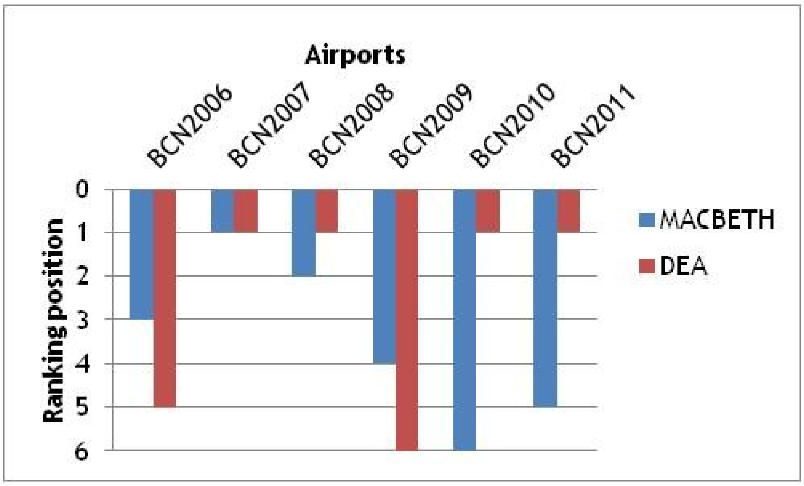

Figure 4.122: Balance between MACBETH and DEA Rankings For Barcelona Airport

In figure 4.122 is shown a comparison between MACBETH and DEA rankings, where there were differences in all years except for 2007; the main changes were for 2010 (from 6th to 1st) and for 2011 (from 5th to 1st). Madrid airport had 1st position on both approaches in 2007, and the less efficient year for MACBETH and DEA, were 2010 and 2009 respectively.

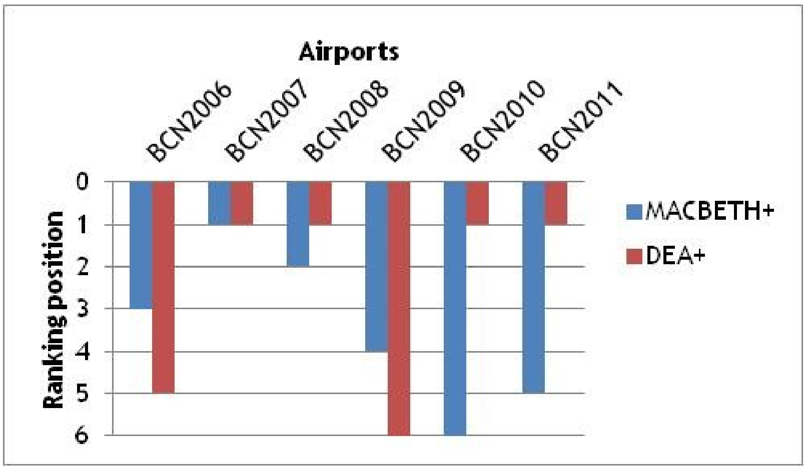

Figure 4.123: Balance between MACBETH+ and DEA+ Rankings for Barcelona Airport

In figure 4.123 is shown a comparison between MACBETH+ and DEA+ rankings, where the differences were for 2006, 2008, 2009, and mainly for 2010 (from 6th to 1st) and for 2011 (from 5th to 1st). The airport got 1st position on both approaches in 2007, and the less efficient year for MACBETH+ and DEA+ were 2010 and 2009 respectively.

The ranking results obtained with MACBETH and DEA approaches are quite different. From figure 4.120 to 4.123, or from figure 4.124 and table 60 (direct comparison), it's possible to observe the variation on ranking places, due the use of those two different tools. Some years have different values between approaches.

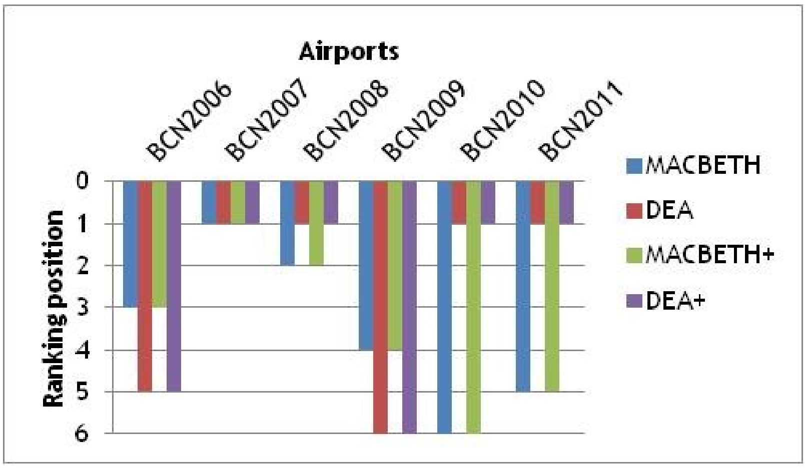

Figure 4.124: Barcelona Airport Comparative Ranking for all Cases

As visible in tables 58 and 59, the maximum scores into MACBETH and MACBETH+ analysis for Barcelona Airport were: 2007 for MOVS/STANDS, MOVS/RWS, PAX/PAX TA, PAX/CHK-IN PAX/GATES, MOVS/GATES and MOVS/BELTS; 2010 for CARGO/CARGO TA.

4.2.5.8. Vigo Airport (VGO)

Vigo Airport (IATA: VGO, ICAO: LEVX) is located 8 km (5.0 mi) east from the centre of Vigo, and is an important infrastructure in Galicia region (figure 4.125). It is an important and potential competitor with Porto (OPO) airport, in Portugal, since *AENA Aeropuertos* is planning an airport expansion to provide infrastructure and facilities in order to improve the quality and safety of aircraft and passenger services; we must underline that the distance between Vigo and Porto is about 109 km.

Figure 4.125: Vigo airport (AENA, 2012b)

As in the previous cases, it was necessary to get data for this airport to produce an efficiency ranking, as presented in table 61. We had already the 2011 data from the Iberian analysis, but now it was necessary to take into account other years and possible changes in the infrastructure.

Table 61: Vigo Airport Data - from the list in the References

									STATISTICS		
	YEARS	RWS	STANDS	PAX TA	CARGO TA	CHK-IN	GATES	BELTS	PAX	MOVS	CARGO
VIGO	VGO2006	1	5	7812	1900	12	8	3	19655	1186568	1254
	VGO2007	1	5	7812	1900	12	8	3	19999	1405968	1952,616
	VGO2008	1	5	7812	1900	12	8	3	17934	1278762	1481,939
	VGO2009	1	5	7812	1900	12	8	3	15698	1103285	796,72
	VGO2010	1	5	7812	1900	12	8	3	14941	1093576	901,192
	VGO2011	1	5	7812	1900	12	8	3	976152	14130	1113,664

In order to use the MACBETH analysis, it was necessary again to obtain the complex indicators of table 62 for each year; the respective weights are those of table 7.

Table 62: Complex Indicators for Vigo Airport

YEARS	PAX/ PAX TA	PAX/ GATES	PAX/ CHK-IN	CARGO/ CARGO TA	MOVS/ STANDS	MOVS/ GATES	MOVS/ RWS	MOVS/ BELTS
VGO2006	151,89	148321,00	98880,67	0,66	3931,00	2456,88	19655,00	6551,67
VGO2007	179,98	175746,00	117164,00	1,03	3999,80	2499,88	19999,00	6666,33
VGO2008	163,69	159845,25	106563,50	0,78	3586,80	2241,75	17934,00	5978,00
VGO2009	141,23	137910,63	91940,42	0,42	3139,60	1962,25	15698,00	5232,67
VGO2010	139,99	136697,00	91131,33	0,47	2988,20	1867,63	14941,00	4980,33
VGO2011	124,96	122019,00	81346,00	0,59	2826,00	1766,25	14130,00	4710,00

Then we use MACBETH and DEA tools to get the airport efficiency ranking based on a combination of the above mentioned indicators, and its related weights (tables 63 to 65, and figures 4.126 to 4.135).

Table 63: Vigo Airport Scores for MACBETH Study Case

	Global	MOVS/STANDS	MOVS/RWS	PAX/ PAX TA	CARGO/ CARGO TA
[tudo sup.]	100	100	100	100	100
VGO2007	99,76	100	100	100	99,04
VGO2008	86,62	89,67	89,67	90,95	75,96
VGO2006	86,33	98,28	98,28	84,39	64,42
VGO2009	69,31	78,49	78,49	78,47	41,35
VGO2010	68,45	74,71	74,71	77,78	46,15
VGO2011	67,14	70,65	70,65	69,43	57,69
[tudo inf.]	**0**	0	0	0	0
	Weights	0,216	0,279	0,258	0,247

Table 64: Vigo Airport Scores for MACBETH+ Study Case

	Global	MOVS/ STANDS	MOVS/ RWS	PAX/ PAX TA	CARGO/ CARGO TA	PAX/ CHK-IN	PAX/ GATES	MOVS/ GATES	MOVS/ BELTS
[tudo sup.]	100	100	100	100	100	100	100	100	100
VGO2007	99,88	100,00	100,00	100,00	99,04	100,00	100,00	100,00	100,00
VGO2006	88,51	98,28	98,28	84,39	64,42	84,40	84,40	98,28	98,28
VGO2008	88,41	89,67	89,67	90,95	75,96	90,95	90,95	89,67	89,67
VGO2009	73,72	78,49	78,49	78,47	41,35	78,47	78,47	78,49	78,49
VGO2010	72,24	74,71	74,71	77,78	46,15	77,78	77,78	74,71	74,71
VGO2011	68,51	70,65	70,65	69,43	57,69	69,43	69,43	70,65	70,65
[tudo inf.]	0	0	0	0	0	0	0	0	0
	Weights	0,1643	0,1288	0,1756	0,1284	0,1116	0,1034	0,0952	0,0927

Table 65: Efficiency Ranking for Vigo Airport in the Four Cases

YEARS	DEA	Rank DEA	DEA+	Rank DEA+	MACBETH	Rank MACBETH	MACBETH+	Rank MACBETH+
VGO2006	84,6768	4	84,6768	4	86,33	3	88,51	2
VGO2007	100,00	1	100,00	1	99,76	1	99,88	1
VGO2008	90,9524	3	90,9524	3	86,62	2	88,41	3
VGO2009	78,472	5	78,472	5	69,31	4	73,72	4
VGO2010	77,781	6	77,781	6	68,45	5	72,24	5
VGO2011	100,00	1	100,00	1	67,14	6	68,51	6

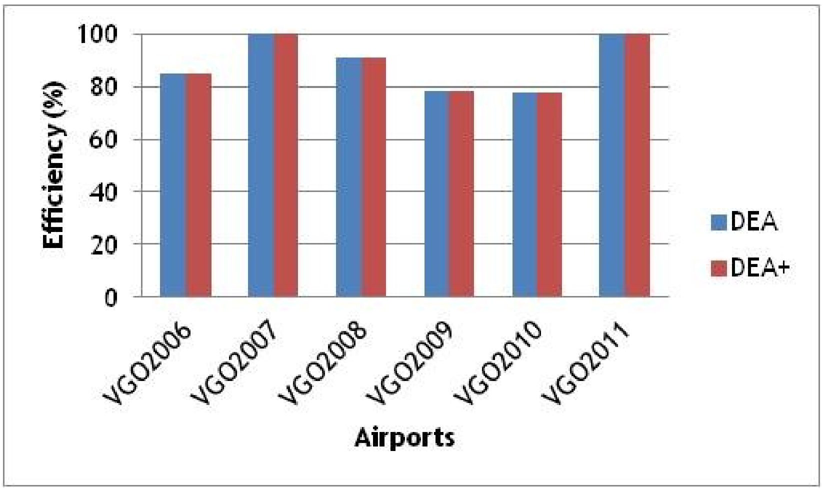

Figure 4.126: Comparative Efficiency between DEA and DEA+ for Vigo Airport

As presented in figure 4.126, the addition of new performance indicators does not affect the efficiency of Vigo airport in DEA analysis, i.e. each year maintains its efficiency value in both cases. The less efficient year was 2010, and the most were 2007 and 2011.

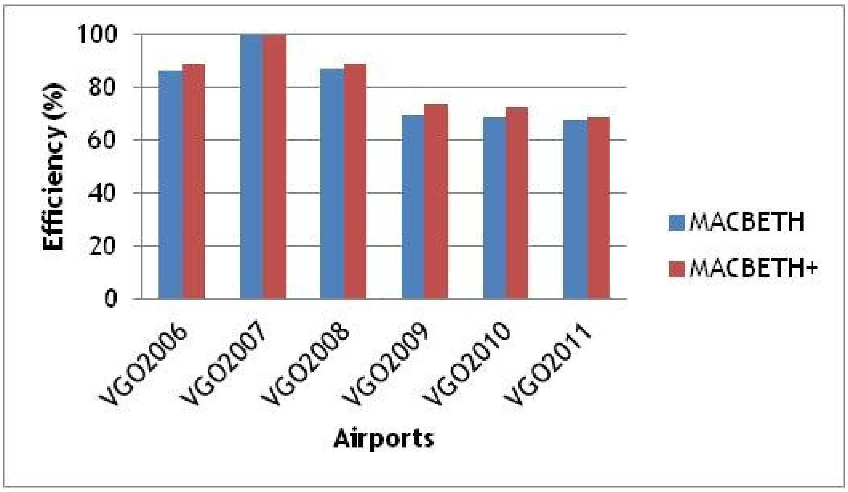

Figure 4.127: Comparative Efficiency between MACBETH and MACBETH+ for Vigo Airport

As presented in figure 4.116, the addition of new performance indicators in MACBETH tool shows an increase in the efficiency for all years, being the main differences for 2009 and 2010. The most efficient year was 2007 (99,76% for MACBETH and 99,88% for MACBETH+, as from table 65).

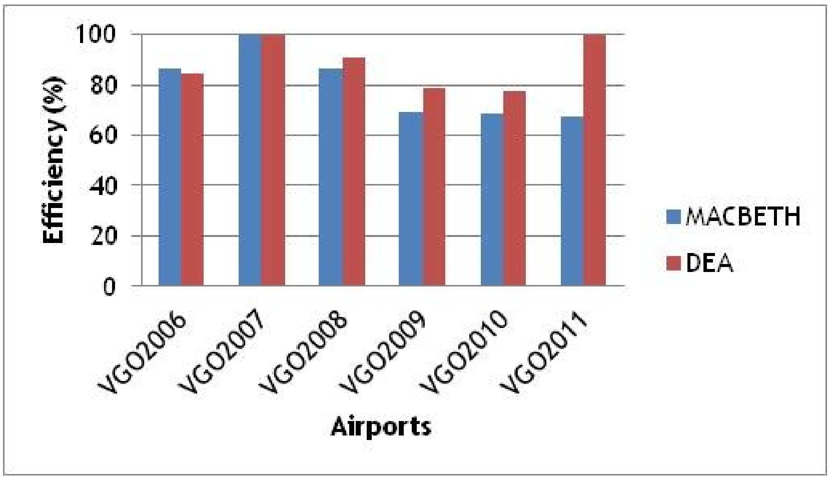

Figure 4.128: Comparative Efficiency between MACBETH and DEA for Vigo Airport

In figure 4.128 is shown a comparison between MACBETH and DEA efficiency values, where DEA values are higher than MACBETH. The main difference was for 2011. Vigo airport had the best value in both approaches in 2007, and the less efficient years were 2011 for MACBETH and 2010 for DEA.

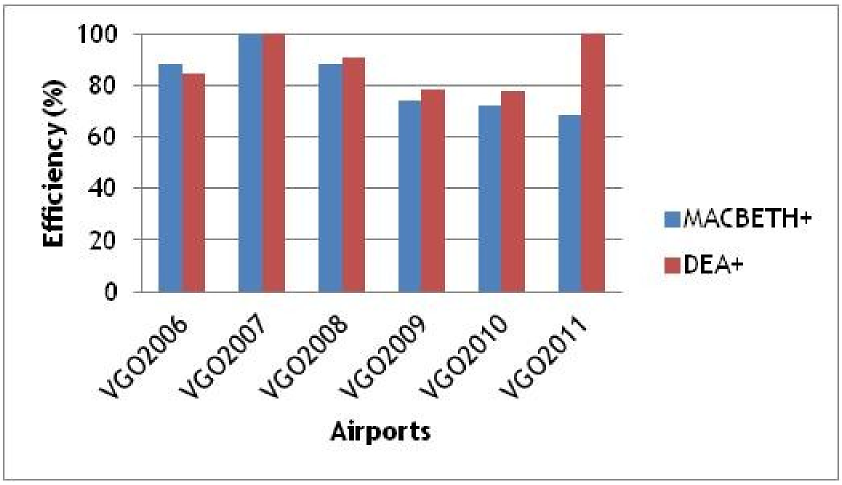

Figure 4.129: Comparative Efficiency between MACBETH+ and DEA+ for Vigo Airport

In figure 4.129 is shown a comparison between MACBETH+ and DEA+ efficiency values, where in general and as in the previous analysis, DEA+ values are again higher than MACBETH+. Vigo airport had the best value in both approaches in the year 2007, and the less efficient year was 2011 for MACBETH+ and 2010 for DEA+. The higher difference in the value was again for 2011.

The efficiency results obtained with MACBETH and DEA approaches are quite different. From figure 4.126 to 4.129, or from figure 4.130 and table 65 (direct comparison), it's possible to observe the variation on efficiency values, due the use of those two different tools.

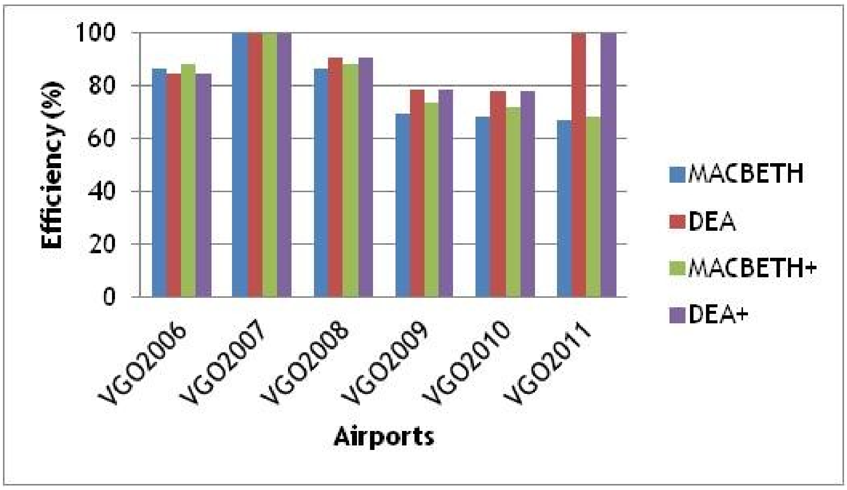

Figure 4.130: Vigo Airport Comparative Efficiency for all Cases

Figures 4.131 to 4.134 permit another perspective, i.e. the efficiency ranking which is the goal of this study. The first two, present a comparison between rankings, before and after the addition of new indicators, and the last a comparison between tools, as in the previous analysis.

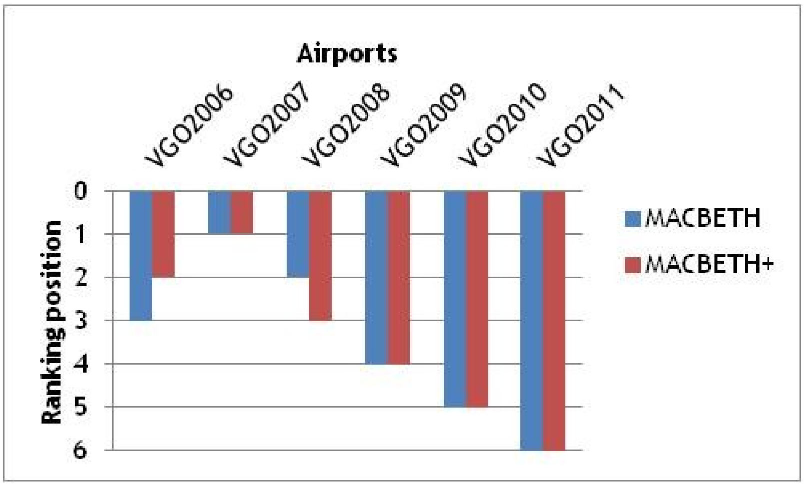

Figure 4.131: Balance between MACBETH and MACBETH+ Rankings for Vigo Airport

Comparing the transition from MACBETH to MACBETH+, in figure 4.131, it's possible to observe that there is no changes in the rankings due to the addition of new indicators for 2007, 2009, 2010 and 2011. For 2006 the position in the ranking changed from 3rd to 2nd, and for 2008 from 2nd to 3rd. The 1st position was obtained in 2007 on MACBETH and MACBETH+, and the last position in 2011.

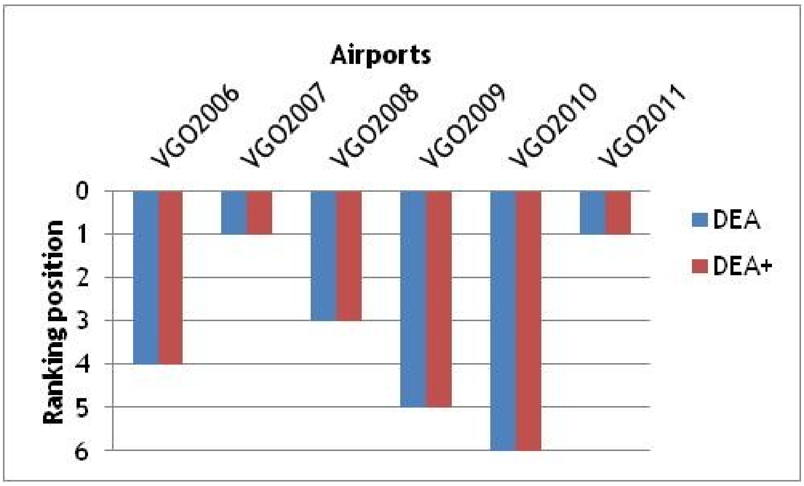

Figure 4.132: Balance between DEA and DEA+ Rankings for Vigo Airport

Comparing the transition from DEA to DEA+ in figure 4.132, which represent again the adding of new indicators, it's possible to observe that there is no changes in the rankings (for the same year) due to the addition of new indicators. Vigo airport got 1st place on DEA and DEA+ for 2007, and 2011 and the last position in 2010.

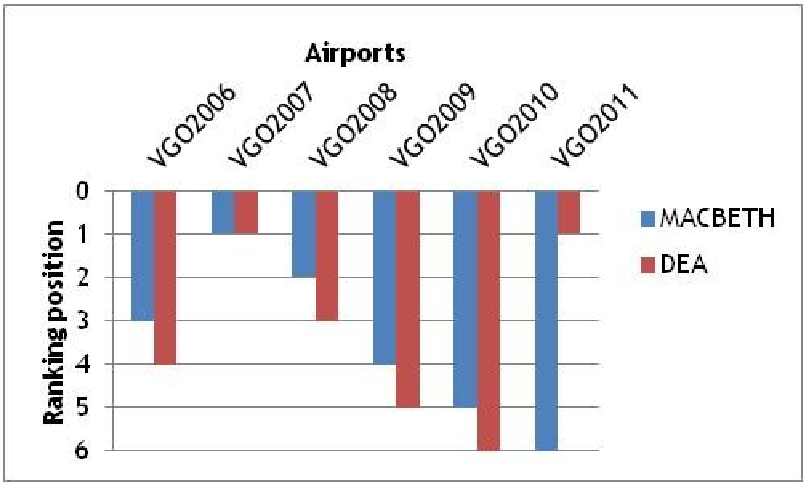

Figure 4.133: Balance between MACBETH and DEA Rankings for Vigo Airport

In figure 4.133 is shown a comparison between MACBETH and DEA rankings, where there were differences in all years except for 2007; the main change was for 2011 (changes from 6th to 1st). Vigo airport had 1st position on both approaches in 2007, and the less efficient year for MACBETH and DEA, were 2011 and 2010 respectively.

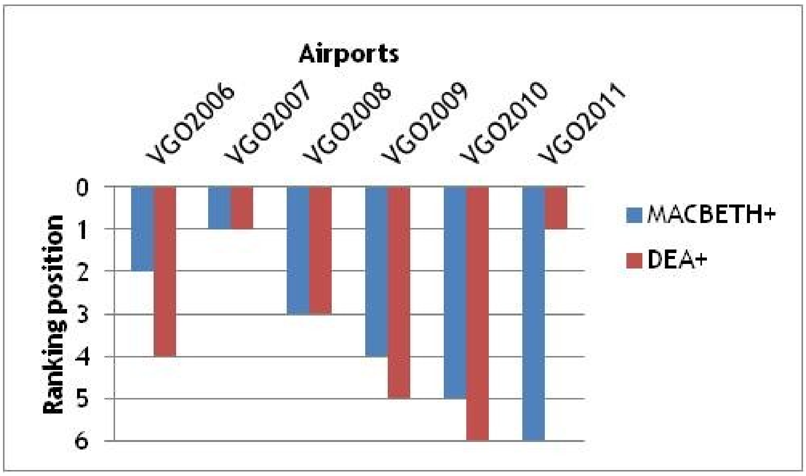

Figure 4.134: Balance between MACBETH+ and DEA+ Rankings for Vigo Airport

In figure 4.134 is shown a comparison between MACBETH+ and DEA+ rankings, where the differences were for 2006, 2009, 2010 and mainly for 2011 (from 6th to 1st). The airport had 1st position on both approaches in 2007, and the less efficient year for MACBETH+ and DEA+ were 2011 and 2010 respectively.

The ranking results obtained with MACBETH and DEA approaches are quite different. From figure 4.131 to 4.134, or from figure 4.135 and table 65 (direct comparison), it's possible to observe the variation on ranking places, due the use of those two different tools. Some years have different values between approaches.

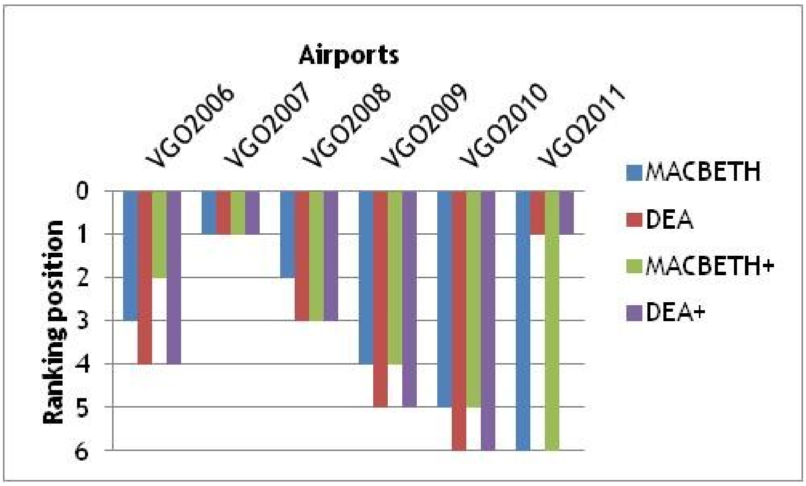

Figure 4.135: Vigo Airport Comparative Ranking for all Cases

As visible in tables 63 and 64, the maximum scores within MACBETH and MACBETH+ analysis for Vigo Airport was 2007 in all complex indicators.

4.2.5.9. Gran Canaria Airport (LPA)

Gran Canaria Airport (IATA: LPA, ICAO: GCLP), also known as Las Palmas Airport, is an important airport in Canary Archipelago (figure 4.136). It is located in the eastern part of Gran Canaria Island, 19 km (12 mi) south of the city centre of Las Palmas de Gran Canaria, and 25 km (16 mi) from Playa del Inglés, the popular touristic area in the south. The airport was an official alternative emergency landing site for the NASA Space Shuttle, before the ending of Space Shuttle programme in July 2011. It is also operated by *AENA Aeropuertos*.

Figure 4.136: Gran Canaria Airport
(Heijst, 2012)

As in the previous cases, it was necessary to get data for this airport to produce an efficiency ranking, as presented in table 66. We had already the 2011 data from the Iberian analysis, but now it was necessary taking into account other years and possible changes in the infrastructure.

Table 66: Gran Canaria Airport Data - from the list in the References

									STATISTICS		
	YEARS	RWS	STANDS	PAX TA	CARGO TA	CHK-IN	GATES	BELTS	PAX	MOVS	CARGO
GRAN CANARIA	LPA2006	2	55	87072	10680	96	38	16	10279594	114938	42234
	LPA2007	2	55	87072	10680	96	38	16	10354903	114355	37491,198
	LPA2008	2	55	87072	10680	96	38	16	10212123	116252	33695,248
	LPA2009	2	55	87072	10680	96	38	16	9155665	101557	25994,738
	LPA2010	2	55	87072	10680	96	38	16	9486035	103093	24528,109
	LPA2011	2	55	87072	10680	96	38	16	10538829	111271	23678,51

In order to use the MACBETH analysis, it was necessary again to obtain the complex indicators of table 67 for each year; the respective weights are those of table 7.

Table 67: Complex Indicators for Gran Canaria Airport

YEARS	PAX/ PAX TA	PAX/ GATES	PAX/ CHK-IN	CARGO/ CARGO TA	MOVS/ STANDS	MOVS/ GATES	MOVS/ RWS	MOVS/ BELTS
LPA2006	118,06	270515,63	107079,10	3,95	2089,78	3024,68	57469,00	7183,63
LPA2007	118,92	272497,45	107863,57	3,51	2079,18	3009,34	57177,50	7147,19
LPA2008	117,28	268740,08	106376,28	3,15	2113,67	3059,26	58126,00	7265,75
LPA2009	105,15	240938,55	95371,51	2,43	1846,49	2672,55	50778,50	6347,31
LPA2010	108,94	249632,50	98812,86	2,30	1874,42	2712,97	51546,50	6443,31
LPA2011	121,04	277337,61	109779,47	2,22	2023,11	2928,18	55635,50	6954,44

Then we use MACBETH and DEA tools to get the airport efficiency ranking based on a combination of the above mentioned indicators, and its related weights (tables 68 to 70, and figures 4.137 to 4.146).

Table 68: Gran Canaria Airport Scores for MACBETH Study Case

	Global	MOVS/STANDS	MOVS/RWS	PAX/ PAX TA	CARGO/ CARGO TA
[tudo sup.]	100	100	100	100	100
LPA2006	98,81	98,87	98,87	97,54	100
LPA2007	95,97	98,37	98,37	98,25	88,78
LPA2008	94,16	100	100	96,89	79,59
LPA2011	86,98	95,72	95,72	100	55,87
LPA2010	81,36	88,68	88,68	90	57,65
LPA2009	80,78	87,36	87,36	86,87	61,22
[tudo inf.]	**0**	0	0	0	0
	Weights	0,216	0,279	0,258	0,247

Table 69: Gran Canaria Airport Scores for MACBETH+ Study Case

	Global	MOVS/ STANDS	MOVS/ RWS	PAX/ PAX TA	CARGO/ CARGO TA	PAX/ CHK-IN	PAX/ GATES	MOVS/ GATES	MOVS/ BELTS
[tudo sup.]	100	100	100	100	100	100	100	100	100
LPA2006	98,5	98,87	98,87	97,54	100	97,54	97,54	98,87	98,87
LPA2007	97,09	98,37	98,37	98,25	88,78	98,25	98,25	98,37	98,37
LPA2008	96,17	100	100	96,89	79,59	96,9	96,9	100	100
LPA2011	92,27	95,72	95,72	100	55,87	100	100	95,72	95,72
LPA2010	85,21	88,68	88,68	90	57,65	90,01	90,01	88,68	88,68
LPA2009	83,81	87,36	87,36	86,87	61,22	86,88	86,88	87,36	87,36
[tudo inf.]	0	0	0	0	0	0	0	0	0
	Weights	0,1643	0,1288	0,1756	0,1284	0,1116	0,1034	0,0952	0,0927

Table 70: Efficiency Ranking for Gran Canaria Airport in the Four Cases

YEARS	DEA	Rank DEA	DEA+	Rank DEA+	MACBETH	Rank MACBETH	MACBETH+	Rank MACBETH+
LPA2006	100,00	1	100,00	1	98,81	1	98,5	1
LPA2007	100,00	1	100,00	1	95,97	2	97,09	2
LPA2008	100,00	1	100,00	1	94,16	3	96,17	3
LPA2009	88,5956	6	88,5956	6	80,78	6	83,81	6
LPA2010	91,0304	5	91,0304	5	81,36	5	85,21	5
LPA2011	100,00	1	100,00	1	86,98	4	92,27	4

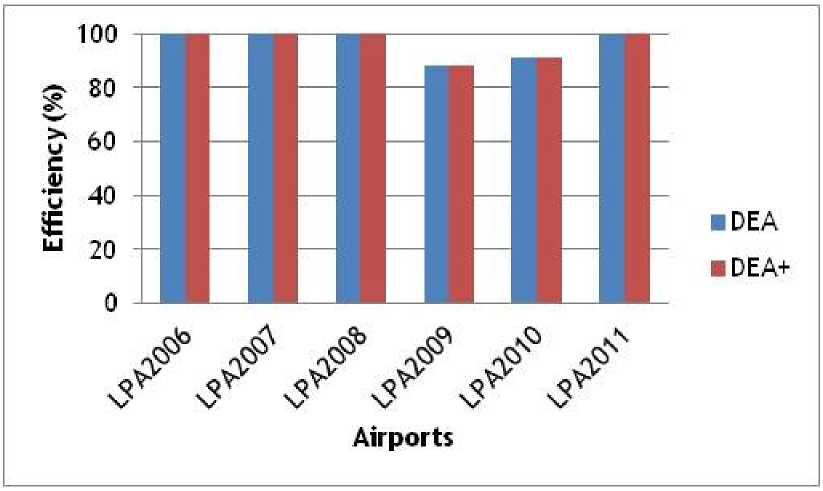

Figure 4.137: Comparative Efficiency between DEA and DEA+ for Gran Canaria Airport

As presented in figure 4.137, the addition of new performance indicators does not affect the efficiency of Gran Canaria airport in DEA analysis, i.e. each year maintain its efficiency value in both cases. The less efficient year was 2009, and the most efficient were 2006, 2007, 2008 and 2011.

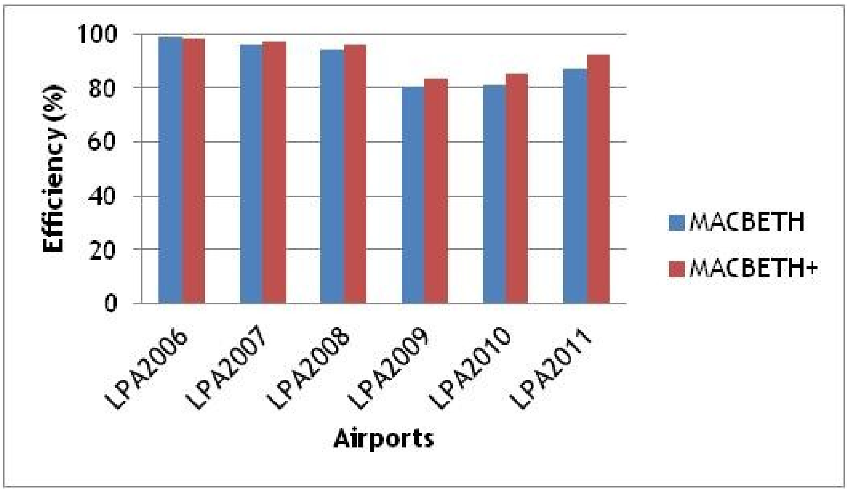

Figure 4.138: Comparative Efficiency between MACBETH and MACBETH+ for Gran Canaria Airport

As presented in figure 4.138, the addition of new performance indicators in MACBETH tool shows an increase in the efficiency for all years, being the main difference for 2011. The most efficient year was 2006 (98,81% for MACBETH and 98,5% for MACBETH+, as in table 70).

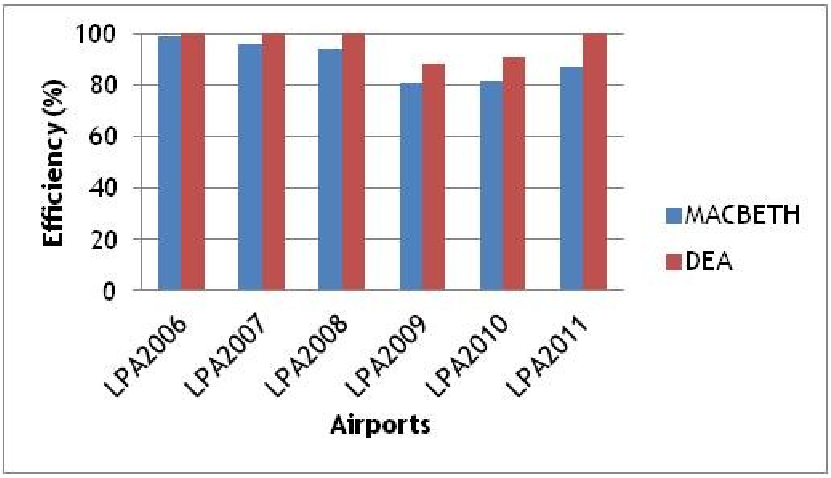

Figure 4.139: Comparative Efficiency between MACBETH and DEA for Gran Canaria Airport

In figure 4.139 is shown a comparison between MACBETH and DEA efficiency values, where DEA values are higher than MACBETH, and the main difference was for 2011. Gran Canaria airport had the best value for 2006, and the less efficient year was 2009, in both approaches.

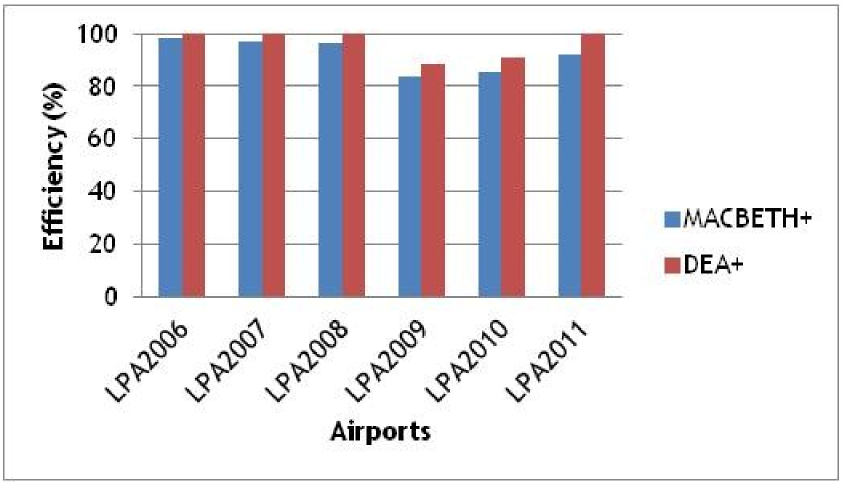

Figure 4.140: Comparative Efficiency between MACBETH+ and DEA+ for Gran Canaria Airport

In figure 4.140 is shown a comparison between MACBETH+ and DEA+ efficiency values, where in general and as in the previous analysis, DEA+ values are again higher than MACBETH+. Gran Canaria airport had the best value in both approaches in the year 2006, and the less efficient year was 2009 for MACBETH+ and 2010 for DEA+. The major difference in the values was again for 2011.

The efficiency results obtained with MACBETH and DEA approaches are quite different. From figures 4.137 to 4.140, or from figure 4.141 and table 70 (direct comparison), it's possible to observe the variation on efficiency values, due the use of those two different tools.

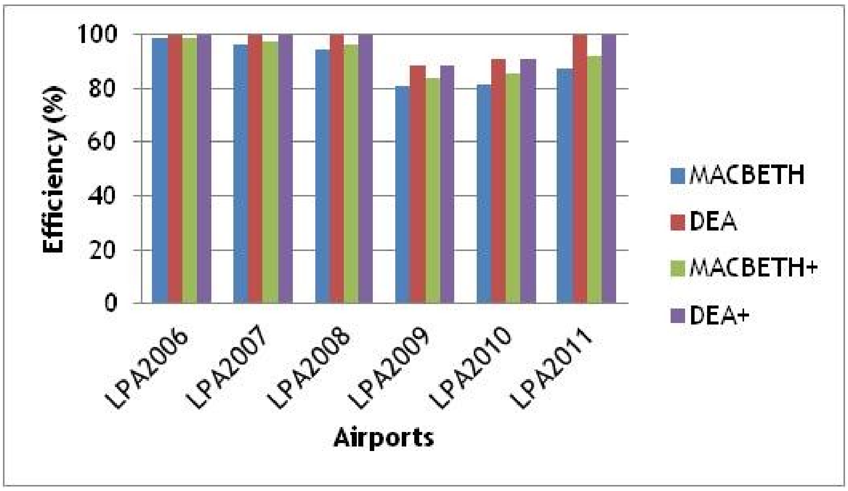

Figure 4.141: Gran Canaria Airport Comparative Efficiency for all Cases

Figures 4.142 to 4.145 permit another perspective, i.e. the efficiency ranking which is the main target of this study. The first two, present a comparison between rankings, before and after the addition of new indicators, and the last a comparison between tools, as in the previous analysis.

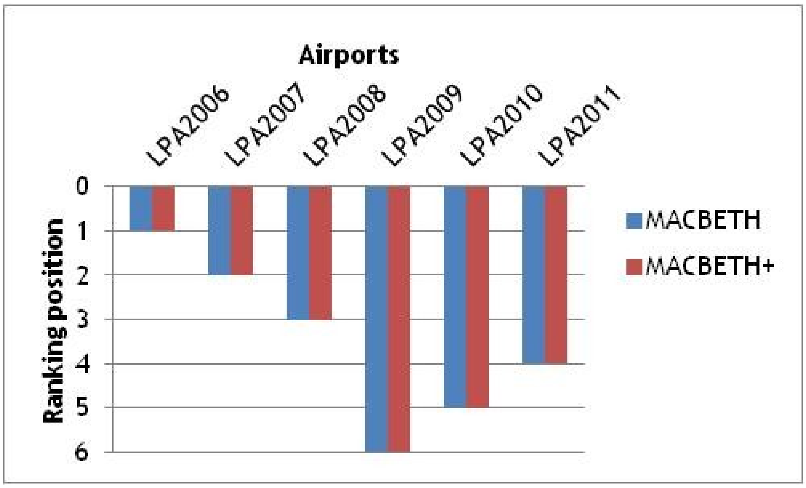

Figure 4.142: Balance between MACBETH and MACBETH+ Rankings for Gran Canaria Airport

Comparing the transition from MACBETH to MACBETH+, in figure 4.142, it's possible to observe that there is no changes in the rankings due to the addition of new indicators for Gran Canaria airport analysis. The 1st position was for 2006 on MACBETH and MACBETH+, and a last position for 2009.

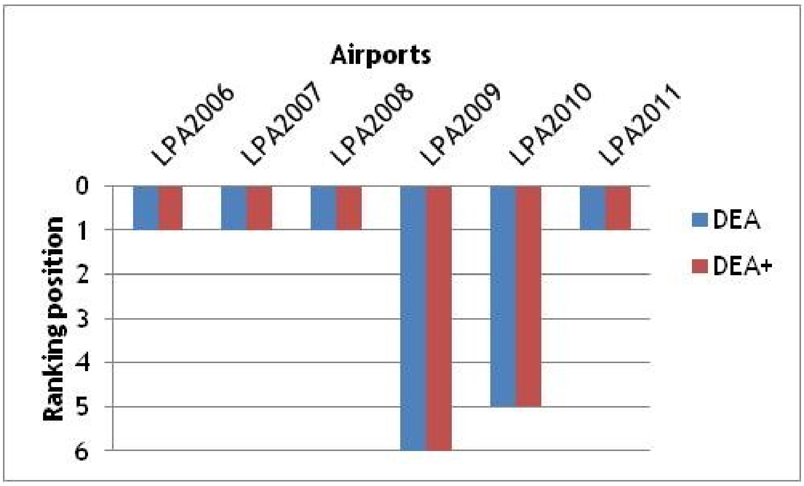

Figure 4.143: Balance between DEA and DEA+ Rankings for Gran Canaria Airport

Comparing the transition from DEA to DEA+ in figure 4.143, which represent again the adding of new indicators, it's possible to observe that there is no changes in the rankings (for the same year) due to the addition of new indicators. Gran Canaria airport got 1st place on DEA and DEA+ for 2006, 2007, 2008 and 2011 and the last position in 2009.

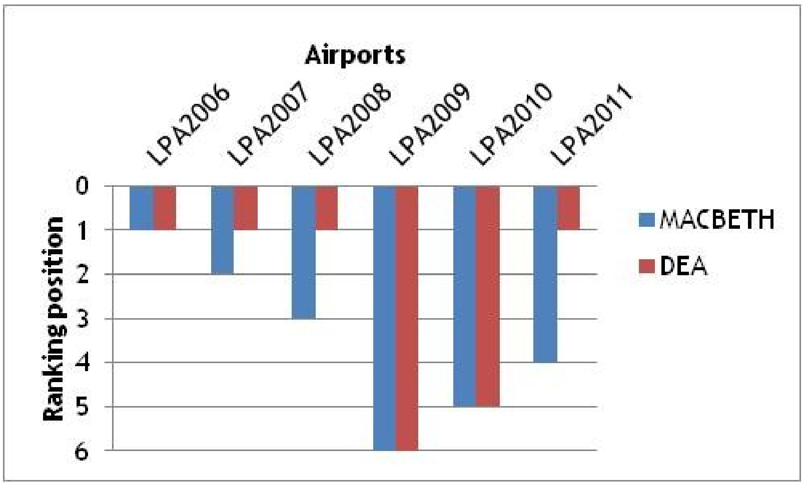

Figure 4.144: Balance between MACBETH and DEA Rankings for Gran Canaria Airport

In figure 4.144 is shown a comparison between MACBETH and DEA rankings, where there were differences in all years except for 2006, 2009 and 2010; the main change was for 2011 (from 4th to 1st). Gran Canaria airport had 1st position on both approaches in 2006, and the less efficient year for MACBETH and DEA, was 2009.

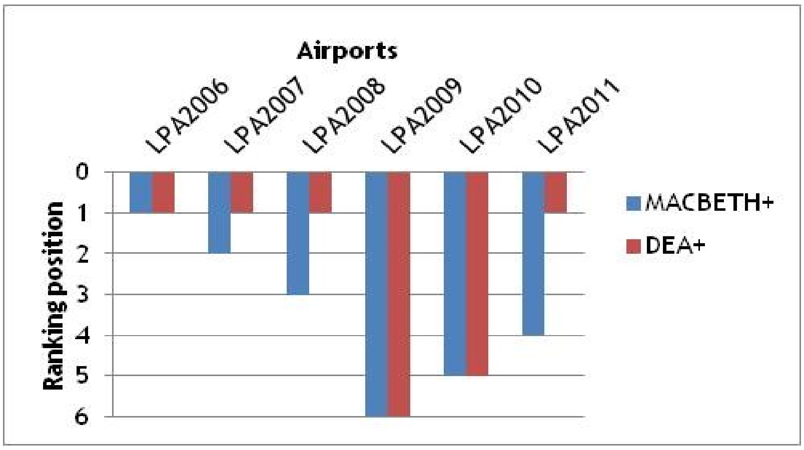

Figure 4.145: Balance between MACBETH+ and DEA+ Rankings for Gran Canaria Airport

In figure 4.145 is shown a comparison between MACBETH+ and DEA+ rankings, where the differences were for 2007, 2008 and mainly for 2011 (from 4th to 1st). The airport had 1st position on both approaches in 2006, and the less efficient year for MACBETH+ and DEA+ was 2009.

The ranking results obtained with MACBETH and DEA approaches are quite different. From figure 4.142 to 4.145, or from figure 4.146 and table 70 (direct comparison), it's possible to observe the variation on ranking places, due the use of those two different tools. Some years have different values between approaches.

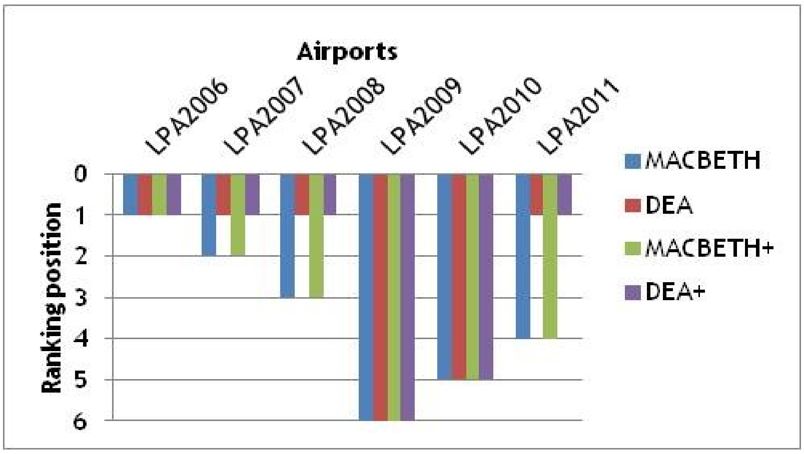

Figure 4.146: Gran Canaria Airport Comparative Ranking for all Cases

As visible in tables 68 and 69, the maximum scores into MACBETH and MACBETH+ analysis for Gran Canaria Airport were: 2008 for MOVS/STANDS, MOVS/RWS, MOVS/GATES and MOVS/BELTS; 2006 for CARGO/CARGO TA; and 2011 for PAX/PAX TA, PAX/CHK-IN and PAX/GATES.

4.2.5.10. Palma de Mallorca Airport (PMI)

Palma de Mallorca Airport (IATA: PMI, ICAO: LEPA) is located 8 km (5.0 mi) east of Palma, Majorca, adjacent to the village of Can Pastilla (figure 4.147). Also known as Son Sant Joan Airport it is the third largest airport in Spain, after Madrid's Barajas Airport and Barcelona Airport, also included in this analysis. It is also operated by *AENA Aeropuertos*.

Figure 4.147: Palma de Mallorca Airport
(Würfel, 2012)

As in the previous cases, it was necessary to get data for this airport to produce an efficiency ranking, as presented in table 71. We had already the 2011 data from the Iberian analysis, but now it was necessary taking into account other years and possible changes in the infrastructure.

Table 71: Palma de Mallorca Airport Data - from the list in the References

									STATISTICS		
	YEARS	RWS	STANDS	PAX TA	CARGO TA	CHK-IN	GATES	BELTS	PAX	MOVS	CARGO
PALMA DE MALLORCA	PMI2006	2	132	86600	5400	204	84	18	22402257	190280	26251
	PMI2007	2	132	86600	5400	204	84	18	23228879	197384	22833,56
	PMI2008	2	132	86600	5400	204	84	18	22832857	193379	21395,79
	PMI2009	2	132	86600	5400	204	84	18	21203041	177502	17086,48
	PMI2010	2	132	86600	5400	204	84	18	21117417	174635	17292,24
	PMI2011	2	132	86600	5400	204	84	18	22726707	180152	15777,1

In order to use the MACBETH analysis, it was necessary again to obtain the complex indicators of table 72 for each year; the respective weights are those of table 7.

Table 72: Complex Indicators for Palma de Mallorca Airport

YEARS	PAX/ PAX TA	PAX/ GATES	PAX/ CHK-IN	CARGO/ CARGO TA	MOVS/ STANDS	MOVS/ GATES	MOVS/ RWS	MOVS/ BELTS
PMI2006	258,69	266693,54	109814,99	4,86	1441,52	2265,24	95140,00	10571,11
PMI2007	268,23	276534,27	113867,05	4,23	1495,33	2349,81	98692,00	10965,78
PMI2008	263,66	271819,73	111925,77	3,96	1464,99	2302,13	96689,50	10743,28
PMI2009	244,84	252417,15	103936,48	3,16	1344,71	2113,12	88751,00	9861,22
PMI2010	243,85	251397,82	103516,75	3,20	1322,99	2078,99	87317,50	9701,94
PMI2011	262,43	270556,04	111405,43	2,92	1364,79	2144,67	90076,00	10008,44

Then we use MACBETH and DEA tools to get the airport efficiency ranking based on a combination of the above mentioned indicators, and its related weights (tables 73 to 75, and figures 4.148 to 4.157).

Table 73: Palma de Mallorca Airport Scores for MACBETH Study Case

	Global	MOVS/STANDS	MOVS/RWS	PAX/ PAX TA	CARGO/ CARGO TA
[tudo sup.]	100	100	100	100	100
PMI2006	97,3	96,4	96,4	96,44	100
PMI2007	96,78	100	100	100	86,98
PMI2008	93,96	97,97	97,97	98,3	81,4
PMI2011	85,22	91,27	91,27	97,84	59,92
PMI2009	84,09	89,93	89,93	91,28	64,88
PMI2010	83,48	88,47	88,47	90,91	65,7
[tudo inf.]	**0**	0	0	0	0
	Weights	0,216	0,279	0,258	0,247

Table 74: Palma de Mallorca Airport Scores for MACBETH+ Study Case

	Global	MOVS/ STANDS	MOVS/ RWS	PAX/ PAX TA	CARGO/ CARGO TA	PAX/ CHK-IN	PAX/ GATES	MOVS/ GATES	MOVS/ BELTS
[tudo sup.]	100	100	100	100	100	100	100	100	100
PMI2007	98,33	100,00	100,00	100,00	86,98	100,00	100,00	100,00	100,00
PMI2006	96,88	96,40	96,40	96,44	100,00	96,44	96,44	96,40	96,40
PMI2008	95,97	97,97	97,97	98,30	81,40	98,30	98,30	97,97	97,97
PMI2011	89,81	91,27	91,27	97,84	59,92	97,84	97,84	91,27	91,27
PMI2009	87,24	89,93	89,93	91,28	64,88	91,28	91,28	89,93	89,93
PMI2010	86,50	88,47	88,47	90,91	65,70	90,91	90,91	88,47	88,47
[tudo inf.]	0	0	0	0	0	0	0	0	0
	Weights	0,1643	0,1288	0,1756	0,1284	0,1116	0,1034	0,0952	0,0927

Table 75: Efficiency Ranking for Gran Canaria Airport in the Four Cases

YEARS	DEA	Rank DEA	DEA+	Rank DEA+	MACBETH	Rank MACBETH	MACBETH+	Rank MACBETH+
PMI2006	100,00	1	100,00	1	97,3	1	96,88	2
PMI2007	100,00	1	100,00	1	96,78	2	98,33	1
PMI2008	98,2951	3	98,2951	3	93,96	3	95,97	3
PMI2009	91,2788	5	91,2788	5	84,09	4	87,24	5
PMI2010	90,9102	6	90,9102	6	83,48	6	86,5	6
PMI2011	97,8382	4	97,8382	4	85,22	5	89,81	4

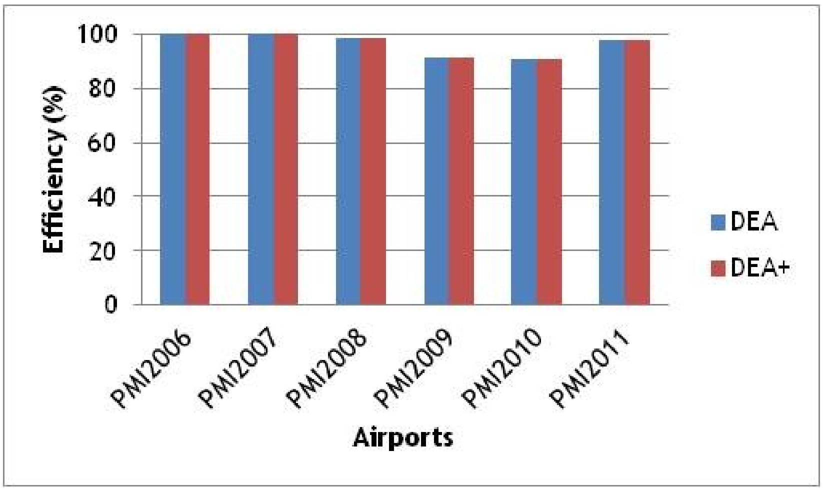

Figure 4.148: Comparative Efficiency between DEA and DEA+ for Palma de Mallorca Airport

As presented in figure 4.148, the addition of new performance indicators does not affect the efficiency of Palma de Mallorca airport in DEA analysis, i.e.it maintains its efficiency value in both cases. The less efficient year was 2010, and the most were 2006 and 2007, as from table 75.

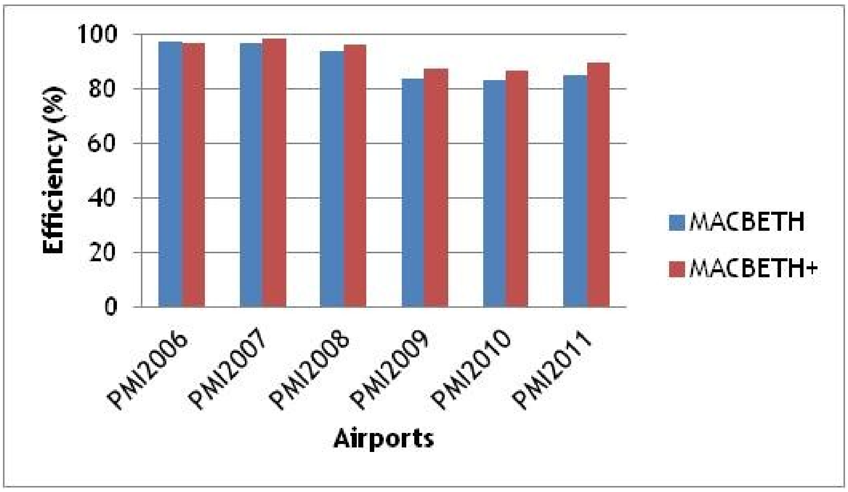

Figure 4.149: Comparative Efficiency between MACBETH and MACBETH+ for Palma de Mallorca Airport

As presented in figure 4.149, the addition of new performance indicators in MACBETH tool shows an increase in the efficiency for all years, except for 2006. The main difference was for 2011, and the most efficient year was 2006 for MACBETH and 2007 for MACBETH+.

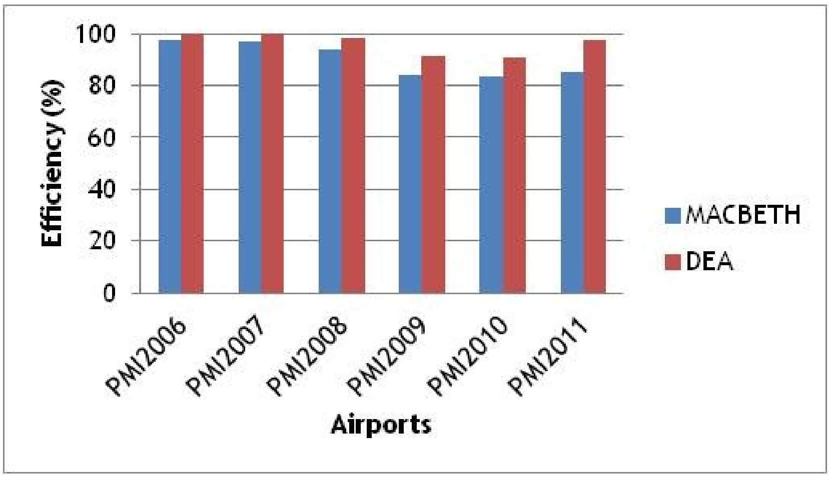

Figure 4.150: Comparative Efficiency between MACBETH and DEA for Palma de Mallorca Airport

In figure 4.150 is shown a comparison between MACBETH and DEA efficiency values, where DEA values are higher than MACBETH, and the main difference was for 2011. Palma de Mallorca airport had the best value for 2006, and the less efficient year was 2010, in both approaches.

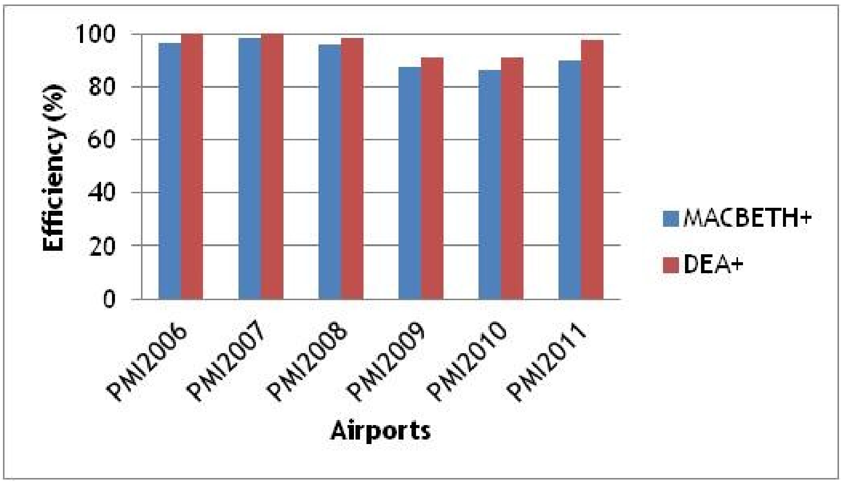

Figure 4.151: Comparative Efficiency between MACBETH+ and DEA+ for Palma de Mallorca Airport

In figure 4.151 is shown a comparison between MACBETH+ and DEA+ efficiency values, where in general and as in the previous analysis, DEA+ values are again higher than MACBETH+. Palma de Mallorca airport had the best value in 2006 for MACBETH and in 2007 for MACBETH+, and the less efficient year was 2010 in both approaches. The major difference in the values was again for 2011.

The efficiency results obtained with MACBETH and DEA approaches are quite different. From figures 4.148 to 4.151, or from figure 4.152 and table 75 (direct comparison), it's possible to observe the variation on efficiency values, due the use of those two different tools.

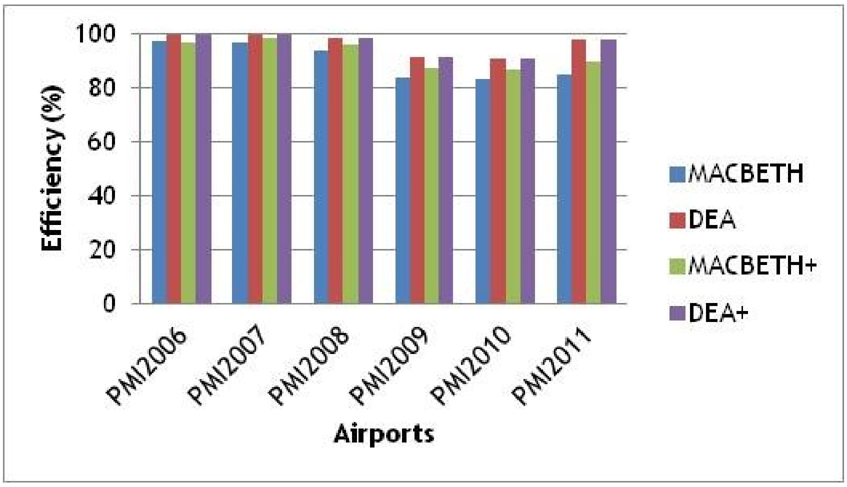

Figure 4.152: Palma de Mallorca Airport Comparative Efficiency for all Cases

Figures 4.153 to 4.156 permit another perspective, i.e. the efficiency ranking which is the main goal of this study. The first two, present a comparison between rankings, before and after the addition of new indicators, and the last a comparison between tools, as in the previous analysis.

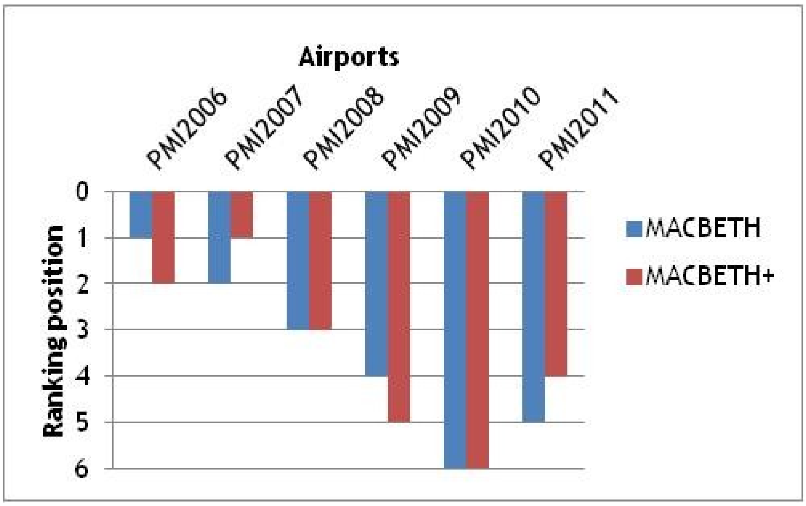

Figure 4.153: Balance between MACBETH and MACBETH+ Rankings for Palma de Mallorca Airport

Comparing the transition from MACBETH to MACBETH+, in figure 4.153, it's possible to observe changes in the rankings due to the addition of new indicators for 2006, 2007, 2009, and 2011; however for 2008 and 2010, there is no variation. Palma de Mallorca airport got 1st place for 2006 in MACBETH and for 2007 in MACBETH+, and last position for 2010.

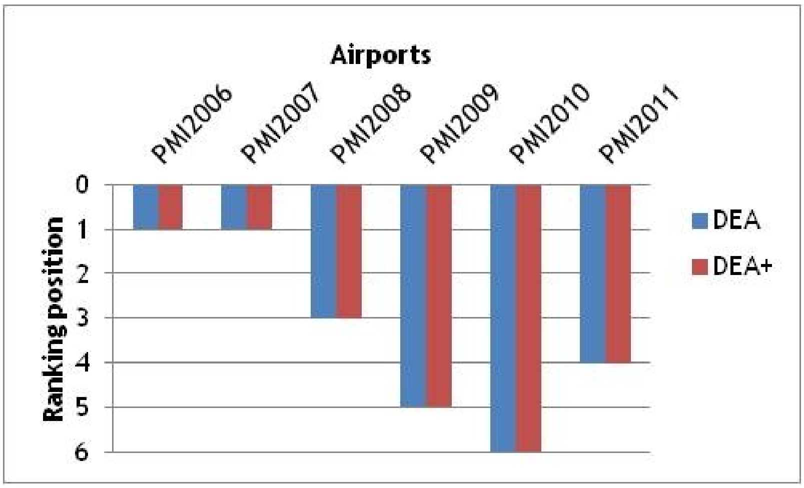

Figure 4.154: Balance between DEA and DEA+ Rankings for Palma de Mallorca Airport

Comparing the transition from DEA to DEA+ in figure 4.154, which represents again the adding of new indicators, it's possible to observe that there is no changing in the rankings (for the same year) due to the addition of new indicators. Palma de Mallorca airport got 1st place on DEA and DEA+ for 2006 and 2007, and last position in 2010.

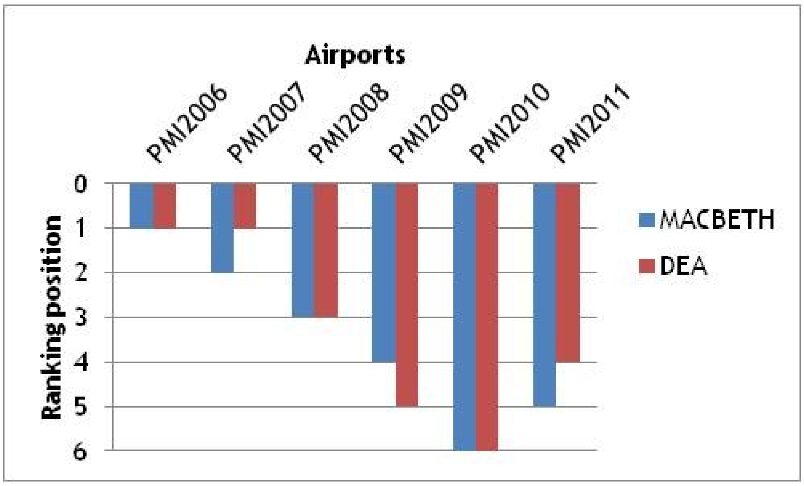

Figure 4.155: Balance between MACBETH and DEA Rankings for Palma de Mallorca Airport

In figure 4.155 is shown a comparison between MACBETH and DEA rankings, where there were differences in all years except for 2006, 2008 and 2010. Palma de Mallorca airport had 1st position on both approaches in 2006 and 2007, and the less efficient year for MACBETH and DEA, were 2010.

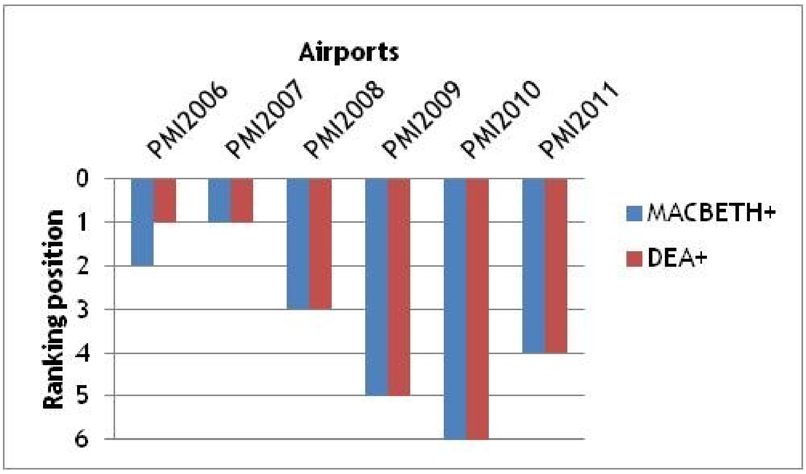

Figure 4.156: Balance between MACBETH+ and DEA+ Rankings for Palma de Mallorca Airport

In figure 4.156 is shown a comparison between MACBETH+ and DEA+ rankings, where the difference was only for 2006 (from 2nd to 1st). The airport got 1st position on both approaches in 2007, and the less efficient year for MACBETH+ and DEA+ was 2010.

The ranking results obtained with MACBETH and DEA approaches are quite different. From figures 4.153 to 4.156, or from figure 4.157 and table 75 (direct comparison), it's possible to observe the variation on ranking places, due the use of those two different tools. Some years have different values between approaches.

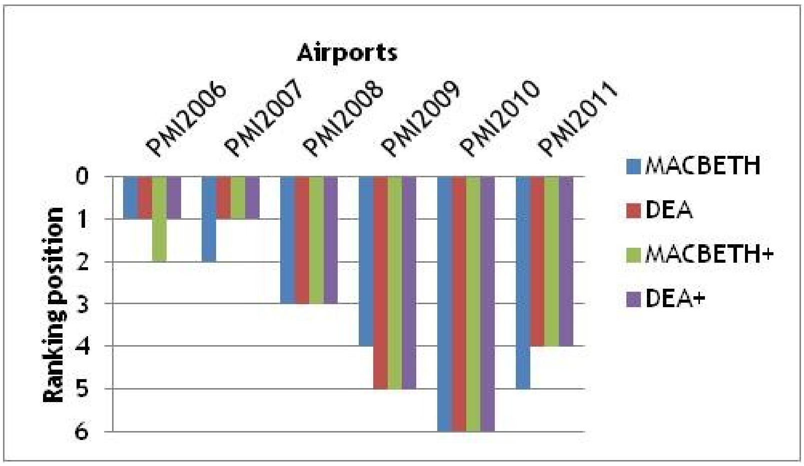

Figure 4.157: Palma de Mallorca Airport Comparative Ranking for all Cases

As visible in tables 73 and 74, the maximum scores within MACBETH and MACBETH+ analysis for Gran Canaria Airport were: 2007 for MOVS/STANDS, MOVS/RWS, MOVS/GATES and MOVS/BELTS, PAX/PAX TA, PAX/CHK-IN and PAX/GATES; 2006 for CARGO/CARGO TA.

4.2.6. CASE VI - Madeira Airport (FNC) Self-Benchmarking Study with Inclusion of Weather Constraints

This case study performs specifically the self-benchmarking of a Portuguese airport, Madeira (FNC) one, in Madeira island, with inclusion of weather constraints, between 2007 and 2011. As stated by Airport Cooperative Research Program report from Transportation Research Board (Hazel *et al.*, 2011), Closures for Adverse Weather (number of airport closures for adverse weather annually) normally caused by snow and ice, although other severe weather such as hurricanes and thunderstorms may also result in closure, are important for self-benchmarking and are applicable to all airports. The number of closures is related both to the severity of weather and the airport's ability to keep runways, taxiways and roadways clear.

Thus, this analysis is divided into three parts: in the first and second ones the indicators structure, and respective weights are the same of the previous case studies - as presented in table 7, but the third one will be called MACBETH++ and DEA++ which corresponds to the inclusion of a new indicator related to the number of closure hours per year due to natural effects (OT/TT – Operational Time/Total Time, where Total Time is $24\,hours\ \times 365\,days$, or 366 in a leap year). As such information is confidential related data cannot be displayed, as requested by the airport authority; nevertheless it will be included in the case study. These three parts/experiences are again to verify possible changes in the ranking between methods, due to additional performance indicators within the analysis. We use data of table 76 for input and output indicators

Table 76: Madeira Airport Data 2007-2011 (ANAM, 2007 to 2011)

									STATISTICS		
DMU	**RWS**	**STANDS**	**PAX TA**	**C TA**	**CHK-IN**	**GATES**	**BELTS**	**OP TIME**	**PAX**	**MOVS**	**CARGO**
FNC2007	1	16	44590	4500	40	16	4	-	2418489	21954	6774,6
FNC2008	1	16	44590	4500	40	16	4	-	2446924	22799	6637,6
FNC2009	1	16	44590	4500	40	16	4	-	2346649	21955	6228,4
FNC2010	1	16	44590	4500	40	16	4	-	2233524	22094	6069,5
FNC2011	1	16	44590	4500	40	16	4	-	2311380	21346	5095

Table 77 specifies information related to complex indicators, as in the previous case study, where data concerning the closure hours per year due to natural effects is, as mentioned, not visible.

Table 77: Complex Indicators for Madeira Airport (FNC)

YEARS	PAX/ PAX TA	PAX/ GATES	PAX/ CHK-IN	CARGO/ CARGO TA	MOVS/ STANDS	MOVS/ GATES	MOVS/ RWS	MOVS/ BELTS	OT/TT
FNC2007	54,24	151155,56	60462,23	1,51	1372,13	1372,13	21954,00	5488,50	-
FNC2008	54,88	152932,75	61173,10	1,48	1424,94	1424,94	22799,00	5699,75	-
FNC2009	52,63	146665,56	58666,23	1,38	1372,19	1372,19	21955,00	5488,75	-
FNC2010	50,09	139595,25	55838,10	1,35	1380,88	1380,88	22094,00	5523,50	-
FNC2011	51,84	144461,25	57784,50	1,13	1334,13	1334,13	21346,00	5336,50	-

Then we use MACBETH and DEA tools again to rank this set of years between 2007 and 2011. The weights for MACBETH and MACBETH+ are those of table 7, and for MACBETH++ are those of table 78, accordingly (again) with the opinion of (the same) 28 (national and international) aeronautic specialists.

Table 78: Complex Indicators Weights For MACBETH++ Case Study

INDICATORS	MACBETH++
MOVS/STANDS	15,44%
MOVS/RWS	11,89%
PAX/PAX TA	16,57%
CARGO/CARGO TA	11,86%
PAX/CHK-IN	10,18%
PAX/GATES	9,36%
MOVS/GATES	8,53%
MOVS/BELTS	8,28%
OT/TT	7,89%
	100%

Then we use MACBETH and DEA tools to get the airport efficiency ranking based on a combination of the above mentioned indicators, and its related weights (tables 79 and 80, and figures 4.158 to 4.160).

Table 79: Madeira Airport Scores for MACBETH++ Study Case

	Global	MOVS/ STANDS	MOVS/ RWS	PAX/ PAX TA	CARGO/ CARGO TA	PAX/ CHK-IN	PAX/ GATES	MOVS/ GATES	MOVS/ BELTS	OT/TT
[tudo sup.]	100	100	100	100	100	100	100	100	100	100
FNC2008	99,77	100	100	100,02	98,03	100	100	100	100	100
FNC2007	97,95	96,29	96,29	98,85	100	98,84	98,84	96,29	96,29	100
FNC2009	95,87	96,3	96,3	95,92	91,45	95,9	95,9	96,3	96,3	100
FNC2010	94,16	96,91	96,91	91,28	89,47	91,28	91,28	96,91	96,91	98,96
FNC2011	92,22	93,63	93,63	94,47	75	94,46	94,46	93,63	93,63	100
[tudo inf.]	0	0	0	0	0	0	0	0	0	0
	Weights	0,1544	0,1189	0,1657	0,1186	0,1018	0,0936	0,0853	0,0828	0,0789

Table 80: Madeira Airport Positions in the Efficiency Rankings for the Six Cases

DMU	DEA	Rank DEA	DEA+	Rank DEA+	DEA++	Rank DEA++
FNC2007	100	1	100	1	100	1
FNC2008	100	1	100	1	100	1
FNC2009	96,30	3	96,30	3	96,64	3
FNC2010	96,91	2	96,91	2	97,61	2
FNC2011	94,46	4	94,46	4	94,51	4
DMU	**MACBETH**	**Rank MACBETH**	**MACBETH+**	**Rank MACBETH+**	**MACBETH++**	**Rank MACBETH++**
FNC2007	97,87	2	97,77	2	97,95	2
FNC2008	99,52	1	99,75	1	99,77	1
FNC2009	95	3	95,52	3	95,87	3
FNC2010	93,62	4	93,76	4	94,16	4
FNC2011	89,24	5	91,56	5	92,22	5

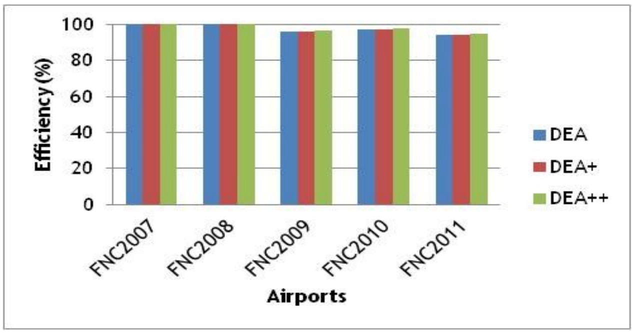

Figure 4.158: Madeira (FNC) DEA case Comparative Efficiency

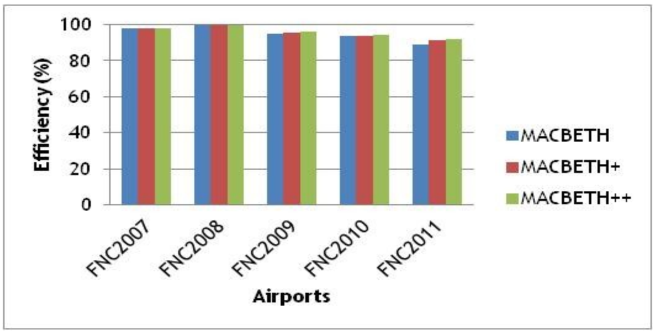

Figure 4.159: Madeira (FNC) MACBETH Case Comparative Efficiency

Comparing on one hand DEA, DEA+, DEA++ and, on the other hand MACBETH, MACBETH+, MACBETH++ (figures 4.158 and 4.159), or from figure 4.160 for direct comparison, it's possible to observe that exist differences in the efficiency values due to the successive addition of new indicators, where we verified a slight increase. For DEA cases the most efficient year was 2007 and 2008, the less efficient was 2011; and for MACBETH cases the most efficient year was 2008 and the less efficient was 2011. Despite closure time, the airport revealed to be efficient.

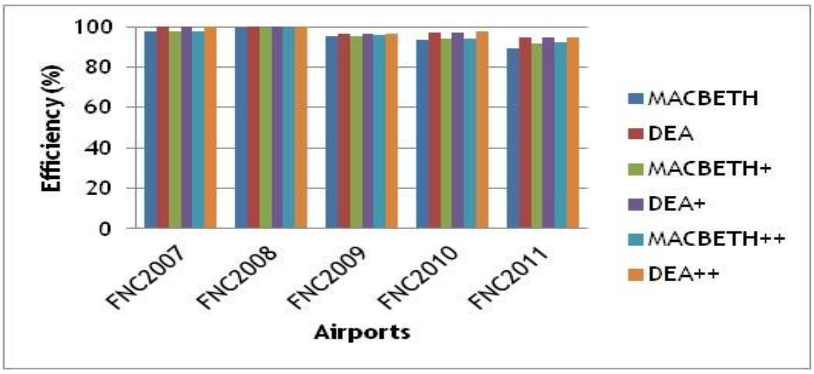

Figure 4.160: Comparative Efficiency for all Madeira Case Studies

Figures 4.161 to 4.163 permit another perspective, i.e. to visualize the efficiency ranking which is the core of this study. The first two, present a comparison between rankings, accordingly the progressive introduction of new indicators, and the last one a comparison between tools, as in the previous analysis.

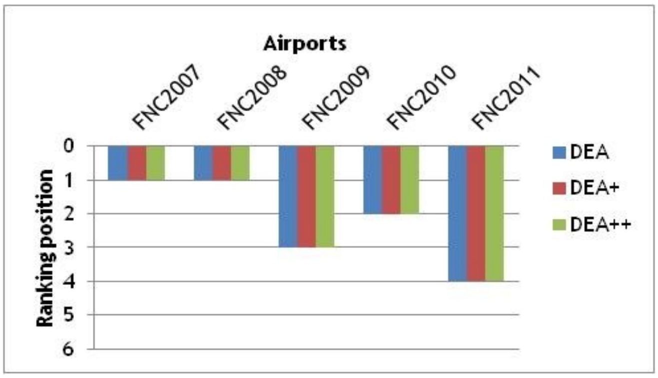

Figure 4.161: FNC Ranking Balance for DEA Case Studies

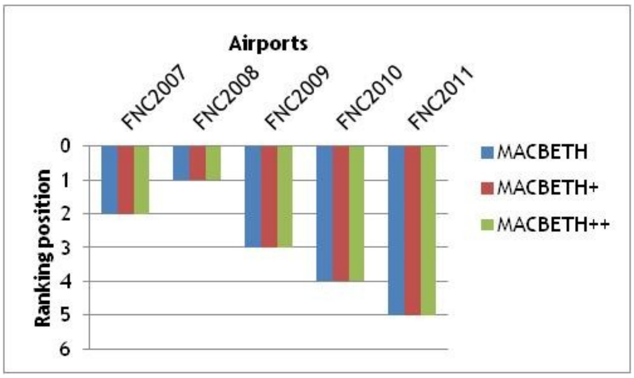

Figure 4.162: FNC Ranking Balance for MACBETH Case Studies

As presented in figures 4.161 and 4.162, despite variation in the efficiency values, there is no changing in the rankings, for each year and each method. However, there are differences in the comparison of the obtained rankings in each tool, as shown in figure 4.163.

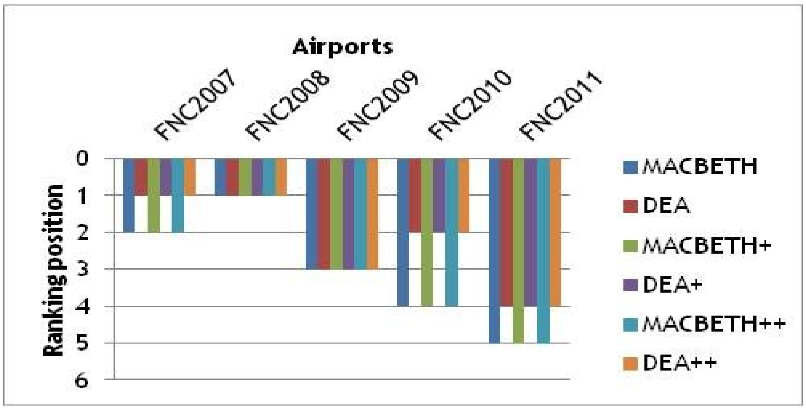

Figure 4.163: Balance between Madeira MACBETH and DEA rankings

As evidenced in figure 4.163, the results obtained with MACBETH and DEA approaches are quite different for 2007 (2nd and 1st, respectively MACBETH and DEA), 2010 (4th and 2nd) and 2011 (5th and 4th). For both, MACBETH and DEA, 2008 was the most efficient year for Madeira airport, as 2011 was the less efficient year. Curiously, with the addition of the closure time (MACBETH++ and DEA++) the efficiency values show a slight increase; this fact is due to the closure time, which revealed to be very low in comparison with the total time of operations in the airport (about to 1% of time closed due to weather constraints in a year), i.e. the airport operated 98% and 99% of total time between 2007 and 2011. Other fact was the weight given by specialists to this indicator (7,89%), revealed as well to be significant to change the airport efficiency to a higher value, justified by the fact of MACBETH attributes score of 100% to weather indicator (OT/TT), as in table 79. Thus it's possible to conclude, despite weather constraints, Madeira airport was been efficient during the last year's.

4.3. Conclusion

Throughout this chapter, the capabilities of DEA and MACBETH software's were explored, by its application to the 6 case studies involving different set of airports: a benchmarking analysis for a Worldwide case, followed by the European and the Iberian ones, and then for the main Portuguese airports; a self-benchmarking analysis for the main Iberian airports (Portugal and Spain); and finally a self-benchmarking analysis only for Madeira airport but including emerging situations/sudden natural phenomenon constraints.

The results are conditioned not only by the difficult to obtained data from all airports, but also by inherent limitations of both methodologies, MCDA/Macbeth and DEA/ISYDS; however it was possible to obtain:

- Efficiency rankings for a reasonable number of airports, allowing the decision makers to check the position of own infrastructure in the ranking and perceive where they can get the increments necessary to modify that position;
- Efficiency rankings of the same airports over several years, allowing the decision maker to have a clear sense of the impact of any investment (or its necessity) in the behavior of the infrastructure;
- Self-benchmarking analysis including emerging situations/sudden natural phenomenon constraints for an airport in particular, allowing the decision makers the perception and interest in such analysis mainly in most competitive environments;
- Comparisons between functionalities and outputs of two multidimensional tools, quite different but complementary, allowing the decision makers with more robust but flexible tools to better sustain policies and practices involving airports management.

Also there were some limitations related to both MACBETH and DEA tools that we verified during the analysis process:

1. MACBETH does not allow to import data from a pre prepared file as DEA does; so values must be inserted in the program desktop one by one; for a Table of Performances with several complex indicator values (as in table 17, for the Iberian airports case study) that operation will require a lot of time and is very susceptible to errors;

2. Also MACBETH only allows the insertion of two decimal places; but we had some airports with low ratios (e.g. 0,002) whose data could not be inserted correctly; this imply the introduction of errors just from the beginning of the process (as the cases for Albacete, Badajoz, etc, in the Iberian airports case study);
3. DEA gives 100% efficiency for more than one airport; this is not clear to identify the best performer(s).

Chapter 5 – Conclusions

5.1. Dissertation Synthesis

This work relates with airport benchmarking analysis, particularly the importance of efficiency rankings to decision makers: States/Governments, Airlines, Business Managers, Passengers, or the Airport Administration itself.

The second chapter deals specifically with the importance of benchmarking and its applicability to any kind of activity, as an essential tool in planning and organizational processes. It is used in any kind of activity, to compare productivity and efficiency, evaluate specific processes, policies and strategies and to assess overall organizational performance. Complex and dynamic organizations such as international airports provide a challenge in establishing an appropriate performance measure system, in order to improve their roles in a increasingly competitive aeronautical activity. Therefore makes perfect sense that benchmarking is used as a means of managing and planning in all sectors of this industry. We focused on the methods commonly used to evaluate performance of airports. After reflecting on their strengths and limitations we focused in particular and successively, in Multicriteria Analysis and two of its tools, MCDA/MACBETH and DEA/ISYDS.

In the third chapter theories behind MCDA and DEA tools were reflected as well as the reasons for its choice and to forward application in our case studies. Particularly we explain the reasons to choose MACBETH and ISYDS tools, its pros and cons.

The fourth chapter explored the capabilities of MACBETH and ISYDS tools applied to 6 case studies involving different sets of airports and under distinct environments: cases I to IV are related to benchmarking studies about (in this sequence) sets of Worldwide, European, Iberian and Portuguese airports; case V is related to a self-benchmarking study involving some Iberian airports; and case VI is related to a self-benchmarking study about Madeira Airport (FNC) which includes in the evaluation process some emerging situations/sudden natural phenomenon constraints. The results are conditioned by the difficult to obtained data from all airports and by inherent limitations of both methodologies; however it was possible to obtain:

- Efficiency rankings for a reasonable number of airports;
- Efficiency rankings of the same airports over several years;
- Self-benchmarking analysis including emerging situations/sudden natural phenomenon constraints for an airport in particular;
- Comparisons between functionalities and outputs of two multidimensional tools, quite different but complementary.

5.2. Concluding Remarks

The main object of this work was the development of airport performance and efficiency predictive models using robust but flexible methodologies and incorporating simultaneously traditional indicators (number of movements and passengers, tons of cargo, number of runways and stands, area of terminals both of passenger and cargo) as well as new constraints as emerging situations and/or sudden natural phenomenon (ramp accidents and incidents, and volcano ashes and weather constraints, respectively).

Therefore this work had two specific objectives: to show the efficiency evaluation of either a set of airports or the same airport along several years and under several constraints based on two multidimensional tools, Multicriteria Decision Analysis (MCDA, particularly through Measuring Attractiveness by a Categorical Based Evaluation Technique - MACBETH) and Data Envelopment Analysis (DEA); and to compare the obtained results using both MACBETH and DEA evidencing pros and cons of each multidimensional tool and searching for the best conditions to apply one or the other within airport management decision processes.

These objectives were clearly achieved however they could go further if we had obtained in useful time all the necessary data particularly those regarding Closures for sudden natural phenomenon. For other airports except Madeira (FNC) these data doesn't exist or isn't available.

Also the introduction of local emerging situations (as ramp accidents/incidents) as a performance/efficiency indicator was not possible since the access is restricted.

Similarly it was not possible to get in useful time as many specialist answers as we desired in order to refine our indicators weight values for MACBETH tool. However, all the existing (28) ones were very important not only for that specific purpose, but also to support and validate the results of this work.

5.3. Prospects for Future Work

As mentioned airports are nowadays complex infrastructures located in the middle of a chain of agents and to promote the performance of the airport itself is also necessary to promote that chain as a whole. To achieve such a goal is necessary to understand the added value of the airport in particular, so the choice of the indicators (simple or complex) to construct the rankings to benchmark the airports must be very accurate. Also there are several sets of indicators as well as several techniques for benchmarking, but the airport stakeholders needs simultaneously robust and flexible tools, mainly because air transportation acts in a very

interactive and iterative world where changes are very quick.
Therefore, future developments in this area must be focused in the following items:

- To research for the best indicators to serve the purposes of airport managers, in particular the most significant indicators to evaluate emerging situations and/or sudden natural phenomenon that can (really) affect the airports performance;
- To research for the best robust and flexible multidimensional tools that can be used in a user-friendly environment by airport managers;
- To make a deep research within the self-benchmarking process, which deserved a special interest from the majority of our specialist and all the stakeholders contacted along this work
- To extend the evaluation of airport performance also to economic and hinterland components; after all the airport is only one element in an integrated chain of multi-actors that needs to be promoted as a whole.

References

2.bp.blogspot.com, http://2.bp.blogspot.com/_TeSwqdZznL8/S8jgG-9QMbI/AAAAAAAADQE/PC1Z9kTsOAo/s1600/DSC00420.JPG, last access: October 4th, 2012

Air Transport Research Society, *Airport Benchmarking Report 2009 – Global Standards For Airport Excellence*, Vancouver, 2009

ACI – Airport Council International, *Airport Benchmarking to Maximize Efficiency*, ACI World Headquarters, Geneve, 2006

ACI – Airport Council International, *Annual Report 2010*, 2010

ACI – Airport Council International, *Guide to Airport Performance Measures*, February 2012

AENA, http://www.aena-aeropuertos.es/csee/Satellite/Aeropuerto-Barcelona/es/Page/1045569607419//Galeria-fotografica.html, last access: October 4th, 2012

AENA, http://www.aena-aeropuertos.es/csee/Satellite/Aeropuerto-Madrid-Barajas/es/Page/1049727006313//Galeria-fotografica.html, last access: October 4th, 2012a

AENA, http://www.aena-aeropuertos.es/csee/Satellite/Aeropuerto-Vigo/es/Page/1055241040652//Galeria-fotografica.html, last access: October 4th, 2012b

ANA – Aeroportos de Portugal, Lisboa, http://routelab.ana.pt/ucm/groups/lisboa/documents/documento/mkt_008144.pdf?airport=Lisboa, 2012, last access: October 4th, 2012

ANAM – Aeroportos da Madeira, http://routelab.ana.pt/DRD/MediaGallery/index.htm?galleryName=Photos&nodeIdVar=20&folderIdAux=830&fragment26_NextRow=1&airport=Madeira, last access: October 4th, 2012

Bana e Costa, C., de Corte, J.-M. and J.-C. Vansnick, *Macbeth*, Working paper 03.56, ISBN 0 7530 1520 X, London School of Economics, 2003

Bana e Costa, C., de Corte, J.-M. and J.-C. Vansnick, *On The Mathematical Foundations of Macbeth*, The London School of Economics and Political Science, 2004

Bana e Costa, C., de Corte, J.-M., Vansnick, J.-C., Costa, J., Chagas, M., Corrêa, É., João, I., Lopes, F., Lourenço, J. and R. Sánchez-López, *MacBeth User´s Guide*, Available: http://www.m-macbeth.com/en/m-home.html, 2005, last access: 4th October, 2012

Brackx, T., Airliners.net, http://cdn-www.airliners.net/aviation-photos/photos/7/9/0/1522097.jpg, last access: October 4th, 2012

Braz, J., Baltazar, E., Silva, J, and M. Vaz, *MacBeth as a MCDA Tool to Benchmark the Iberian Airports*, 2011, Presented at: ERSA 2011, 51st European Regional Science Association Congress, Barcelona, Spain, 30th August – 3rd September 2012

Braz, J., *O MACBETH como Ferramenta MCDA para o Benchmarking de Aeroportos*, MSc Thesis in Aeronautical Engineering, University of Beira Interior, Covilhã, Portugal, 2011

Centre for Aviation, Passenger and Freight Load Factors on International Markets from 2007 to 2011, http://www.centreforaviation.com/analysis/airline-industry-in-continued-crisis-state-amid-uncertain-outlook-iata-60122, last access: October 4th, 2011

Couceiro, F., Jetphotos.net, http://jetphotos.net/viewphoto.php?id=7330168&nseq=18, last access: October 4th, 2012

Csmonitor.com, http://www.csmonitor.com/var/ezflow_site/storage/images/media/images/2010/0210/010-snowstorm-east-coast-airports-laguardia/7375969-1-eng-US/0210-snowstorm-east-coast-airports-laguardia_full_600.jpg, last access: 23rd June, 2012

dnoticias.pt, http://www.dnoticias.pt/sites/default/files/imagecache/body_640/07MAI02799C_Small_0.jpg, last access: October 4th, 2012

easydestination.net, http://www.easydestination.net/blog/media/AM/Heathrow_Airport_Terminal.jpg, last access: 23rd June, 2012

Fairbanks, M., *Optimizing airport performance: a careful balancing act*, Helios Adviser, 2009

Ferreira, E.Z., Junior, H.V., Correia, R.C., *Worldwide Efficiency Evaluation of Airports: The use of DEA Methodology*, Aeronautics Institute of Technology, Brazil, 2010

Fodness, D., and B. Murray, *Passengers expectations of airport service quality*, Journal of Services Marketing, Emerald, 2005

Gómez, C., Ladevesa J., Prieto R., Gibert, K. and A. Valls, *Use and evaluation of M-MACBETH*, 2007

Graham, A., *Airport benchmarking: a review of the current situation*, Benchmarking: An International Journal, Vol. 12 Iss: 2, pp.99 – 111, 2005

Graham, A.; *Managing Airports: An International Perspective*, Elsevier, Oxford, 2003

Great Circle Mapper, Airport Location, http://www.gcmap.com/, last access: 3rd October, 2012

Hazel, R., Blais, J., Browne, T. and D. Benzon, *Resource Guide to Airport Performance Indicators*, ACRP Report 19-A, TRB – Transportation Research Board, Washington D.C., 2011

Heijst, JPC v., AirplanePictures.net, http://www.airplane-pictures.net/images/uploaded-images/2009-5/21/46853.jpg, last access: October 4th, 2012

Humphreys, I. and G. Francis, *Performance measurement: a review of airports*, International Journal of Transport Management, Volume 1, Pages 79-85, Elsevier, 2002

INAC - Instituto Nacional de Aviação Civil, I.P., *A Evolução do Transporte Aéreo do Aeroporto de Lisboa [1990-2009]*, INAC, 2010

Infraton.blogdevoo.com, http://infraton.blogdevoo.com/files/2011/04/168009_140433706017090_131267846933676_266666_2513588_n1.jpg, last access: October 4th, 2012

Jardim, J., Baltazar, M. and J. Silva, *Airport Performance and Efficiency Evaluation based on Multidimensional Tools*, Presented at: ERSA 2012, 52nd European Regional Science Association Congress, Bratislava, Slovakia, 21st-25th August 2012

Lai, P., Potter. A and M. Beynon, *The development of benchmarking techniques in airport performance evaluation research*, Presented at: 14th Air Transport Research Society Conference, Porto, Portugal, 6-9 July 2010

Liebert, V. and H.-M. Niemeier, *Benchmarking of airports—a critical assessment*, Paper presented at the 12th World Conference on Transport Research (WCTR), July 2010, Lisbon, Portugal, 2010

Marques, A. and M. Galves; *Application of the Multicriteria Decision Aid (MCDA) to the Industrial Airport Project of Viracopos*; Universidade Estadual de Campinas, Faculdade de Engenharia Civil, Arquitetura e Urbanismo; 2009

Martín, J. and C. Román, *A Benchmarking Analysis of Spanish Commercial Airports*. A comparison Between SMOP and DEA Ranking Methods, Springer Science, 2006

Marttunen, M., *Description of Multi-Criteria Decision Analysis (MCDA)*, Finnish Environment Institute, 2010

Meza, L., Neto, L., Soares de Mello, J., Gomes, E., and P. Coelho, *Free software for Decision Analysis. A software package for Data Envelopment models*, ICEIS 2005 Proceedings of the 7th International Conference on Enterprise Information Systems, pp. 207-212, 2005

Meza, L., Neto, L., Soares de Mello, J., Gomes, E., and P. Coelho, *SIAD – Sistema Integrado de Apoio à Decisão: Uma Implementação Computacional de Modelos de Análise de Envoltória de Dados*, VI Simpósio de Pesquisa Operacional Da Marinha, VII Simpósio de Logística da Marinha, 16th-17th December 2003, Rio de Janeiro, Brazil, 2003

Morales, R., Airliners.net, http://www.airliners.net/photo//1997873/L/&sid=59e58578479082447f32436a822ef06b, last access: October 4th, 2012

Morrison, W., *Understanding the complexities and challenges of airport performance benchmarking*, Airport Management Vol.3, No.2, 145-158, January-March 2009

Ostblom and Karloff, Benchmarking: *A SignPost to Excellence in Quality and Productivity*, Wiley, New York, 1993

Oum, T., Yu, C. and X. Fu; *A comparative analysis of productivity performance of the world's major airports: summary report of the ATRS global report benchmarking research report 2002*; Journal of Air Transport Management; Elsevier; 2003

Oxford Economics; *Economic Benefits from Air Transport in Portugal*; 2011

Perelman, S. and T. Serebrisky, *Measuring Technical Efficiency of Airports in Latin America*, Utilities Policy, Volume 22, September 2012, Pages 1–7 , Elsevier, 2012

Piavani, S., Airliners.net, http://cdn-www.airliners.net/aviation-photos/photos/9/9/8/1867899.jpg, last access: October 4th, 2012

Raposo, B., *Determinação de Rotas Aéreas com Base em Análise Multicritério de Apoio à Decisão*, MSc Thesis in Aeronautical Engineering, University of Beira Interior, Covilhã, Portugal, 2008

Rederer, S., *Airline Industry Overview For the Regional Airline Association*; OAG – Official Airline Guide; 2010

Redrif.com, http://www.redrif.com/images/ff/0611/27/bvolcanic_ashis_very_dangerousfor_aircraftbrparticles_of_5.jpg, last access: June 23rd, 2012

Resendes, J.C., Airliners.net, http://www.airliners.net/photo//1590226/L/&sid=06aad0d494ef7187c22b1142862abf73, last access: October 4th, 2012

Sasse, M. and T. Hauf, *A study of thunderstorm-induced delays at Frankfurt Airport*, Germany, Hannover, 2003

Schaar, D. and L. Sherry, *Comparison of Data Envelopment Analysis Methods Used in Airport Benchmarking*, Fairfax, Virginia, USA, 2008

Sousa, R., Jetphotos.net, http://images2.jetphotos.net/img/4/4/5/2/83069_1314798254.jpg, last access: October 4th, 2012

Talluri, S., *Data Envelopment Analysis: Models and Extensions, Silberman College of Business Administration*, Fairleigh Dickinson University, 2000

The Institute of Transport Management, *Current Aviation Industry Overview*, http://www.itmworld.com/cat_images/pics_itm/RESEARCH_Doc_Current%20Aviation%20Industry%20Overview_20051130020208.pdf, last access: October 4th, 2012

Wang, W.-K. and H.-C. Huang, *Measuring the Relative Efficiency of European MBA Programs: A Comparative analysis of DEA, SBM, and FDH Model*, Yuan-Ze University, 2004

Wikipedia.org, http://ga.wikipedia.org/wiki/%C3%8Domh%C3%A1:Arrivals_board,_Heathrow_T5,_April_16_2010.JPG, last access on 23rd June, 2012

Wilhelm, V., *Data Envelopment Analysis – DEA*, Curitiba, 2006

Würfel, D., Airliners.net, http://www.airliners.net/photo/0912321/L/&sid=0413cca6d6644ace99d9552517955a0c, last access: October 4th, 2012

Zagope, http://www.zagope.pt/resources/ImageHandler.ashx?t=ProjectsImages&c=Source&id=c8fc8d0f-9be0-4b3b-9232-ff7eb2064b6b&d=z&pkC=ImageID&width=482&height=312, last access: October 4th, 2012

Airport Data Sources:

Worldwide Airport Data Sources

Aeroparque	Email contact airport autorithy: Customer Service, Aeropuertos Argentina 2000 Ferreira, E., Junior, H. and A. Correia (2010)
Atlanta	http://www.atlanta-airport.com/docs/Facilities/airport_complan.pdf http://www.atlanta-airport.com/Airport/ATL/ATL_Factsheet.aspx http://www.azworldairports.com/airports/a2740atl.cfm http://www.atlanta-airport.com/Airport/ATL/operation_statistics.aspx
Barcelona	Email contact airport autorithy: Raquel Remón Fernández, Secretaría División Gabinete de Dirección, Aeropuerto de Barcleona - El Prat http://www.aena-aeropuertos.es/csee/ccurl/206/811/anualDefinitivos_2011.pdf http://www.aeropuertodebarcelona.net/index_archivos/documentos/historia/presentacion_terminal_sur.pdf
Belgrade	Email contact airport autorithy: Belgrade “Nikola Tesla” Airport PR Team Ferreira, E., Junior, H. and A. Correia (2010) http://www.beg.aero/about_us/traffic_figures.446.html
Calgary	Email contact airport autorithy: Calgary Airport Authority Ferreira, E., Junior, H. and A. Correia (2010) http://www.calgaryairport.com/data//1/rec_docs/33_BR_PaxTotal.pdf http://www.calgaryairport.com/data//1/rec_docs/507_YYC_AccountReport_2011_Web.pdf
Central Japan	Email contact airport autorithy: Yuji Ando, Central Japan International Airport Co.,Ltd Ferreira, E., Junior, H. and A. Correia (2010) http://www.cjiac.co.jp/english/eng_cs/Centrair%20Traffic%20Record%20%28FY2011%29.pdf
Dubai	http://www.dubaiairport.com/en/media-centre/facts-figures/Pages/factsheets-reports-statistics.aspx http://www.dubaiairport.com/EN/MEDIA-CENTRE/Pages/press-releases.aspx?id=69
Ezeiza	Email contact airport autorithy: Customer Service, Aeropuertos Argentina 2000 Ferreira, E., Junior, H. and A. Correia (2010) http://en.wikipedia.org/wiki/Ministro_Pistarini_International_Airport
Frankfurt	Email contact airport autorithy: Raphael Orlandi, Customer Service, Fraport Flughafen Frankfurt http://www.prnewswire.com/news-releases/fraport-traffic-figures---december--full-year-2011-fra-achieves-new-passenger-records-137235398.html
Galeão	Email contact airport autorithy: Francisco Primo, Gerente de Ouvidoria Ferreira, E., Junior, H. and A. Correia (2010) http://www.infraero.gov.br/images/stories/Estatistica/2011/Dez.pdf
Gatwick	http://www.gatwickairport.com/business/about/facts-figures/ http://www.azworldairports.com/airports/a2720lgw.cfm http://www.gatwickairport.com/business/about/facts-figures/
Guarulhos	Email contact airport autorithy: Francisco Primo, Gerente de Ouvidoria Ferreira, E., Junior, H. and A. Correia (2010) http://www.infraero.gov.br/images/stories/Estatistica/2011/Dez.pdf
Hong kong	http://www.hongkongairport.com/eng/business/about-the-airport/facts-figures/facts-sheets.html http://www.hongkongairport.com/eng/pdf/business/statistics/2011e.pdf http://www.azworldairports.com/airports/a1720hkg.cfm

Manaus	Email contact airport autorithy: Francisco Primo, Gerente de Ouvidoria Ferreira, E., Junior, H. and A. Correia (2010) http://www.infraero.gov.br/images/stories/Estatistica/2011/Dez.pdf
Milan	http://www.milanomalpensa1.eu/en/airport/information/technical-information http://www.milanomalpensa2.eu/en/airport/information/information-technical-information http://www.milanomalpensacargo.eu/en/cargo-city/available-structures/cargo-facilities http://www.assaeroporti.it/defy.asp http://www.azworldairports.com/airports/a1810mxp.cfm
Montreal	Email contact airport autorithy: Anne-Marie Urban, Agent Relations clients, Officer Customer Relations, AÉROPORTS DE MONTRÉAL Ferreira, E., Junior, H. and A. Correia (2010) http://en.wikipedia.org/wiki/Montr%C3%A9al-Pierre_Elliott_Trudeau_International_Airport
Munich	Email contact airport autorithy : Mit freundlichen Gruessen, Flughafen München GmbH http://www.munich-airport.de/media/download/general/publikationen/en/facts_and_figures.pdf http://www.munich-airport.de/media/download/bereiche/daten/jahresberichte/en_2011.pdf
Singapore	Email contact airport autorithy: Karen Ganzon, Changi Contact Centre Ferreira, E., Junior, H. and A. Correia (2010) http://www.changiairportgroup.com/cag/html/the-group/passenger_movement.html http://www.changiairportgroup.com/cag/html/the-group/airfreight_movement.html http://www.changiairportgroup.com/cag/html/the-group/commercial_movement.html
Sydney	http://www.sydneyairport.com.au/corporate/community-environment-and-planning/~/media/Files/Corporate/Environment%20Plan/Master%20Plan/MasterPlan09.pdf http://www.sydneyairport.com.au/corporate/about-us/~/media/Files/Corporate/About%20Us/Fact%20Sheets/Fact_Sheet_Sydney_Airport_Capacity_The_Facts.pdf http://airfreightstats.com/grid.asp?a=sydney#
Tampa	Email contact airport autorithy: Mark Witt, Terminal Operations, Tampa International Airport Ferreira, E., Junior, H. and A. Correia (2010) http://www.tampaairport.com/about/facts/tia_fact_sheet_short-2012-06-11.pdf http://www.tampaairport.com/about/facts/activity_reports/2011/activity_dec2011.pdf
Tokyo	Email contact airport autorithy: Facilities Business Department, Passenger Terminal Management Department, Narita International Airport Corporation(NAA) Ferreira, E., Junior, H. and A. Correia (2010) http://www.naa.jp/en/traffic/pdf/statistics2011.pdf
Toronto	Ferreira, E., Junior, H. and A. Correia (2010) http://www.azworldairports.com/airports/a1290yyz.cfm http://www.torontopearson.com/TerminalListing.aspx#
Vancouver	Email contact airport autorithy: Amy, Customer Call Centre YVR Ferreira, E., Junior, H. and A. Correia (2010) http://www.yvr.ca/en/about/facts-stats.aspx
Viracopos	Email contact airport autorithy: Francisco Primo, Gerente de Ouvidoria Ferreira, E., Junior, H. and A. Correia (2010) http://www.infraero.gov.br/images/stories/Estatistica/2011/Dez.pdf

European Airport Data Sources

Amesterdam	http://www.schiphol.com/B2B/RouteDevelopment/AirportFacts.htm http://www.schiphol.nl/B2B.htm
Athens	Email contact airport authority: Terminal Services, Athens International Airport S.A., "Eleftherios Venizelos"
Berlin	Email contact airport autorithy: Johannes Mohrmann, Airline Marketing, Marketing and Public Relations Flughafen Berlin Brandenburg GmbH ATRS 2009 Report **http://www.berlin-airport.de/EN/UeberUns/Flughafenanlagen/TXL.html** **http://en.wikipedia.org/wiki/Berlin_Tegel_Airport**
Bratislava	Email contact airport authority: Dana Madunicka, PR Manager & Spokesperson, Bratislava Airport, Slovak Republic
Brussels	http://www.brusselsairport.be/en/cf/res/pdf/corp/en/brutrends2011 http://www.brusselsairport.be/en/cf/res/pdf/en/terminalmapen http://www.brusselsairport.be/en/cf/res/pdf/cargo/en/cargo_brochure http://www.azworldairports.com/airports/a1140bru.cfm
Bucarest	http://www.bucharestairports.ro/page.php?pg=dezvoltaremodernizare http://www.bucharestairports.ro/otp/index.php?cat=227&article=2273 http://en.wikipedia.org/wiki/Henri_Coand%C4%83_International_Airport Google Maps
Budapest	Email contact airport authority: Diana Szabo, Product development marketing coordinator, Budapest Airport Zrt. http://www.routesonline.com/airports/2380/budapest-airport/ http://www.bud.hu/english/business-and-partners/aviation/facts_and_figures
Copenhagen	Email contact airport autorithy: Charlotte K, Copenhagen Airports A/S http://www.cph.dk/CPH/UK/ABOUT+CPH/International/United+Kingdom/Traffic/2011/ http://www.cph.dk/CPH/UK/B2B/Cargo/Traffic+Statistics/2011/ http://www.cph.dk/CPH/UK/B2B/Cargo/Facilities.htm
Dublin	http://www.dublinairport.com/gns/at-the-airport/latest-news/10-12-15/Snow_and_Ice_FAQs.aspx http://www.dublinairport.com/gns/at-the-airport/airport-maps/terminal1.aspx http://www.dublinairport.com/gns/at-the-airport/airport-maps/terminal-2.aspx http://www.dublinairport.com/gns/at-the-airport/airport-maps/airport-gates.aspx http://en.wikipedia.org/wiki/Dublin_Airport Google Maps
Helsinki	ATRS 2009 Report http://www.finavia.fi/files/kronodoc/2284/202669/EFHK%20matk%20kuukausittain%20eng-fi.pdf http://www.finavia.fi/files/kronodoc/2284/202720/EFHK%20tavaraliikenne%20eng-fi.pdf http://www.finavia.fi/files/kronodoc/2284/202714/Laskeutumiset%20eng-fi.pdf https://ais.fi/ais/eaip/en/ http://www.helsinki-vantaa.fi/more-information/maps-and-images/servicemap http://www.azworldairports.com/airports/a1560hel.cfm Google Maps
Larnaka	ATRS 2009 Report Email contact airport autorithy: Elias Elia, Senior Officer, Operations Centre, Hermes Airports Ltd http://www.hermesairports.com/ http://en.wikipedia.org/wiki/Larnaca_International_Airport

Lisbon	Email contact airport authority: ANA Aeroportos, Sr. Dr. João Nunes, Airport Director http://routelab.ana.pt/DRD/TheAirport/OperationInfo/index.htm?airport=Lisboa http://www.ana.pt/SiteCollectionDocuments/Negocios_Empresas/Sobre_Aeroportos/Relatorio%20Anual%20ANA_2011.pdf
Ljubljana	Email contact airport authority: Alenka Knaflič, Ljubljana Airport http://www.lju-airport.si/eng/about-the-company/traffic-figures
London	http://www.heathrowinformation.co.uk/heathrow-airport-INF-information-terminal-5.php http://www.heathrowairport.com/about-us/facts-and-figures http://www.heathrowairport.com/heathrow-airport-guide/airport-maps http://www.baa.com/investor-centre/results-and-performance/traffic-statistics Google Maps
Luxemburg	Email contact airport authority: Customer Service http://www.ana.public.lu/fr/statistiques/evolution-des-mouvements/evo-mouvements.pdf http://www.ana.public.lu/fr/statistiques/fret/fret1.pdf http://www.ana.public.lu/fr/statistiques/passagers/passagers1.pdf http://www.luxaircargo.lu/cms/luxairCargo?p=EN,53751,27,,3
Madrid	Email contact airport authority: AENA Aeropuertos, Secretaría Gabinete de Dirección Aeropuerto Madrid-Barajas http://www.fomento.es/NR/rdonlyres/2AFEDA1A-D3B0-4CC1-8206-A25F73CE7604/54813/Estusituaaeropuerto.pdf
Paris	ATRS 2009 Report http://www.azworldairports.com/airports/a1570cdg.cfm http://www.aeroportsdeparis.fr/ADP/Resources/b075cd65-a887-4cae-9d36-3f71768f055b-122011trafficfigures.pdf http://en.wikipedia.org/wiki/Paris-Charles_de_Gaulle_Airport http://www.aeroportsdeparis.fr/ADP/Resources/e6317a50-d2a4-46c5-94f4-5abdd0117f35-BrochureCargo.pdf http://www.aeroportsdeparis.fr/ADP/en-GB/Professionnals/Cargo/Exceptionaladvantages/Characteristics-of-our-airports/ http://www.aeroportsdeparis.fr/ADP/Resources/b8134acc-2214-48f7-9dd8-24b954e4a1c8-guideduclientVA2011CDG.PDF
Prague	ATRS 2009 Report http://www.prg.aero/en/business-section/aviation-business/statistics-and-reports/prague-airport-traffic-reports/Contents.4/0/98608081C43DE3180A42573FE2038AEE/resource.pdf http://www.prg.aero/en/business-section/aviation-business/airport-facts-prague/technical-information/ http://www.prg.aero/en/business-section/aviation-business/cargo/cargo-traffic-development/
Riga	http://www.riga-airport.com/en/main/about-company/statistics/in-total-per-year http://www.riga-airport.com/en/main/b2b/aviation/cargo/statistics http://www.riga-airport.com/en/main/b2b/aviation/cargo/for-all-your-cargo-solutions http://www.riga-airport.com/en/main/about-company/facts-about-rix/technical-information http://www.azworldairports.com/airports/a1900rix.cfm
Rome	Email contact airport authority: ADR for CLIENT
Sofia	Email contact airport autorithy: Ralitza Iankova, *Aviation Marketing Expert*, SOFIA AIRPORT http://www.sofia-airport.bg/pages/content.aspx?lm01=107&lm02=72 http://www.sofia-airport.bg/pages/content.aspx?lm01=107&lm02=73&lm03=76

Stockholm	Email contact airport authority: Elin Mattsson, Swedavia AB, Stockholm Arlanda Airport http://www.swedavia.com/about-swedavia/statistics/ http://www.swedavia.com/arlanda/about-stockholm-arlanda-airport-/about-stockholm-arlanda-airport/facts-about-the-airport/
Tallinn	Email contact airport authorithy: Asko Kivinuk, Head of Terminal Services Department, Tallinn Airport Ltd http://www.tallinn-airport.ee/eng/associates/GeneralInfo/technicaldata http://eaip.eans.ee/2012-05-03/html/index-en-GB.html http://www.tallinn-airport.ee/upload/Editor/REPO7-kodulehele-ik_10.pdf
Valeta	http://www.azworldairports.com/airports/a2060mla.cfm http://www.maltairport.com/filebank/documents/statistics/2011%20Annual%20Statistical%20Summary.pdf
Vienna	Email contact airport autority: Mag. uPM Isabelle Schefberger, Flughafen Wien http://www.viennaairport.com/jart/prj3/va/main.jart?rel=en&content-id=1249344074274&reserve-mode=active
Vilnius	http://www.vilnius-airport.lt/lt/oro-uostas/faktai-ir-skaiciai/oro-uosto-statistika/Traffic_report_2011-12.pdf http://www.azworldairports.com/airports/a1960vno.cfm Google Maps
Warsaw	http://www.lotnisko-chopina.pl/en/airport/about-the-airport/airport-specifications http://www.lotnisko-chopina.pl/en/airport/about-the-airport/statistics/passenger-aircraft-movements http://www.lotnisko-chopina.pl/en/airport/about-the-airport/statistics/passengers http://www.lotnisko-chopina.pl/en/airport/about-the-airport/pressroom/news/2012/2/chopin-airport-cargo-hits-new-record-high/?searchterm=cargo%202011 http://www.azworldairports.com/airports/a2310waw.cfm

Iberian Airport Data Sources

Spanish Airports	Email contact airport authority: AENA Aeropuertos AENA – Aeropuertos de España, *Annual Traffic Reports*, 2006, 2007, 2008, 2009, 2010 and 2011, AENA, Madrid, 2011 http://www.fomento.es/MFOM/LANG_CASTELLANO/DIRECCIONES_GENERALES/AVIACION_CIVIL/POLITICAS_AEROPORTUARIAS/ITA/PLANES_DIRECTORES/ http://www.aena-aeropuertos.es/csee/Satellite/HomeAenaAeropuertos/es/
Faro	http://routelab.ana.pt/DRD/TheAirport/OperationInfo/index.htm?airport=Algarve http://www.ana.pt/SiteCollectionDocuments/Negocios_Empresas/Sobre_Aeroportos/Relatorio%20Anual%20ANA_2011.pdf Airport Master Plan ANA - Aeroportos de Portugal, S.A., *Annual Traffic Reports*, 2006, 2007, 2008, 2009, 2010, and 2011, ANA, Lisboa, 2011
Flores	Email contact airport authority: Rui Medeiros, SATA Gestão de Aeródromos http://www.ana.pt/SiteCollectionDocuments/Negocios_Empresas/Sobre_Aeroportos/Relatorio%20Anual%20ANA_2011.pdf ANA - Aeroportos de Portugal, S.A., *Annual Traffic Reports*, 2006, 2007, 2008, 2009, 2010, and 2011, ANA, Lisboa, 2011
Horta	Email contact airport authority: ANA Aeroportos, Sr. Dr. João Corvelo, Airport Director http://www.ana.pt/SiteCollectionDocuments/Negocios_Empresas/Sobre_Aeroportos/Relatorio%20Anual%20ANA_2011.pdf ANA - Aeroportos de Portugal, S.A., *Annual Traffic Reports*, 2006, 2007, 2008, 2009, 2010, and 2011, ANA, Lisboa, 2011
Lisboa	Email contact airport authority: ANA Aeroportos, Sr. Dr. João Nunes, Airport Director http://routelab.ana.pt/DRD/TheAirport/OperationInfo/index.htm?airport=Lisboa http://www.ana.pt/SiteCollectionDocuments/Negocios_Empresas/Sobre_Aeroportos/Relatorio%20Anual%20ANA_2011.pdf ANA - Aeroportos de Portugal, S.A., *Annual Traffic Reports*, 2006, 2007, 2008, 2009, 2010, and 2011, ANA, Lisboa, 2011
Madeira	Email contact airport authority: ANAM Aeroportos da Madeira, Sr. Miguel Nóbrega, Operations Manager http://routelab.ana.pt/DRD/TheAirport/OperationInfo/index.htm?airport=Madeira http://www.anam.pt/trafego-mensal-anual ANAM - Aeroportos da Madeira, *Annual Traffic Reports*, 2006, 2007, 2008, 2009, 2010 and 2011, ANAM, Funchal, 2011
Ponta Delgada	http://www.ana.pt/SiteCollectionDocuments/Negocios_Empresas/Sobre_Aeroportos/PD_AJP.pdf http://www.ana.pt/SiteCollectionDocuments/Negocios_Empresas/Sobre_Aeroportos/Relatorio%20Anual%20ANA_2011.pdf ANA - Aeroportos de Portugal, S.A., *Annual Traffic Reports*, 2006, 2007, 2008, 2009, 2010, and 2011, ANA, Lisboa, 2011

Porto	http://routelab.ana.pt/DRD/TheAirport/OperationInfo/index.htm?airport=Porto http://www.ana.pt/SiteCollectionDocuments/Negocios_Empresas/Sobre_Aeroportos/PD_ASC.pdf http://www.ana.pt/SiteCollectionDocuments/Negocios_Empresas/Sobre_Aeroportos/Relatorio%20Anual%20ANA_2011.pdf ANA - Aeroportos de Portugal, S.A., *Annual Traffic Reports*, 2006, 2007, 2008, 2009, 2010, and 2011, ANA, Lisboa, 2011
Porto Santo	http://routelab.ana.pt/ucm/groups/madeira/documents/documento/mkt_008645.pdf?airport=Madeira http://www.anam.pt/anual-aeroporto-porto-santo-trafego-mensal-anual ANAM - Aeroportos da Madeira, *Annual Traffic Reports*, 2006, 2007, 2008, 2009, 2010 and 2011, ANAM, Funchal, 2011
Santa Maria	Email contact airport authority: ANA Aeroportos, Sr. Dr. Roberto Amorim, Airport Director http://www.ana.pt/SiteCollectionDocuments/Negocios_Empresas/Sobre_Aeroportos/Relatorio%20Anual%20ANA_2011.pdf ANA - Aeroportos de Portugal, S.A., *Annual Traffic Reports*, 2006, 2007, 2008, 2009, 2010, and 2011, ANA, Lisboa, 2011

Annex - Specialist Survey (English and Portuguese)

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AIRPORT OPERATIONAL EFFICIENCY ANALYSIS

Among the following ten criteria (new ones are shown in bold) used to evaluate airport efficiency, give a weight (percentage) to each, making a total of 100% (giving higher weight to those you understand most relevant).

Number of Processed Passengers / Passengers Terminal Area		
Processed Cargo / Cargo Terminal Area		
Number of Aircraft Movements / Number of Parking Stands		
Number of Aircraft Movements / Number of Runways		
Number of Processed Passengers / Number of Barding Gates		
Number of Processed Passengers / Number of Check-In Desks		
Number of Aircraft Movements / Number of Barding Gates		
Number of Aircraft Movements / Number of Baggage Claim Belts (Arrivals)		
Natural Hazards: $\frac{\textit{inoperability hours}}{(24\times365)\ \textit{hours operability}}$		
Rama accidents/incidents: $\frac{\textit{Number of Aircraft Movements}}{\textit{Number of ocorrences}}$		
	Total	100 %

If desired, make a few comments on the above criteria, or about others who would find important for this work.

Thank you for your collaboration!

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Covilhã | Portugal

DEPARTAMENTO DE CIÊNCIAS AEROESPACIAIS

Núcleo de Investigação em Transportes
Transportation Research Team

ESTUDO DE EFICIÊNCIA OPERACIONAL AEROPORTUÁRIA

De entre os seguintes dez critérios (os novos estão apresentados a negrito) que permitem avaliar a eficiência de um aeroporto, atribua um peso (em percentagem) a cada um deles, perfazendo 100% no total (atribua maior peso àqueles que entenda mais relevantes).

Número de Passageiros Processados / Área do Terminal de Passageiros		
Quantidade de Carga Processada / Área do Terminal de Carga		
Número de Movimentos / Número de Posições de Estacionamento das Aeronaves		
Número de Movimentos / Número de Pistas		
Número de Passageiros Processados / Número de Portas de Embarque		
Número de Passageiros Processados / Número de Balcões de Check-in		
Número de Movimentos / Número de Portas de Embarque		
Número de Movimentos / Número de Tapetes de Recolha de Bagagem (chegadas)		
Fenómenos Naturais: $\frac{horas\ inoperabilidade}{(24\times365)\ horas\ operabilidade}$		
Ocorrências de Placa (acidentes ou incidentes): $\frac{Número\ de\ Movimentos}{Número\ de\ ocorrências}$		
	Total	100 %

Caso pretenda, faça alguns comentários sobre os critérios acima referidos, ou sobre outros que acharia oportunos para a realização deste trabalho.

Muito Obrigado!