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Nuno Rafael Valente

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List of Publications

Articles produced as a result of this dissertation research (see annexe A.6):

1. **Modelling and Forecasting Airport Performance**
   Nuno Valente, Maria E. Baltazar, Jorge Silva (2017) 24th APDR Congress - Intellectual Capital and Regional Development: New landscapes and challenges for space planning, 6-7 July, Covilhã (Portugal)

2. **Airport Performance Analysis and Forecasting**
   Nuno Valente, Maria E. Baltazar, Jorge Silva (2017) ICEUBI2017 – International Congress on Engineering – A Vision for the Future, 5-7 November, Covilhã (Portugal) (Manuscript accepted for presentation).

Resumo

Os aeroportos constituem uma parte essencial do sistema de transporte aéreo, disponibilizando infraestruturas que permitem a transferência de passageiros e carga entre a superfície terrestre e veículos aéreos, o armazenamento e a manutenção de aeronaves e a acomodação de outros fornecedores de serviços essenciais ao mesmo. Os aeroportos têm ainda um elevado valor estratégico para as regiões em que estão instalados, uma vez que criam riqueza, oportunidades de emprego, promovem o turismo regional e incentivam o desenvolvimento económico. Desde o início da aviação civil, o tráfego aéreo tem crescido de forma exponencial sem ter sido acompanhado por um investimento correspondente nas infraestruturas aeroportuárias, atingindo recentemente um ponto em que os aeroportos começam a enfrentar problemas de congestionamento devido à falta de capacidade. Devido a estes fatores, há uma pressão crescente sobre os gestores aeroportuários, companhias aéreas e entidades que regulam o espaço aéreo para uma gestão mais eficiente do sistema do setor. A análise do desempenho aeroportuário, bem como a previsão dos fatores de que este depende, assumem-se então como tarefas essenciais.

Este estudo aborda o desempenho aeroportuário tentando prever o mesmo através da projeção do crescimento de passageiros e movimentos de aeronaves. Para tal, o desempenho é aferido através da metodologia MACBETH (Measuring Attractiveness by a Categalized Based Evaluation Technique) na qual se baseia o modelo PESA-AGB (Performance Efficiency Support Analysis – Airport Global Benchmarking) adotado neste estudo. O método utilizado na previsão consiste numa técnica de alisamento exponencial, que permitiu a construção de três cenários de crescimento e que pode ser facilmente aplicado pelos gestores aeroportuários.

Os resultados apresentam os valores previstos de passageiros e movimentos de aeronaves num aeroporto fictício - representativo de um dos principais aeroportos em Portugal, bem como as pontuações de desempenho. É também mostrado que o peso do indicador de desempenho aeroportuário considerado o mais importante pelos especialistas, acaba por ter um menor impacto no computo geral quando se considera em simultâneo a influência direta sobre outros indicadores.

Palavras-chave

Desempenho Aeroportuário; Previsão; MCDA; MACBETH; Alisamento Exponencial

Resumo alargado

Introdução

Esta secção serve o propósito de resumir, em língua portuguesa, o conteúdo da presente dissertação. Inicialmente é feito o enquadramento da dissertação e são identificados o objeto e objetivos do estudo. O resumo prossegue com apresentação dos principais resultados e conclusões retiradas e termina com a enumeração dos aspetos sugeridos para objeto de trabalhos futuros.

Enquadramento

Um aeroporto mais do que uma infraestrutura que serve uma gama de necessidades crescentes relacionadas com o transporte aéreo, é um sistema que incorpora um conjunto heterogéneo de componentes interligados e que, além disso, tem uma forte interação com o meio em que está inserido.

Um dos principais problemas enfrentados pelos aeroportos atualmente é o volume crescente de tráfego aéreo. De facto, este tem crescido de forma praticamente exponencial e tem-se mostrado resiliente a fatores externos negativos mais acentuados, como ataques terroristas, conflitos e crises financeiras. Este crescimento do tráfego aéreo não tem sido acompanhado por um investimento correspondente ao nível das infraestruturas de transporte aéreo levando a que os principais aeroportos mundiais enfrentem atualmente períodos de forte congestionamento que colocam em risco a operacionalidade e a segurança da infraestrutura. Devido a estes fatores, há uma pressão crescente sobre os gestores aeroportuários, companhias aéreas e entidades que regulam o espaço aéreo para uma gestão mais eficiente do sistema de transporte aéreo.

Para melhorar o desempenho aeroportuário, é necessário analisar e modelar as dinâmicas de um aeroporto no sentido de facilitar o entendimento, definição, quantificação e simulação das mesmas.

É esperado pela generalidade da indústria da aviação civil, que o crescimento do tráfego aéreo se mantenha no futuro. Tendo em conta que o transporte aéreo assume uma influência cada vez maior sobre os cenários económicos, é importante assegurar que as necessidades futuras deste setor são asseguradas. Como tal, o desenvolvimento de previsões sobre tráfego aéreo e atividades de gestão do transporte aéreo assume um papel critico nos processos de planeamento das várias organizações envolvidas com esta indústria.

Objeto e Objetivos

O objeto de estudo desta dissertação é o desempenho aeroportuário, sendo o principal objetivo a modelação e previsão do mesmo. Para tal, foram traçados dois objetivos secundários. Primeiro, é necessário definir desempenho aeroportuário através da identificação dos aspetos avaliados e dos indicadores através dos quais este deve ser medido. É necessário conhecer e distinguir os diferentes conceitos associados ao desempenho aeroportuário (eficiência, desempenho comercial, etc.) bem como os conjuntos de indicadores ou inputs e outputs de modelos que são utilizados neste tipo de estudos.

Em segundo lugar, é necessário identificar a metodologia que melhor se adequa ao problema, à natureza dos dados e aos recursos disponíveis. Este princípio é valido tanto para a análise de desempenho como para a construção da previsão.

Pretende-se que este estudo se aplique a um aeroporto Português, geralmente adotado como referência.

Casos de Estudo

Este estudo adota o modelo PESA-AGB para quantificar o desempenho aeroportuário e recorre a uma base de dados parcialmente constituído por dados relativos a diferentes áreas de desempenho publicados em relatórios públicos referentes a 3 aeroportos portugueses do grupo VINCI/ANA S.A.: Lisboa, Porto e Faro. Este trabalho de investigação utiliza apenas os dados referentes ao aeroporto de Lisboa. Tendo em conta que os dados em falta foram inferidos a partir de aeroportos mundiais semelhantes em dimensão (passageiros e movimentos) e categoria, as simulações apresentadas nesta dissertação aplicam-se a um aeroporto fictício representativo do aeroporto de Lisboa.

Três casos de estudo são apresentados, correspondendo à análise da evolução do desempenho aeroportuário em função do crescimento de:

- passageiros (Caso I);
- movimentos de aeronaves (Caso II);
- passageiros e movimentos de aeronaves em simultâneo (Caso III).

Para os dois primeiros casos são consideradas 3 hipóteses a fim de aferir quais as condições mais adequadas para avaliar o impacto do crescimento de cada um dos indicadores no desempenho do aeroporto:

- hipótese 1 - previsão por projeção de tendência para o indicador considerado aplicando a condição “ceteris paribus” para todos os outros indicadores;
- hipótese 2 – previsão por projeção de tendência para o indicador em estudo, considerando, adicionalmente, o possível impacto diretamente observável do seu crescimento sobre outros indicadores;
- hipótese 3 – previsão aplicando a técnica de alisamento exponencial assumindo as condições de uma das hipóteses anteriores que sejam consideradas as mais adequadas.

Principais conclusões

A revisão bibliográfica conduzida para a análise de desempenho aeroportuário mostra que as técnicas de Stochastic Frontier Analysis (SFA) e Data Envelopment Analysis (DEA) são as mais populares. No entanto, para modelar o desempenho aeroportuário apenas o SFA é aplicável juntando-se as técnicas baseadas no método dos mínimos quadrados. O DEA por si só não fornece uma medida de desempenho. Uma forma encontrada na literatura para contornar esta questão consiste em atribuir um peso a cada medida de desempenho através de modelos híbridos como DEA/Analytic Hierarchy Process (AHP).

Relativamente às técnicas de previsão, os métodos mais populares consistem em técnicas de séries temporais e métodos econométricos. A seleção da ferramenta de previsão mais adequada depende, no entanto, de uma série de fatores identificados nesta dissertação.

Os resultados obtidos da primeira hipótese para o Caso I e para o Caso II confirmam o maior impacto do número de passageiros no desempenho aeroportuário medido, através da pontuação obtida do modelo PESA-AGB, resultante do maior peso atribuído pelos especialistas a este indicador. No entanto, quando se considera o impacto direto que a alteração do número de passageiros e movimentos de aeronaves podem ter sobre outros indicadores, o segundo acaba por ter maior impacto no desempenho aeroportuário uma vez que a soma do seu peso com os pesos dos indicadores afetados acaba por ser maior do que no caso dos passageiros, mostrando que as suposições estabelecidas na segunda hipótese têm uma influência considerável na análise desempenhada.

Na terceira hipótese, é introduzida a técnica Exponential Triple Smoothing (ETS) que permite a construção de três cenários de crescimento (expectável, otimista e pessimista) para cada indicador, com base nos limites de confiança. O cenário expectável mostra, para ambos os casos, um crescimento contínuo ainda que abaixo da taxa média registada entre 2003 e 2013. O cenário otimista mostra, no caso dos passageiros, um número ligeiramente acima da capacidade máxima projetada para 2013. Apesar de tais projeções não serem totalmente precisas, os números previstos mostram que o aeroporto teria de realizar um esforço adicional para ter a capacidade de dar resposta a essa procura.

No caso III, a performance do aeroporto é estimada para o cenário expectável de passageiros e movimentos de aeronaves, uma vez que a correlação entres os dois indicadores é muito elevada. As pontuações mostram que o aumento do tráfego aéreo (passageiros e movimentos) não leva, por si só, a um aumento significativo do desempenho quando comparado com as flutuações da pontuação registadas entre 2003 e 2013. Significa isto que, se os gestores aeroportuários pretendem obter aumentos significativos de desempenho global, mais do que lidar com o aumento do tráfego aéreo sem piorar o desempenho relativo às diferentes áreas, este último teria que ser melhorado.

Perspetivas de trabalhos futuros

A diversidade de técnicas de análise e previsão de desempenho e eficiência deixam ainda margem para explorar outras metodologias, permitindo o aumento da eficiência das mesmas.

Também o conjunto de indicadores de desempenho e respetivas variáveis explicativas poderão ser alvo de estudos mais aprofundados que contribuam para um melhor entendimento da anatomia do desempenho aeroportuário, isto é, refinando a sua especificidade e eventual aplicabilidade para aquele fim.

Assim sendo, iniciativas futuras de trabalho nesta área deverão contemplar os seguintes pontos:

- análise do impacto de outros indicadores no desempenho aeroportuário e estudo de correlações adicionais entre todos eles para se obter uma perspetiva mais alargada e consistente das dinâmicas desse desempenho;

- análises econométricas que identifiquem as vaiáveis explicativas que têm uma relação causal com os diferentes indicadores;
- aplicação de metodologias de previsão diferentes que possam fornecer previsões mais exatas;
- considerar processos de consulta de especialistas e atribuição de pesos aos indicadores mais direcionados para o modelo em causa, que permitam uma distribuição mais consistente dos pesos aos indicadores das diferentes áreas;
- incorporar metodologias quantitativas ou outras alterações no modelo PESA-AGB que permitam aumentar a objetividade da avaliação da performance e tornar o modelo mais preciso em análises comparativas entre diferentes aeroportos.

Abstract

Airports are an essential part of air transport system, providing infrastructures to enable the transfer of passengers and freight between the land surface and air vehicles, to store and maintain aircraft and to accommodate other service providers needful to air transportation. Moreover, airports have strategic importance to the regions they serve as they bring wealth, employment opportunities, promote regional tourism and encourage economic development. Over the years, air traffic has grown exponentially without a corresponding investment in airport infrastructures and is now reaching a stage where airports may face congestion due to lack of capacity. Due to these facts, there is a growing pressure to manage the air transport system more efficiently. Therefore, it is of utmost importance to analyse airport performance and predict the development of the factors that may affect it.

This study addresses airport performance by predicting it through the passengers and aircraft movements forecasts. For this purpose, airport performance is measured through Measuring Attractiveness by a Categorical Based Evaluation Technique (MACBETH) methodology by adopting Performance Efficiency Support Analysis – Airport Global Benchmarking (PESA-AGB) model. The forecasting method consists of an exponential smoothing technique that could be easily used by airport managers and that allow creating three different scenarios of development.

Results show the forecasted number of passengers and aircraft movements at a fictitious airport representative of a major Portuguese airport as well as its consequent performance score. Moreover, it is shown that the weight, empirically assigned by experts, that each indicator has on airport performance may invert when considering the direct impact on other indicators.

Keywords

Airport Performance; Forecasting; MCDA; MACBETH; Exponential Smoothing

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List of Acronyms

ACI	Aiport Council International
AHP	Analytic Hierarchy Process
ARIMA	Autoregressive Integrated Moving Average
ARIMAX	Autoregressive Integrated Moving Average with additional explanatory variables
ARMA	Autoregressive Moving Average
DEA	Data Envelopment Analysis
DMU	Decision Making Unit
ETS	Exponential Triple Smoothing
ICAO	International Civil Aviation Organization
KPA	Key Performance Area
KPI	Key Performance Indicator
MACBETH	Measuring Attractiveness by a Categorical Based Evaluation Technique
MCDA	Multi-Criteria Decision Analysis
MSE	Mean Squared Error
PESA-AGB	Performance and Efficiency Support Analysis for Airport Global Benchmarking
PLS	Partial Least Squares
SARIMA	Seasonal Autoregressive Integrated Moving Average
SFA	Stochastic Frontier Analysis
TFP	Total Factor Productivity

List of Symbols

y	observation
S	smoothed observation
b	trend factor
I	seasonal index
L	periods
t	time period index
α	estimated constant
β	estimated constant
γ	estimated constant
F	forecast

Chapter 1

Introduction

1.1 Motivation

Most common problems faced by the air traffic control system are primarily related to the volume of air traffic demand placed on the system and those related to the weather. Focusing on air traffic demand, it has been recorded a high growth rate and it has proven to be resilient to external factors (see Figure 1.1).

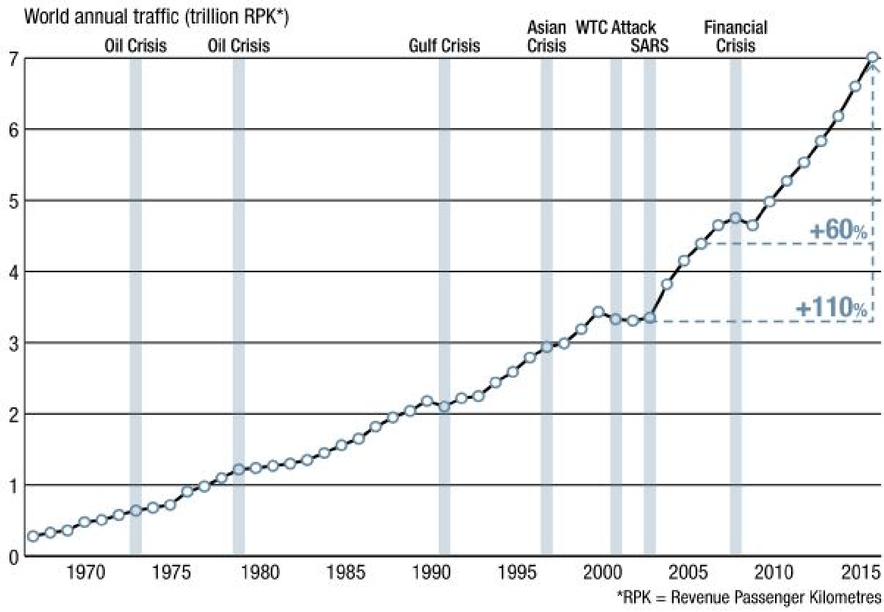

Figure 1.1: World annual traffic growth over last crisis. Source: [1].

Several world major airports are already facing periodic congestion, which may cause operational constraints to the airport. For example, Lisbon airport is often reported to be facing congestion problems at the same time of year [2] [3] which affects not only the airport itself but also some stakeholders like airlines [4], [5]. Despite several reports of the intentions to expand the airport, the air traffic growth has been faced essentially, through operational adjustments to improve airport performance and efficiency.

Several factors dictate the amount of traffic that can land at an airport in a given amount of time. Due to the increasing demand for air transportation, which is expected to continue in the following years (see Figure 1.2), in conjunction with different kind of constraints on providing capacity, there has been increasing political pressure for improvements in airport performance through better and sustainable management of existing resources.

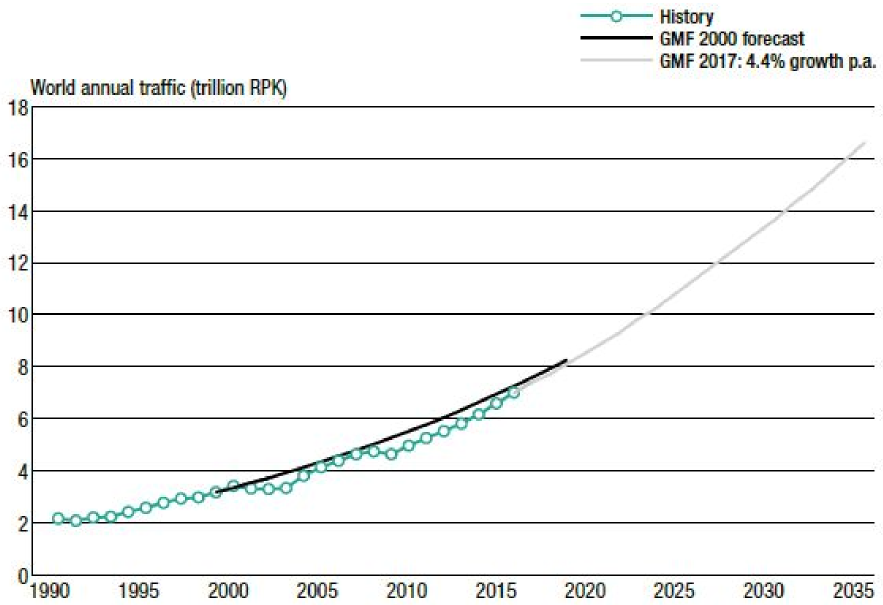

Figure 1.2: Long term air traffic demand forecast. Source: [1].

This study intends to contribute to the assessment of the most suitable tools and criteria to analyse and forecast airport performance and, consequently, provide managers and/or decision-making units (DMUs) with useful tools and knowledge to improve airport performance as a means to respond to air traffic growth.

1.2 Object and Objectives

The object of this study is airport performance and the model to measure and predict it. Therefore, this work has two main objectives: model and forecast airport global performance.

Other specific objectives are inherent to the framework of this study. Firstly, it is necessary to define "airport performance". The objective is to identify the criteria/indicators from which we can quantify or qualify this performance; this may be achieved through a literature review where attention is paid to the object of previous studies on airports and to the indicators (or inputs and outputs) selected.

To analyse airport performance is then necessary to identify the methodology that best suits the problem and data nature. The problem refers to what the object is in specific (commercial performance, productivity, etc.) and to the main objective, which in this study is to describe airport performance through a cost function or a scoring system.

The same happens for forecasting, which has seen several techniques being applied. The selection of the most suitable forecast depends on several features that must be identified. This study is intended to be applied to a Portuguese benchmark airport.

1.3 Dissertation Structure

The subjects and sequence of the main chapters of this dissertation can be summarised as follows:

Chapter 1 contains an introduction where it is described the theme of this work, the study's object and objectives are identified, and the dissertation structure is detailed.

In Chapter 2, airport is regarded as a complex system composed of several interconnected subsystems and that also must deal with demanding stakeholders and external factors; thus a literature review on airport performance and efficiency analysis is presented depicting the characteristics of some methodologies to do so. The choice of study objects and indicators or inputs and outputs made by previous studies on this subject is referred too.

Chapter 3 presents the state-of-the-art of air traffic and airport performance forecasting. It is identified the aspects that must be considered before starting the process of forecasting and the different techniques developed so far.

Chapter 4 presents first an explanation of the MCDA model adopted to measure airport performance. The chapter continues by identifying the case studies. For each case study, it is presented the scores obtained for each of the hypotheses that are formulated as well as the related analysis. The results are compared to assess the impacts of different indicators and assumptions on airport performance score.

Lastly, Chapter 5 concludes by pointing out the major findings of this work and presenting the dissertation summary. Also, some aspects that may be the object of future work are identified.

Chapter 2

Airport Performance Analysis

2.1 Introduction

To analyse airport performance, firstly, one needs to understand the dynamics of such an organisation. Airports embody a range of services, must deal with several stakeholders and have a significant impact on the regional economies. Also, it is necessary to identify the several methodologies available to carry out this kind of analysis.

In this chapter, an airport is seen as a complex organisation encompassing the previous aspects. In addition to the analysis of the economic impact of an airport in a region, it is identified the several factors on which the economic self-sufficiency of an airport depends. This chapter also offers an overview of the several performance analysis methodologies available as well as an extensive literature review.

2.2 Airport - A Complex Organization

Airports are intermodal hubs and natural interfaces between ground and air transport. However, more than an interchange of transport modes, an airport is a system that serves a broad and complex range of needs related to the movements of people and cargo worldwide [6] and embodies several interconnected heterogeneous components. It must be efficient, secure, pleasant to its users, have a capacity greater than demand, have a profitable commercial exploitation, etc.

Airports accommodate manoeuvre area, passenger's terminals, cargo terminals, control tower, meteorological service, flight information centre, communication services, commercial area, etc.

A system is considered to be complex when it is composed of a group of interrelated components and subsystems, for which the degree and nature of the relationships between them is imperfectly known, with varying directionality, magnitude and timescales of interactions [7].

Running a complex organisation such as an airport involves dealing with divergent interests between different stakeholders; this means that stakeholders may seek to influence or even become involved in route development decisions at an airport so that airport managers may prioritise and clarify organisational goals. For example, airlines require airports to capacity at low costs, efficient services, flexibility to deal with different kind of companies, elevated levels of safety and security, etc. Hossain and Alam [8, pp. 1] consider an air transportation system as "probably one of the most complex man-made systems that operates on the edge of chaos and exhibits emergent behaviour whereby small changes in one part of the system can cause major changes in another or in the system as a whole".

Planning and management at an airport are not easy tasks. Authorities invest large sums in equipment for a specific purpose to respond to a demand on which airports only have an indirect control. An airport manager is required to have a clear perception of costs and revenues structure to obtain profits or at least minimize losses depending on the ownership form.

Airports are often viewed as spheres of influence for regional development [9],[10] as they can enhance the growth potential of a region. It is accepted that transports infrastructures are potentially influential on the economic performance of the region by expanding the use of existing resources (labour, capital, etc.), attracting additional resources, and making economies more productive [11]. However, as it stressed by European Investment Bank, infrastructures of this kind contribute only indirectly to this aim, acting as a catalyst in promoting development [12].

The economic self-sufficiency of any airport depends on many factors, like its size and location, current infrastructure conditions, maintenance costs, investment in future development and efficiency of capital goods utilisation [13]. The importance of the location of an airport to attract passenger services and air freight services is supported by the studies of Dennis [14] and Zhang [15], respectively. Halpern and Graham [16] found that market growth has a significant positive effect on route development performance while airport constraints have a significant negative effect. Using Data Envelopment Analysis to determine the relative quality of several airports, Adler and Berechman [17] found that aspects regarding delay times, runway capacity, airport charges, etc. were important for passenger airlines location. Gardiner et al. [18] identified and evaluated the factors that influence cargo airlines' choice of airport and concluded that the ability of an airport to operate at night and the quest to minimise costs were the most important factors. Regarding efficiency, Oum et al.[19] concluded that airports owned and/or controlled by majority private firms, autonomous public corporations or independent authorities are more efficient than those owned and/or controlled by government branch (city/state), multiple level governments, or ports authorities.

Doganis and Graham [20] surveyed the use of performance measures in Europe and found that most airports relied on purely financial measures of performance. The range of circumstances regarding aviation activities, commercial activities, site constraints, governance and ownership structure, etc., in which airports operate results in a mismatch between different airports to define most relevant performance indicators. ACI [21] defined a useful set of performance measures across some categories. The forty-two individual measures are referred to as Key Performance Indicators (KPIs). These indicators are divided into six categories called Key Performance Areas (KPAs) (see Figure 2.1) which can be described as follows:

- Core – core measures used to characterise and categorise airports, such as the number of passengers and operations;
- Safety and Security – safety indicators used to track airfield and other portions of the airport safety issues related to the operations while security indicators are used to monitor security violations, criminal acts and responsiveness;
- Service Quality - service quality indicators focus both on how passengers perceive the level of service provided by the airport;

- Productivity/Cost Effectiveness – these indicators measure the resources used to produce a certain volume of activity;
- Financial/Commercial – these indicators are used to track the airport's financial performance, including airport charges, airport financial strength and sustainability, and the performance of individual commercial functions;
- Environmental – used to monitor an airport's progress in minimising the environmental impacts of its operations.

The metrics of the KPI's can be observed in Annex A.1.

Figure 2.1: Performance Indicators in Six Key Performance Areas. Adapted from [21].

Also, ICAO [22, 23] recommends that States (i.e., national governments) ensure that airports have performance management systems prepared, and that those systems include one or more performance indicators but only in four specified KPAs (Safety, Quality of service, Productivity and Cost-effectiveness).

2.3 Performance and Efficiency Analysis

In 2010, European airports handled around 800 million passengers and air traffic is expected to almost double by 2030.Currently, major European airports are congested at some time of the day; this represents a major problem for the airports since efficiency and safety problems may derive from operating near to the capacity limit. Besides, “congestion and the lack of slot availability at international hubs were found to drive carriers and integrators to secondary airports” [18, pp. 394].

In 2016, over 140 countries added 5% or more capacity than in 2015 while 80% added more than 10% [1]. However, to overcome this problem, more than simply adding capacity, world’s airports are also seeking to improve its efficiency.

First, it necessary to analyse and model the dynamics within an airport with the aim of making it easier to understand, define, quantify and simulate.

This kind of activity is widely used in many industries and was introduced to the airport sector in the mid-1990’s, being the number of studies in this field still relatively modest [24].

The emergent interest from airport managers and governments in measure airport performance has the assessment or monitoring of the following features as main goals [25]:

- Financial and operational efficiency;
- Alternative investment strategies;
- Airport safety;
- Environmental impact.

Performance has many dimensions, and its definition is not clear in the literature as well as its components’ distinction. Lai et al. stated that “the research on airport performance can be classified into two main types: the efficiency evaluation approach and the productivity evaluation approach”; they consider that “efficiency does take the maximum potential output which can be produced with the available inputs, into account, while productivity considers actual outputs” [26, pp. 2]. It was also verified that the two terms have been used interchangeably and considered equivalent. Hooper and Hensher [27] distinguished efficiency and effectiveness defining the first as the way the physical inputs are used to produce the physical services, being concerned with supply-side relationships; while the other one relates service levels to a large extent under their control, given passenger levels and/or landings, and is concerned with demand-side relationships. This study addresses the global performance of the airport encompassing the several areas of airport operations.

As stated before, airports are complex and dynamic organisations which can have different priorities and ownership forms resulting in a diversity of methods used in its performance and efficiency analysis. Although previous studies [6], [28] on airport performance frequently classify these methods into two groups (parametric methods and non-parametric methods) there is a greater diversity of tools used (see Figure 2.2).

The literature review conducted for this study only addresses the multidimensional tools which can be divided into average approaches, frontier approaches and Multi-Criteria Decision Analysis (MCDA) (see Table 2.1).

Frontier approaches have been widely used in the literature. A review of the same shows that DEA is the most used non-parametric approach while Stochastic Frontier Analysis (SFA) is the most studied parametric method.

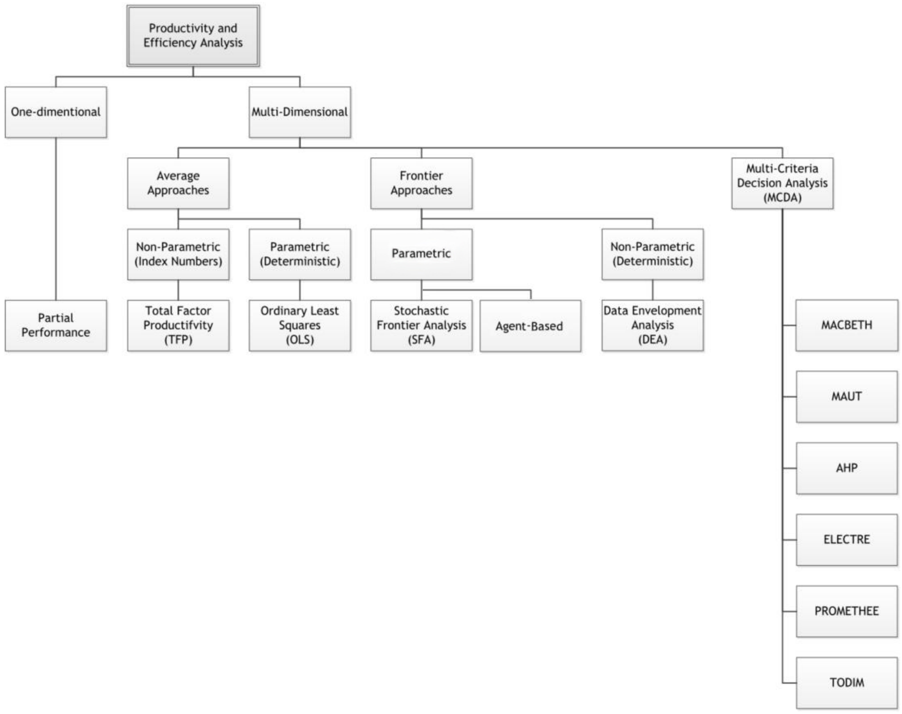

Figure 2.2: Quantitative Methodologies to Assess Productivity and Efficiency. Adapted from [29].

Data Envelopment Analysis (DEA) has been appointed as the most popular method in airport benchmarking [30]. It consists of a linear programming-based method (non-parametric) to construct an efficiency frontier based on the sample. If the organisation is on the frontier it is efficient and if it is inside the frontier then it is inefficient. DEA handles multiple outputs easily, but it can be influenced by noise assuming away measurement error and impermissibility as factors affecting the outcome. It is fair to say that DEA provides a measure of inefficiency rather than an explanation of it. Barros and Dieke [31] and Barros [32] used DEA to analyse the financial and operational performance of 31 Italian airports and to estimate Argentina's airports' relative technical efficiency, respectively. Barros and Sampaio [33] used DEA to determine the technical and allocative efficiency (a comparative measure of how well an airport adopts prices that suit its marginal productivity) of Portuguese airports.

Stochastic Frontier Analysis (SFA) is one of the main parametric approach used by researchers to evaluate efficiency or, more specifically, technical efficiency. This method can deal with random shocks and measurement errors. Environmental variables are also easier to deal with. Although the parametric approaches take these errors into account, its methods still face challenges on separating random error from efficiency. Also, most papers focusing on the parametric frontier approach estimated a production frontier function, while ignoring multi-output nature of airports [6]. For example, Diana [34] used stochastic frontier models to assess technical efficiency at 3 New York airports, and Barros [35] estimated the technical efficiency of UK airports using a random stochastic frontier model.

Airport productivity is frequently analysed using Total Factor Productivity (TFP). This method "requires an aggregation of all outputs into a weighted output index and all inputs into a weighted input index using pre-defined weights" [26, pp.4]. Cahill et al. [36] used TFP and labour productivity indicators, as well as basic financial indicators to analyse Dublin Airport Authority's economic performance. TFP has also been combined with other methodologies to evaluate airports' productivity. Tovar and Martín-Cejas [6] used a stochastic distance function to measure Spanish airports' productivity changes and calculated the evolution and decomposition of the Total Factor Productivity (TFP) for those airports, while Fung et al. [28] used the non-parametric method of DEA to compute the relative efficiency of airports in China in each year of the study period, and Malmquist productivity change indices were used to estimate variations in the overall productivity of each airport over time.

Regression analysis has been used to analyse commercial performance. Appold and Kasarda [37] used simple regressions to impact of passenger demography on the volume and nature of airport retail sales to later evaluate appropriate capital investments for terminal retail expansions. Fasone et al. [38] address the business performance of German airports using regression and partial least squares (PLS) allowing to use simultaneously variables that were dropped by past contributors because of collinearity.

Also, Multi-Criteria Decision Analysis (MCDA) has been applied in air transportation field. MCDA evaluates multiple conflicting criteria in decision-making and "consider evaluation criteria derived from a literature review or expert opinions, which might be subjective due to the vagueness of human judgements and preferences" [39, pp. 3]. Also, different weighting may be obtained by querying different experts. Analytic Hierarchy Process (AHP) is amongst the most popular techniques in this kind of analysis. AHP does not provide a measure of performance of a unit. Instead, it is used to assess the relative importance of the factors or criteria. For example, Yoo and Choi [40] utilised an AHP analysis on surveyed data about the relative importance of the factors and elements concerned with the improvement of passenger screening. Because of that, AHP is frequently combined with other techniques to analyse airport performance. Chao and Yu [41] developed a quantitative evaluation model for analysing air cargo competitiveness of airports by combining Delphi method and AHP. Others methods include MACBETH presented by Bana e Costa and Vansnick [42]. Baltazar et al. [43] used and compared the results of MACBETH and DEA in the efficiency analysis of 3 Iberian airports and found MACBETH to be more accurate than DEA and easily applicable in managerial practice involving stakeholders.

Further approaches have been used to analyse the performance of airports. Xiao et al. [44] modelled airport capacity investment using real options. Agent-based was also indicated as a promising tool to model and analyse a complex and sociotechnical system like an airport since it represents the interaction among system components [45]. However, Agent-based have been mostly used to model traffic system [46], [47].

Table 2.1: Summary of airport performance studies. Source: own elaboration.

Paper	Method	Object	Units	Inputs	Outputs
Hooper and Hensher (1997) [27]	TFP	Productivity	6 Australian airports	Capital stock, labor	Deflated revenue
Barros and Sampaio (2004) [33]	DEA	Technical and allocative efficiency	12 Portuguese airports	No. of employees, capital	No. of planes, no. of passengers, general cargo, mail cargo, sales to planes, sales to passengers
Appold and Kasarda (2006) [37]	Simple regression	Commercial performance	75 American airports	No. of passengers	Food and beverage sales, non-food sales, total domestic sales, total sales (including duty-free)
Barros and Dieke (2007) [31]	DEA	Performance	31 Italian airports	Labour costs, capital invested, operational costs	No. of planes, no. of passengers, general cargo, handling receipts, aeronautical sales, commercial sales
Barros (2008a) [48]	DEA	Technical efficiency	13 Portuguese airports	Operating costs, price of capital, price of labour	Sales to planes, sales to passengers, non-aeronautical fees
Barros (2008b) [32]	DEA	Technical efficiency	32 Argentina airports	No. of labour, no. of runways, aprons area, passenger terminal area	No. of planes, no. of passengers, cargo
Barros (2008c) [35]	SFA	Technical efficiency	27 UK airports	Operational cost, price of workers, price of capital-premises	Price of capital investment, no. of passengers, aircraft movs.
Fung et al. (2008) [28]	DEA and TFP	Productivity	25 Chinese airports	Runway length, passenger terminal area	No. of passengers, aircraft movs, tonnes of cargo

Paper	Method	Object	Units	Inputs	Outputs
Diana (2010) [34]	SFA	Technical efficiency	3 New York airports	Airport operations, taxi-out delays, block delays, airborne delays, taxi-in delays, arrival delays, departure delays, arrival and departure rates	System airport efficiency rates (SAER)
Tovar and Martín-Cejas (2010) [6]	SFA and TFP	Technical efficiency and productivity	26 Spanish airports	Labor, airport area, no. of gates	Aircraft movs., average size of aircraft, share of non-aeronautical revenue
Chao and Yu (2013) [41]	Delphi/AHP and simple additive weight	Cargo competitiveness	10 Asian-Pacific airports	No. of airlines operating at airports, no. of flights, no. of source and destination cities, airport charges, airport opening hours, cargo clearance times, cargo volumes, cargo growth, GDP	Competitiveness subtotal
Baltazar et al. (2014) [43]	MACBETH (MCDA)	Productivity		Passenger terminal area, cargo terminal area, aircraft parking stands, no. of runways, no. of boarding gates, no. of check-in desks, no. of baggage claim belts	Aircraft movs., no. of passengers, tonnes of cargo
Coto-Millan et al. (2014) [49]	DEA	Technical efficiency	35 Spanish airports	Labour cost, capital invested, other expenses	No. of passengers, aircraft movs., tonnes of cargo
Lai et al. (2015) [50]	AHP and DEA	Productivity	25 European and Asian-Pacific airports	No. of employees, no. of gates, no. of runways, terminal area, length of runway, operational expenditure	Aircraft movs., no. of passengers, amount of freight and mail

Paper	Method	Object	Units	Inputs	Outputs
Da Rocha et al. (2016) [51]	De Borda and AHP	Operational performance	12 Brazilian airports	Access, check-in, emigration, security inspection, immigration, customs, access airport facilities	Performance score
Fragoudaki and Giokas (2016) [30]	DEA	Performance	38 Greek airports	Runway length, apron size, passenger terminal area	No. of passengers, aircraft movs., tonnes of cargo
Fasone et al. (2016) [38]	Ridge regression and PLS	Commercial performance	15 German airports	Nos. of passengers, %'s of passengers, aircraft movs., no. of operating airlines, surface of commercial activities, surface of non-aviation activities, no. of retail shops, no. of restaurants and food/beverage shops	Non-aviation revenues per passenger, non-aviation revenues per square meter
Cahill et al. (2017) [36]	TFP	Performance	Dublin Airport Authority (DAA)	Non-capital inputs (labour costs, cost of other inputs)	No. of passenger, deflated revenues

2.4 Conclusion

Airports not only serve a range of increasing needs related to transportation, but also encompass several services in a single infrastructure. Moreover, an airport accommodates several stakeholders with divergent interests that put pressure on its management units.

The network of influences of an airport is very complex, and it is not yet perfectly known, and its sustainability and success end up in depending in part on factors on which airport managers only have an indirect control. Added to this is the variety of ownership forms of the airports.

These complexities result in uncertainty in the definition most relevant performance indicators. International regulatory entities have set up a framework of performance measures, addressing that issue.

Due to air traffic's exponential growth and the threat of congestion, it has been verified an increasing growth in airport performance and efficiency analysis in which several methods have been applied. From these, DEA and SFA are the most popular. However, alternative methods have shown promising results.

Chapter 3

Forecasting

3.1 Introduction

The rapid growth experienced by air transport industry over the most recent decades is expected to remain in the following years without a corresponding increase of investment in airport infrastructures, resulting in a growing pressure to manage air transport system more efficiently [52]. Additionally, civil aviation is closely associated with the economic development of regions, and because of its increasing role in economic scenarios, it is necessary to ensure that future air transport needs are adequately assessed [53].

Keeping in mind the above considerations, reliable forecasts of civil aviation and airport management activities play a critical role in the planning processes of the several organisations working in this industry. Forecasting is the process of making predictions of the future based on past and present data. It helps to make decisions regarding the development of infrastructures and evaluating air transport demand resulting in an improvement of services to passengers and reduced organisation's risks. In civil aviation field, forecasts are used to [53]:

- Assist in the planning of airspace and airport infrastructure;
- Assist airlines in the long-term planning of equipment and route structures;
- Assist aircraft manufacturers in planning future specifications

So, after we analyse airport performance and efficiency considering past data relative to its indicators, we must then be able to predict its development in the following years. To do it, forecasters use any one of a range of forecasting techniques, of varying mathematical complexity and ,each of which, presenting different advantages and disadvantages.

Following, forecasting methodologies are presented as well as other aspects to be considered when predicting the future.

3.2 Methodologies

Over past decades, several applications of forecasting field to various sectors of civil aviation planning were developed resulting nowadays in a choice of ways to perform forecasts, ranging from purely intuitive approaches to structured and complex quantitative methods, like time-series techniques or econometric modelling, for representing air travel market.

ICAO refers that the first consideration about a forecast is its time horizon, which can be short-term (1 year), medium-term (1 to 5 years) or long-term (more than 5 years), depending on the intended use.

Short-term forecasts involve some form of scheduling. Tactical or operational decisions stems from short-term traffic forecasts. For example, to determine best months to do repairs and maintenance in an airport it is necessary to predict its air passengers demand. Since it can be stated that this demand tends to follow a cyclical pattern, a short-term forecast may be enough since it is just necessary to determine peaks in each year.

Medium-term forecasts are prepared for planning, scheduling, budgeting and resource requirement purposes, and trend factor join cyclical components as a key feature.

Lastly, long-term forecasts are used mostly in strategic planning to determine the level and direction of capital expenditures with the trend element dominating in these situations. Decisions on aircraft procurement, the opening-up of new routes and markets, the training of new flight crews and other similar decisions are all results from longer-term forecasts.
Forecasting methods can be divided into three broad categories: quantitative, qualitative and decision analysis (see Figure 3.1).

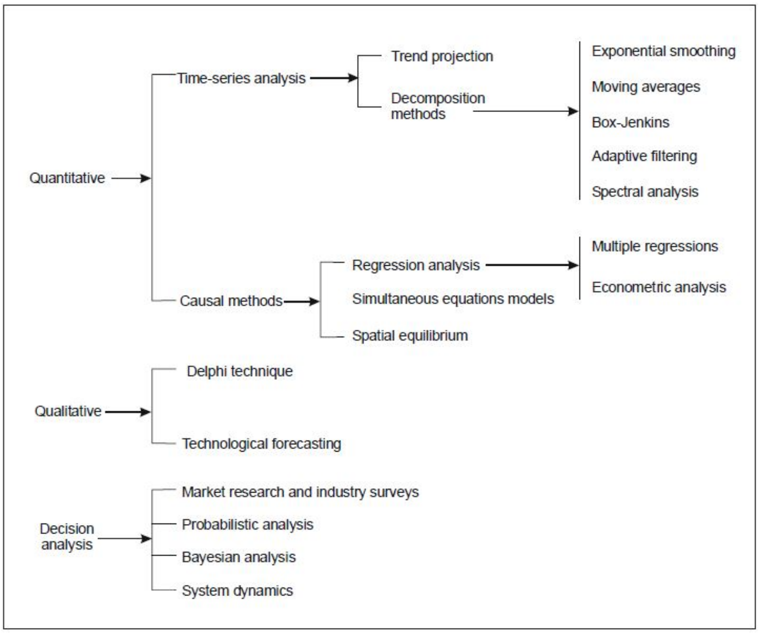

Figure 3.1: Alternative forecasting techniques. Adapted from [53].

Most common quantitative methods include time series techniques and econometric modelling.

Time-series approaches include trend projection and decomposition methods, which are the most used techniques for forecasting the traffic demand [54]. However, these methods are not able to identify causes of market growth neither can explain the impact of economic development or future regulations. Specifically, using trend projections the forecaster assumes that factors that determined the historical development and steady-state conditions will continue to be verified in the future. Due to air transportation industry's complex nature, records of trend extrapolation forecasts have not been impressive [54]. Decomposition methods, by its turn, depict the various components of the problem, being particularly relevant when strong seasonality or cyclical patterns are verified in the historical data. These methods cannot also identify economic factors among others, making it more suitable for short-term forecasts.

Econometric analysis stands for multiple regression analysis with a price-income structure. Using econometric analysis, analysts try to estimate the change in demand from year to year, which makes it more suitable for medium-term and long-term forecasts. It is a useful tool if we want to understand better the way an economic system works and for testing and evaluating alternative policies. However, it requires consistent historical data and good knowledge of the causative factors underlying traffic growth. Ahmadzade [55] identifies five steps involved in an econometric forecast:

- Selection of the relevant causal factors (independent variables);
- Collection of data;
- Specification of the type of functional relationship that exists between the dependent and the independent variables;
- Statistical estimating and testing of the proposed relationship between the dependent and independent variables. Statistical estimating and testing of the proposed relationship between the dependent and independent variables;
- Forecasting of the future development of variables from which the traffic forecast is subsequently derived.

Other quantitative methods include simultaneous equations models and spatial equilibrium.The first one addresses the issue of supply-demand interactions. An advantage of a simultaneous equations model is that it provides the values of several explanatory variables from within the model itself. However, estimation of the parameters of the equations involves more complex issues than those encountered in a single equation model [53]. Spatial equilibrium models establish a relationship for the movement of traffic between any two traffic centres or regions which is, in a simplistic analysis, proportional to a characteristic related to the size and/or development of one or both regions and inversely proportional to the distance between regions.

Quantitative methods require historical data that represents some underlying pattern. When such data are short or not available, qualitative methods are used. Also, these methods are particularly useful if one wants to assess how alternative developments would affect the forecast. However, qualitative methods are based on the judgment of experts being largely intuitive. The state of the art of these methods is not so consistent as in quantitative analysis as shown below.

Most widely used qualitative method is Delphi technique. Delphi is a method for attaining consensus among experts. Initial estimates are obtained from each expert. These estimates are arranged in a composite that shows each participant how his forecast compares to the group and a new forecast based on this information may be submitted [56]. After one or more rounds a consensus forecast may be obtained. Other qualitative methods include technological forecasting or specialists' evaluation. Also, executive judgements are widely used, usually to modify and adapt more mathematical forecasts. Such judgement is based on the insight and assessment of a person, who may have the expertise of the route or market in question.

Lastly, Decision Analysis can be considered a combination of both quantitative and qualitative methods. Expert's judgement is combined with statistical or mathematical techniques to make a forecast. It is particularly useful in the assessment of uncertainty and risk analysis. Decision Analysis is used by major corporations to make multimillion-dollar capital investments but it has seen a limited application in airport performance academic research.

To sum up, different methods have been used depending on the forecasting time horizon and data availability among other features. Table 3.1 shows how some of these methods meet these criteria.

Table 3.1: Performances of airport demand forecasting methods. (H: high, M: medium, L: low). Adapted from [57].

		Specialists' evaluation	Delphi method	Market surveys	Scenario writing	Time-trend projections	Econo-metrics	Gravity methods
Time-range of the forecast ability	**1 year**	H	H	H	H	H	H	H
	2-3 years	M	H	M	H	H-M	H	H
	5 years	L	M	M	M	M-L	H	H
	10 years	L	L	L	M	L	M	M
Required expertise		H	M	H	M	M-L	H	H
Required time		L	H	L	M	L	H	H
Data availability and accuracy		M	M	M	M	H-M	H	H
Cost		M	H	M	L	L	H	H

Forecasting researchers have been mainly focused on air traffic growth instead of airport performance. Three main methods have been used: decomposition, econometric methods and industry surveys (see Table 3.2).

Econometric analysis has been by far the most popular technique on air passenger demand forecasting. For example, Abed et al. [54] and Priyadarshana and Fernando [65] used econometric methods to predict airport passenger demand. Econometrics models' accuracy was examined by Song et al. [61] by using six econometric models and two univariate time series models for benchmark comparison purposes to predict Denmark tourism demand. They obtained more accurate short-term forecast from a TVP model while the static model generated more accurate forecasts for medium-term forecasts. Maximum-likelihood approach and ARIMA models generated the least accurate forecasts.

Table 3.2: Summary of forecasting studies on airports. Source: own elaboration.

Paper	Methodology	Time horizon	Object
Liu (1988) [58]	Delphi	Long-term	Tourism demand
Profillidis (2000) [59]	Trend projection and Econometric analysis	Long-term	Airport passengers
Grubb and Mason (2001) [60]	Holt-Winters (Decomposition method)	Long-term	Airport passengers
Abed et al. (2001) [54]	Econometric analysis	Medium-term	Airport passengers
Song et al. (2003) [61]	Econometric and Time-series models	Short-term and Medium-term	Tourism demand
Abdelghany and Guzhva (2010) [62]	Decomposition methods	Short-term	Airport passengers
Linz (2015) [63]	Delphi	Long-term	Aviation scenarios
Tsui et al. (2014) [64]	Decomposition methods	Medium-term	Airport passengers
Priyadarshana and Fernando (2015) [65]	Econometric analysis	Medium-term	Airport passengers
Lordan et al. (2016) [52]	Trend projection	Short-term	Taxi times
Dantas,et al. (2017) [66]	Bagging and Holt-Winters	Short-term	Airport passengers

Profillidis [59] used a conventional regression method (trend projection) to forecast future demand of the airport of Rhodes by extrapolating past passenger growth trends using a polynomial trend as well as an econometric model and a fuzzy regression method for comparison. Lordan et al. [52] used log-linear regression analysis to estimate taxi times which proved to have a strong predictive validity.

Decomposition methods have also seen several applications in air passengers demand forecasts. Abdelghany and Guzhva [62] used an autoregressive moving average model (ARMA) for forecasting short-term airport demand and emphasise that “while the model is more appropriate for short-term prediction (0–2 years), its use can be extended for longer-term forecasting (2–5 years)” [62, pp.86] Tsui et al. [64] employed the Box-Jenkins Seasonal ARIMA (SARIMA) model and the ARIMAX model to forecast airport passenger traffic for Hong Kong and projecting its future growth trend to 2015. Another particularly popular decomposition method is Holt-Winters method which consists of an exponential smoothing technique that depicts three components: level, trend and seasonal. Grubb and Mason [60] introduced a modification to the Holt–Winters method that greatly improves forecasting performance for long lead-times, by damping the future trend towards the historical average trend. Dantas et al. [66], by their turn, introduced a combination of the Bootstrap aggregating (Bagging) method with the exponential smoothing Holt-Winters method to the air industry to predict future demand for air transportation.

Delphi method has been used for many years, and it has been mainly applied in long-term forecasts. Liu [58] used this technique to forecast tourism to Hawaii, particularly Oahu, by the year 2000, questioning local experts and travel agents. More recently, Linz [63] attempted to anticipate probable and wildcard scenarios on the future of aviation in 2025 using a Delphi panel of aviation experts.

3.3 Conclusion

Forecasts play a fundamental role in the planning activities, not only in airports but several organisations working in the aviation industry.

Several forecasting methods have emerged over the past years. These can be classified into quantitative, qualitative and decision analysis.

The most accurate forecasting technique may differ from study to study depending on several criteria, such as the intended time horizon, data nature and availability, forecaster expertise, etc.

The literature review presented in this chapter shows that econometric analysis and decomposition methods are among the most popular. The first one becomes notorious when longer-term forecasts are needed or when the forecaster intends to infer a cause-and-effect relationship. The second one has been mainly used in short-term and medium term-forecasts and when time series present cyclical or seasonal patterns. Also, trend-projections have been used for shorter-term forecasts. Among qualitative methods, Delphi is the most popular, and it has been mostly employed in long-term forecasts.

Chapter 4

Case Study

4.1 Introduction

This chapter depicts the attempts to predict and model the impact that changes that may occur in core indicators have on airport performance.

In this study, airport performance is measured through the score obtained from PESA-AGB model [67] (see Figure 4.1) built to assess airports performance and efficiency through a self and peer benchmark for three main international airports managed by the same group - Airport 1, Airport 2 and Airport 3 being, respectively representative of Humberto Delgado Airport, Francisco Sá Carneiro Airport and Faro Airport operated by the airport group VINCI/ANA S.A.

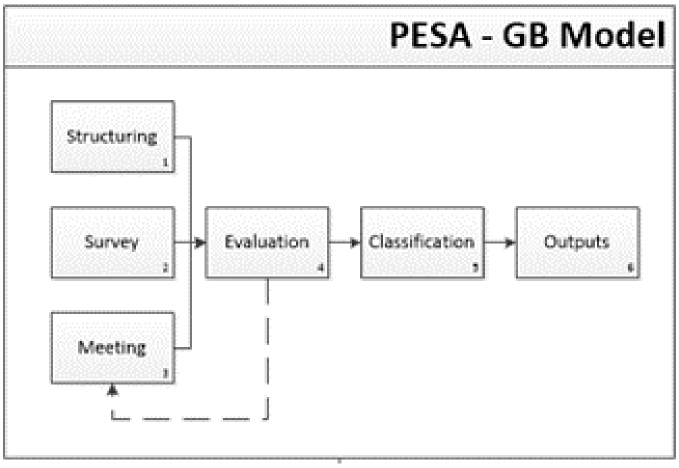

Figure 4.1: PESA-GB model building tasks. Source: [67].

This model is based on MACBETH methodology. Its decision tree, from which performance descriptors stem, was built upon the KPAs and KPIs mentioned above and it uses expert's judgement to obtain an ordinal value scale. The descriptors and the ordinal value scales are used to derive the value functions and weight ponderations which, by their turn, are used to get the score. An overview of the PESA-AGB model is shown in Annexe A.2.

This model is fed by a database gathering data for the three airports for all KPIs of each KPA retrieved from airports annual public sustainability reports for the years 2003 to 2013 [68, 69, 70] [1]. It contains partial data collected from the public reports for the mentioned airports. Missing data were inferred from world airports similar in category and scale (passengers and movements). Database can be consulted in Annexe A.3.

Three case studies were developed consisting of the analysis of passengers' growth, aircraft

[1] The reports were not published every single years. Data referring to missing years were determined by Statistical inference.

movements' growth and simultaneous passenger and aircraft movements' growth on the airport score as described in Figure 4.2. The choice of these indicators is explained by their weight in the Core area (see Figure 4.3).

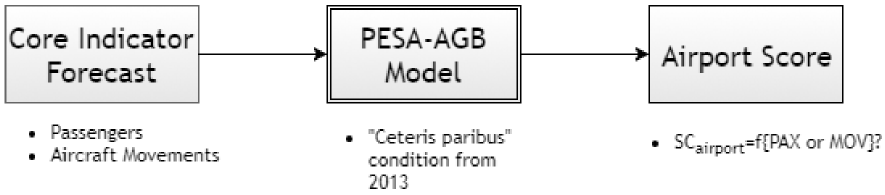

Figure 4.2: Case studies process. Source: own elaboration.

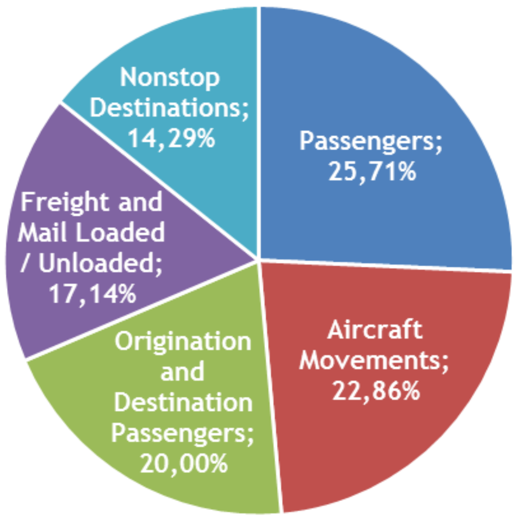

Figure 4.3: Core Key Performance Indicators' weights. Adapted from [67].

These case studies intended to answer the following questions:

"What is the impact of passengers/movements growth in airport score keeping the ceteris paribus? Is there a direct, quantifiable relationship?"

Firstly, medium-term forecasts (3 years) were performed on the considered indicators for the Airport 1. All the other indicators were held constant, assuming what in economics is named *ceteris paribus* condition. A *ceteris paribus* assumption is often key to scientific inquiry, as scientists seek to screen out factors that perturb a relation of interest [2]. This new scenario is inserted on PESA-AGB to observe the changes in the KPA's score and airport score. The relationship between the number of passengers or aircraft movements and the airport score is analysed to figure out if it can be quantified through a cost function as follows:

$$y_t = b_0 + b_1 \times x_t + ... + e \quad (4.1)$$

where:

- *y* is the dependent variable (airport score in the case of this study);
- *b* is a constant;
- *X* is the independent variable (passengers or aircraft movements);
- *e* is the error;
- *t* is the year;

4.2 Case I - Passengers

4.2.1 Hypothesis 1

For passengers' growth impact analysis, it was first considered to vary the numerical values only for the passengers' indicator, keeping all other indicators unchanged, and observe the corresponding changes in the airport score as shown in Figure 4.4.

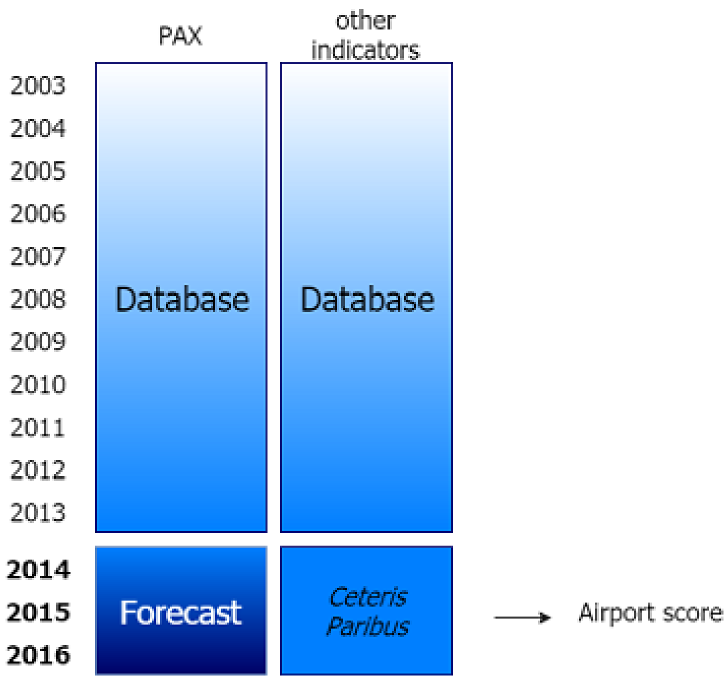

Figure 4.4: Process used to conduct Hypothesis I. Source: own elaboration.

The forecast process adopted in this hypothesis consists merely in the projection of the number of passengers for the following three years maintaining the same average growth rate verified during the historical data time span. The values obtained are presented in Figure 4.5.

The behaviour of the curve changes slightly from 2013 once it was applied the constant increase corresponding to the average growth observed in the previous years. The number of passengers obtained from the trend projection was assumed as achievable since the capacity of Lisbon airport projected for 2013 was about 18 million passengers [2]. The Value Function of the PESA-AGB model allows comparing the scores obtained from the projected number of passengers with the scores recorded for the observed time span (see Figure 4.6).

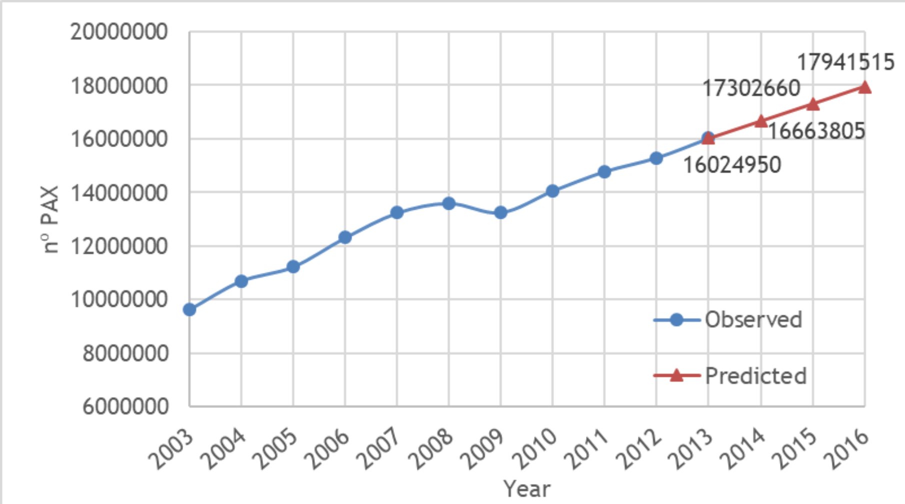

Figure 4.5: Projection of the number of passengers in Airport 1 for the years 2014-2016. Source: own elaboration.

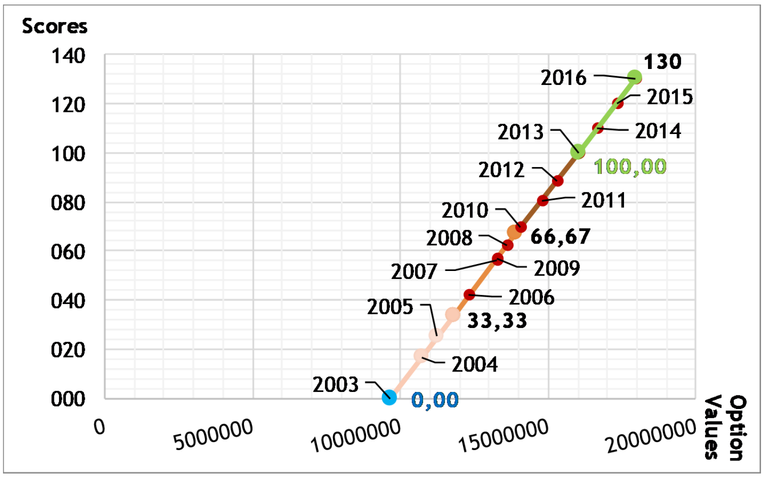

Figure 4.6: Value function for Passengers KPI of the Airport 1 Core KPA. Source: own elaboration.

Originally, Value Function consists in the characterisation of the criteria values in a set of 3 linear equations, working like thermometers. For this analysis, a fourth set was created to keep the previous score scale and to identify better the years in which the best score registered was exceeded. The scores obtained for the forecasting period overtook the previous best result recorded in 2016 as expected, since the growth rate for the years 2003-2013 is positive (see 4.1).

The increase of Passengers KPI's score led the corresponding KPA's score to annual increases of 2,86%, 2,79% and 2,71% in the 3 years forecasted, resulting in an increase of 5,42% from 2013 to 2016 (see Table 4.2).

Table 4.1: Historical and predicted no. of passengers and KPA'S score (hypothesis I). Source: own elaboration.

Year	Value	Score
2003	9.636.400	0,00
2004	10.705.000	16,73
2005	11.234.700	25,02
2006	12.314.314	41,92
2007	13.239.756	56,40
2008	13.603.620	62,10
2009	13.261.203	56,74
2010	14.066.534	69,35
2011	14.788.480	80,65
2012	15.301.176	88,67
2013	16.024.950	100,00
2014	16.663.805	110,00
2015	17.302.660	120,00
2016	17.941.515	130,00

Table 4.2: Core KPIs' scores and KPA's score. Source: own elaboration.

Year	Passengers	Aircraft Movements	Origin and Destination Passengers	Freight and Mail Loaded/ Unloaded	Destinations - Nonstop	KPA Score
2003	0,00	0,00	0,00	31,29	0,00	5,36
2004	16,73	28,65	15,49	55,88	9,02	24,82
2005	25,02	34,26	23,24	56,04	20,30	31,42
2006	41,92	58,94	40,38	52,92	31,58	45,91
2007	56,40	72,68	55,10	24,15	45,11	52,72
2008	62,10	81,26	61,94	64,51	42,86	64,11
2009	56,74	58,71	57,47	30,32	49,62	51,79
2010	69,34	75,74	69,78	100,00	66,17	75,70
2011	80,65	79,73	81,00	23,25	86,47	71,50
2012	88,67	83,90	89,01	0,00	100,00	74,07
2013	100,00	100,00	100,00	39,36	83,08	87,19
2014	110,00	100,00	100,00	39,36	83,08	89,76
2015	120,00	100,00	100,00	39,36	83,08	92,33
2016	130,00	100,00	100,00	39,36	83,08	94,90
Weights	25,71%	22,86%	20,00%	17,14%	14,29%	100%

The increases observed for airports performance score are mild with annual increases of 0,83% for the first forecasted year and 0,82% for each of the other two years (see Table 4.3). The percentage increase between 2013 and 2016 was 1,63% which is lower than, for example, the percentage increase recorded between 2012 and 2013.

As could be expected, the airport score variation according to the number of passengers is described by a linear function as shown in Figure 4.7. The function equation was obtained through a trend line whose R squared is 1, which means that describes the totality of the original function.

Table 4.3: KPAs' scores and Airport 1 performance score. Source: own elaboration.

Year	Safety and Security	Core	Productivity/ Cost effectiveness	Service Quality	Financial/ Commercial	Enviromental	Airport Score
2003	69,37	5,36	25,59	24,64	68,27	5,81	34,95
2004	44,14	24,82	28,71	25,83	49,34	12,15	31,92
2005	58,67	31,42	29,38	31,09	53,32	38,56	41,08
2006	75,22	45,91	44,41	37,23	45,58	40,03	50,05
2007	87,06	52,72	82,13	50,50	46,43	40,65	62,56
2008	81,75	64,11	85,97	44,32	40,15	37,92	62,12
2009	58,15	51,79	68,92	41,72	52,19	53,95	54,96
2010	50,99	75,70	70,67	59,34	42,98	45,50	58,55
2011	72,51	71,50	72,60	62,66	55,71	57,48	66,60
2012	56,95	74,07	40,90	58,06	42,36	69,55	57,11
2013	73,47	87,19	36,61	65,64	15,81	70,29	59,88
2014	73,47	89,76	36,61	65,64	15,81	70,29	60,38
2015	73,47	92,33	36,61	65,64	15,81	70,29	60,89
2016	73,47	94,90	36,61	65,64	15,81	70,29	61,39
Weights	21,95%	19,51%	17,07%	14,63%	14,63%	12,20%	100%

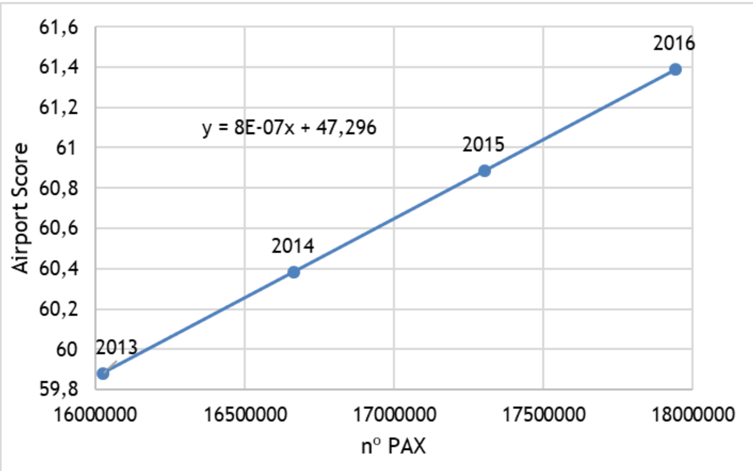

Figure 4.7: Airport Score as a function of the number of passengers (Hypothesis I). Source: own elaboration.

4.2.2 Hypothesis 2

Identifying which indicators could be affected directly or indirectly by the passengers' growth may be an arduous task, and it may require a deeper econometric analysis to establish the relationships between different KPIs from different KPAs. However, it is possible to observe that some indicators are directly influenced by passengers' indicator being easy to determine the increase of the correspondent value without interfering with *ceteris paribus* condition. Observing the indicators' metrics, we can see, for example, that the value of passengers per employee rate is given by dividing the number of passengers by the number of employees of the airport. Metrics of some other indicators include the number of passengers in the denominator. Those indicators were kept unchanged since the increase of the number of passengers would result in its decrease. Such assumption would imply a drop of the airport performance. Considering this, for this second hypothesis it was decided to work only on the Passengers Per Employee KPI in addition to Passengers indicator (see figure 4.8). For this, it was determined the number of employees in 2013. This figure was kept constant to calculate this ratio for the following years, and only the number of passengers varied according to the forecast. Since in 2013 the number of passengers recorded was below the capacity projected for the Airport 1, this assumption can be considered feasible.

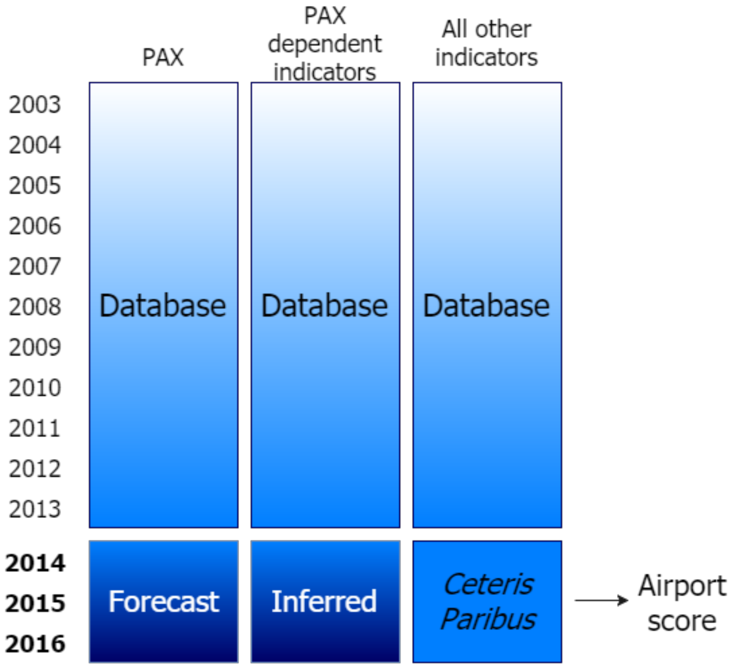

Figure 4.8: Process used to conduct Hypothesis II. Source: own elaboration.

The forecasting process was the same as in the first hypothesis (see subsection 4.2.1). Consequently, the number of passengers and the scores of the correspondent KPI are the same presented in Table 4.1.

The number of employees in 2013 was obtained dividing the number of passengers reported that year by the passengers per employee ratio related to the same year. The number of employees at Airport 1 in 2013 was 674. Passengers per employee ratio values calculated for the years of 2014-2016, as well as correspondent scores, are listed in Table 4.4.

Table 4.4: Historical and predicted no. of passengers per employee and KPA's scores for the hypothesis II. Source: own elaboration.

Year	Value	Score
2003	14.757	0,00
2004	16.394	18,15
2005	17.205	27,14
2006	18.858	45,47
2007	20.275	61,19
2008	20.832	67,36
2009	19.473	52,29
2010	20.870	67,78
2011	22.543	86,33
2012	22.702	88,09
2013	23.776	100,00
2014	24.724	110,51
2015	25.672	121,02
2016	26.619	131,53

The value function of this KPI is shown in Figure 4.9.

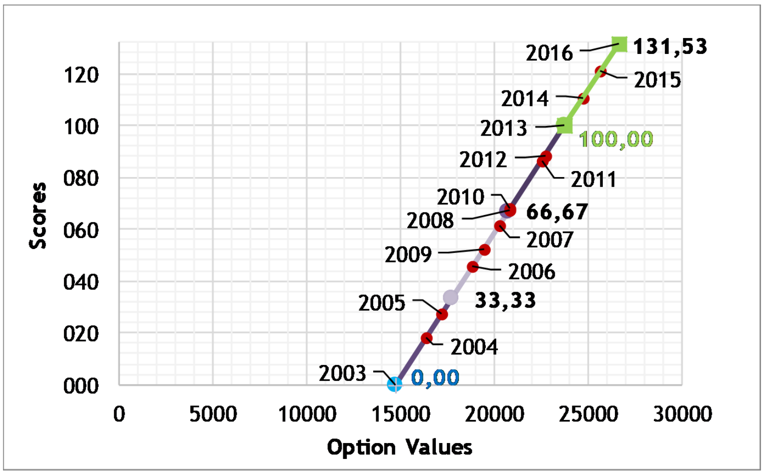

Figure 4.9: Value function for Passengers Per Employee KPI of the Airport 1 Core KPA. Source: own elaboration.

As in the case of the number of passengers, Passenger Per Employee KPI overtake its previous best score during the forecasting period with the years 2014, 2015 and 2016 being distributed in the fourth set line (marked in green).

The scores obtained for Core KPA were, as expected, the same as in Hypothesis I since only the Passengers indicator varied and the forecasting method was the same. However, Productivity/Cost-Effectiveness KPA registered changes in its score with the variation of no. of passengers/employee ratio values as shown in Table 4.5. The KPA score registered percentage increases of 2,46%, 2,40% and 2,35%. Comparatively, this score in 2016 is 4,69% greater than in 2013.

These increases have expectably a greater impact on airport score than in the previous hypothesis. In Table 4.6, we can observe the airport score increases in the three forecasted years: 1,09%, 1,08% and 1,07%. Airport score registered a percentage growth of 2,13% since 2013, looking at the forecasting period as a whole.

Table 4.5: Productivity/Cost Effectiveness KPIs' scores and KPA's score. Source: own elaboration

Year	Total Cost per Passenger	Total Cost per Movement	Operating Cost per Movement	Aircraft Movements per Gate	Total Cost per WLU	Operating Cost per WLU	Operating Cost per Passenger	Passengers Per Employee	Aircraft Movements per Employee	KPA Score
2003	0,00	39,81	30,16	84,21	10,34	37,93	21,57	0,00	0,00	25,59
2004	27,43	60,34	7,25	100,00	0,00	3,63	0,69	18,14	33,11	28,71
2005	41,30	63,04	0,38	78,85	5,36	0,00	0,00	27,14	39,59	29,38
2006	61,64	87,84	0,00	90,82	25,59	6,37	5,50	45,47	68,11	44,41
2007	84,49	100,00	98,79	97,49	33,70	76,56	94,42	61,19	83,99	82,12
2008	83,98	96,55	97,26	36,58	100,00	100,00	94,12	67,36	93,91	85,97
2009	70,62	64,51	100,00	29,19	57,34	90,19	100,00	52,29	49,27	68,92
2010	87,43	79,40	88,97	0,00	55,15	83,61	94,45	67,78	72,84	70,67
2011	100,00	77,81	75,40	0,97	52,65	78,08	90,68	86,33	89,96	72,60
2012	57,09	0,00	28,25	1,98	18,80	52,91	63,47	88,09	81,98	40,90
2013	61,51	5,13	3,36	5,88	12,23	27,47	41,96	100,00	100,00	36,61
2014	61,51	5,13	3,36	5,88	12,26	27,47	41,96	110,51	100,00	37,54
2015	61,51	5,13	3,36	5,88	12,23	27,47	41,96	121,02	100,00	34,48
2016	61,51	5,13	3,36	5,88	12,23	27,47	41,96	131,53	100,00	39,38
Weights	14,29 %	13,19%	12,09%	10,99%	10,99%	10.99%	9,89%	8,79%	8.79%	100%

Table 4.6: KPAs' scores and Airport 1 performance score (hypothesis 2). Source: own elaboration.

Year	Safety and Security	Core	Productivity/ Cost effectiveness	Service Quality	Financial/ Commercial	Enviromental	Airport Score
2003	69,37	5,36	25,59	24,64	68,27	5,81	34,95
2004	44,14	24,82	28,71	25,83	49,34	12,15	31,92
2005	58,67	31,42	29,38	31,09	53,32	38,56	41,08
2006	75,22	45,91	44,41	37,23	45,58	40,03	50,05
2007	87,06	52,72	82,13	50,50	46,43	40,65	62,56
2008	81,75	64,11	85,97	44,32	40,15	37,92	62,12
2009	58,15	51,79	68,92	41,72	52,19	53,95	54,96
2010	50,99	75,70	70,67	59,34	42,98	45,50	58,55
2011	72,51	71,50	72,60	62,66	55,71	57,48	66,60
2012	56,95	74,07	40,90	58,06	42,36	69,55	57,11
2013	73,47	87,19	36,61	65,64	15,81	70,29	59,88
2014	73,47	89,76	37,54	65,64	15,81	70,29	60,38
2015	73,47	92,33	38,46	65,64	15,81	70,29	60,89
2016	73,47	94,90	36,61	65,64	15,81	70,29	61,39
Weights	21,95%	19,51%	17,07%	14,63%	14,63%	12,20%	100%

The growth of the airport score as a function of the number of passengers is shown in Figure 4.10. Although it is being considered the impact of passengers' growth on other KPIs, the relationship with Airport Score remains linear. The greater impact of passengers' growth under the conditions assumed in this hypothesis is confirmed by the slope of the line which is higher than the one obtained in the first hypothesis (see subsection 4.2.1).

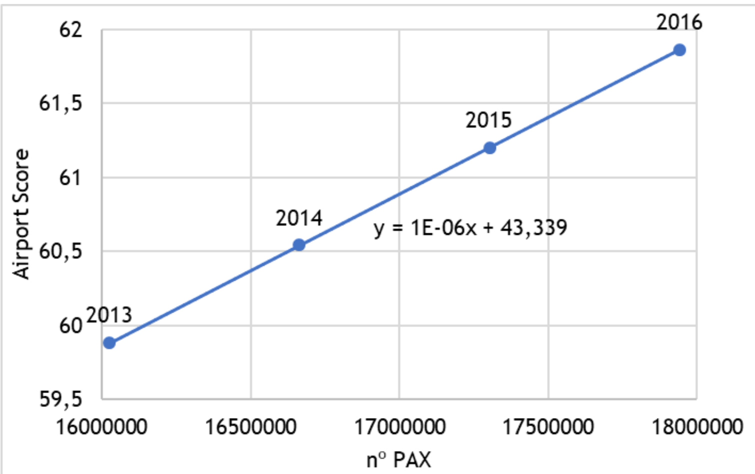

Figure 4.10: Airport Score as a function of the number of passengers (Hypothesis II). Source: own elaboration.

4.2.3 Hypothesis 3

The previous two hypotheses meant to be simply experimental, helping to define how passengers' growth could be analysed. In Hypothesis III, passengers' growth impact is assessed as in Hypothesis II, but introducing a different forecasting method which consists in calculating or predicting a future value based on existing (historical) values by using Exponential Triple Smoothing (ETS) algorithm. This methodology was put into effect by using *Microsoft Excel 2016*.

This method is one of the decomposition methods mentioned in the quantitative methods review presented in section 3.2. It “is used to predict future sales, inventory requirements, or consuming trends” [71] and requires the timeline to be organised with a constant step as is the case of this study. By using Exponential Smoothing, “recent observations are given relatively more weight in forecasting than the older observations” [72]. Exponential Triple Smoothing is helpful when trend and seasonality may be observed in data. Its name is due so, to the application of exponential smoothing to seasonal in addition to level and trend. The resulting set of equations is also called “Holt-Winters” method and are given by [72]:

$$S_t = \alpha \frac{y_t}{I_{t-L}} + (1-\alpha)(S_t - 1 + b_{t-1}), \qquad Overall\,Smoothing \quad (4.2)$$

$$b_t = \gamma(S_t - St - 1) + (1-\gamma)b_{t-1}, \qquad Trend\,Smoothing \quad (4.3)$$

$$I_t = \beta \frac{y_t}{S_t}(1-\beta)I_{t-L}, \qquad Seasonal\,Smoothing \quad (4.4)$$

where:

- *y* is the observation;
- *S* is the smoothed observation;
- *b* is the trend factor;
- *I* is the seasonal index;
- *L* corresponds to the periods;
- *t* is an index denoting the time period;
- *α*,*β* and *γ* are constants that must be estimated in such a way that the MSE of the error is minimized.

The forecast is then given by:

$$F_{t+m} = (S_t + mb_t)I_{t-L+m} \quad (4.5)$$

The forecasting parameters that had to be defined are shown in Annexe A.4, in which the inferface presented by the software is illustrated.

The confidence level was set to 95%. Besides this value being commonly used [73], this choice is also owing to the sample size. Larger samples result in smaller errors which means more closely clustered sampling distributions; this indicates that our intervals will be narrower and more precise. Since the data of each KPI only contain 10 entries, the present sample is not large, meaning that a high confidence level must be set. The forecast and the confidence interval bounds allow to create three possible scenarios as shown in Figure 4.11. The analysis of how passengers’ growth affects airport score is done for the three scenarios that are referred above to perceive the impact of opting for a more optimistic forecast instead of a more pessimistic one. They are: expected, worst-case and best-case, which corresponds to the forecast, lower confidence bound and upper confidence bound, respectively.

Statistic details of the forecast are presented in Annexe A.5.

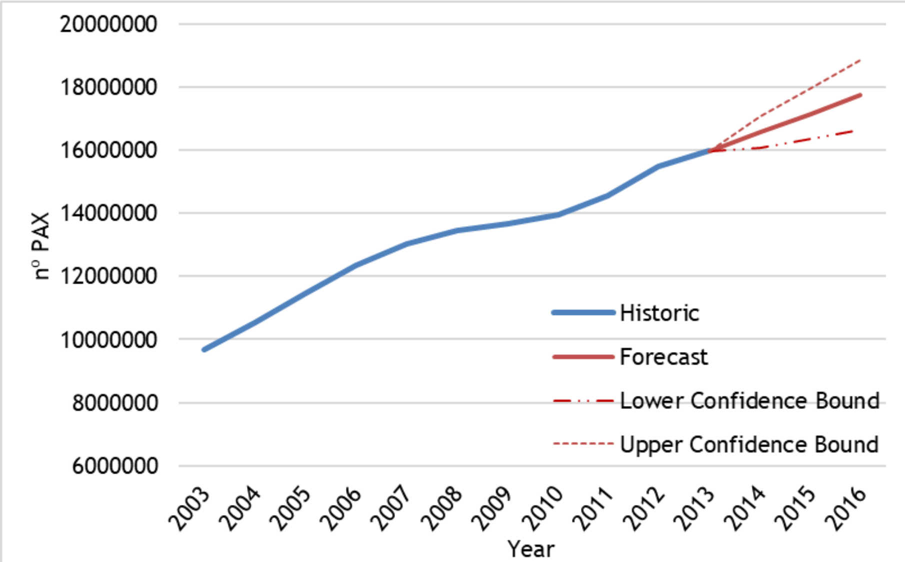

Figure 4.11: Passengers ETS forecast for Airport 1. Source: own elaboration.

The three growth scenarios show no rupture with the recorded tendency since the number of passengers is growing. Once the number of passengers predicted in the three cases is always greater than the previous record, none of the scenarios represents a threat to the airport sustainability (see Table 4.7). However, it can be observed in the best-case scenario that the number of passengers processed by Airport 1 is above the maximum capacity projected in 2013. Although this issue can be overcome by increasing the efficiency of certain sectors of the airport, it should be stressed out that an airport operating close to its limit can cause operational constraints as discussed in section 2.3.

Table 4.7: Values predicted by passengers' ETS forecast for Airport 1. Source: own elaboration.

Year	Historical data	Expected scenario	Worst-case scenario	Best-case scenario
2003	9.673.919			
2004	10.538.583			
2005	11.450.979			
2006	12.348.332			
2007	13.045.980			
2008	13.454.735			
2009	13.673.849			
2010	13.959.558			
2011	14.569.229			
2012	15.481.089			
2013	15.989.553			
2014		16.578.481	16.067.830	17.089.133
2015		17.167.198	16.350.953	17.983.444
2016		17.755.915	16.637.947	18.873.883

Respective Passengers KPI's scores for the three growing scenarios are aggregated in Table 4.8.

Table 4.8: Passengers KPI's scores for three growth scenarios (hypothesis 3). Source: own elaboration.

Year	Historical scores	Expected scenario	Worst-case scenario	Best-case scenario
2003	0,00			
2004	16,73			
2005	25,02			
2006	41,92			
2007	56,40			
2008	62,10			
2009	56,74			
2010	69,35			
2011	80,65			
2012	88,67			
2013	100,00			
2014		108,66	100,67	116,66
2015		117,88	105,10	130,66
2016		127,09	109,60	144,59

By starting with the expected scenario the score grows every year as in the previous hypotheses. However, the scores achieved in each of the three years are slightly lower; this means that this forecasting method is predicting increases below the annual average recorded between 2003 and 2013. Passengers' growth in the best-case scenario is equally almost constant but sharper than in the expected scenario. Lastly, the worst-case scenario presents the smoother growth, with Airport 1 not reaching the mark of 17 million passengers in a year.

Resulting values and scores for Passengers per Employee KPI obtained for all three scenarios are shown in Table 4.9.

Table 4.9: Passengers per Employee KPI's values and score (hypothesis 3). Source: own elaboration.

Year	History		Expected scenario		Worst-case scenario		Best-case scenario	
	Value	Score	Value	Score	Value	Score	Value	Score
2003	14.757	0,00						
2004	16.394	18,14						
2005	17.205	27,14						
2006	18.858	45,47						
2007	20.275	61,19						
2008	20.832	67,36						
2009	19.473	52,29						
2010	20.870	67,78						
2011	22.543	86,33						
2012	22.702	88,09						
2013	23.776	100,00						
2014			24.597	109,11	23.840	100,71	25.355	117,51
2015			25.471	118,79	24.260	105,36	26.682	132,22
2016			26.344	128,48	24.685	110,08	28.003	146,87

The resulting scores obtained in the expected scenario for Core and Productivity/Cost-effectiveness KPAs are shown in Tables 4.10 and 4.11, respectively.

Table 4.10: Core KPIs' scores and KPA's score obtained for the expected scenario. Source: own elaboration.

Year	Passengers	Aircraft Movements	Origin and Destination Passengers	Freight and Mail Loaded/ Unloaded	Destinations - Nonstop	KPA Score
2003	0,00	0,00	0,00	31,29	0,00	5,36
2004	16,73	28,65	15,49	55,88	9,02	24,82
2005	25,02	34,26	23,24	56,04	20,30	31,42
2006	41,92	58,94	40,38	52,92	31,58	45,91
2007	56,40	72,68	55,10	24,15	45,11	52,72
2008	62,10	81,26	61,94	64,51	42,86	64,11
2009	56,74	58,71	57,47	30,32	49,62	51,79
2010	69,34	75,74	69,78	100,00	66,17	75,70
2011	80,65	79,73	81,00	23,25	86,47	71,50
2012	88,67	83,90	89,01	0,00	100,00	74,07
2013	100,00	100,00	100,00	39,36	83,08	87,19
2014	108,66	100,00	100,00	39,36	83,08	89,42
2015	117,88	100,00	100,00	39,36	83,08	91,78
2016	127,09	100,00	100,00	39,36	83,08	94,15
Weights	25,71%	22,86%	20,00%	17,14%	14,29%	100%

Core KPA score increases around 2,5% each year due to passengers increase in the expected scenario. At the end of the forecast period, the score is 5% greater than in 2013. Productivity/Cost-Effectiveness KPA gains were close to Core KPA, with annual percentage increases close to 2,2% and a global increase of 4,35% of the end of the forecast period.

In this scenario, Airport 1 performance score grows by 1% yearly. The global increase since 2013 is just about 1,97% (see Table 4.12).

Moving on to the best-case scenario, the sharp increases in each indicator have a quite significant impact in the respective KPA (see Tables 4.13 and 4.14).

The increase of passengers in Airport 1 causes a percentage growth greater than 3% every year, being even greater than 4% in 2014. The score was 7,28% higher when comparing 2016 with the beginning of the forecast period. These significant increases are also verified in Productivity/Cost Effectiveness KPA, whose scores also increase more than 3% each year.

Table 4.11: Productivity/Cost-Effectiveness Key Performance Indicators scores and Key Performance Area score for the expected scenario. Source: own elaboration.

Year	Total Cost per Passenger	Total Cost per Movement	Operating Cost per Movement	Aircraft Movements per Gate	Total Cost per WLU	Operating Cost per WLU	Operating Cost per Passenger	Passengers Per Employee	Aircraft Movements per Employee	KPA Score
2003	0,00	39,81	30,16	84,21	10,34	37,93	21,57	0,00	0,00	25,59
2004	27,43	60,34	7,25	100,00	0,00	3,63	0,69	18,14	33,11	28,71
2005	41,30	63,04	0,38	78,85	5,36	0,00	0,00	27,14	39,59	29,38
2006	61,64	87,84	0,00	90,82	25,59	6,37	5,50	45,47	68,11	44,41
2007	84,49	100,00	98,79	97,49	33,70	76,56	94,42	61,19	83,99	82,12
2008	83,98	96,55	97,26	36,58	100,00	100,00	94,12	67,36	93,91	85,97
2009	70,62	64,51	100,00	29,19	57,34	90,19	100,00	52,29	49,27	68,92
2010	87,43	79,40	88,97	0,00	55,15	83,61	94,45	67,78	72,84	70,67
2011	100,00	77,81	75,40	0,97	52,65	78,08	90,68	86,33	89,96	72,60
2012	57,09	0,00	28,25	1,98	18,80	52,91	63,47	88,09	81,98	40,90
2013	61,51	5,13	3,36	5,88	12,23	27,47	41,96	100,00	100,00	36,61
2014	61,51	5,13	3,36	5,88	12,26	27,47	41,96	109,11	100,00	37,41
2015	61,51	5,13	3,36	5,88	12,23	27,47	41,96	118,79	100,00	38,26
2016	61,51	5,13	3,36	5,88	12,23	27,47	41,96	128,48	100,00	39,11
Weights	14,29 %	13,19%	12,09%	10,99%	10,99%	10.99%	9,89%	8,79%	8.79%	100%

Table 4.12: KPAs' scores and Airport 1 performance score for the expected scenario. Source: own elaboration.

Year	Safety and Security	Core	Productivity/ Cost effectiveness	Service Quality	Financial/ Commercial	Environmental	Airport Score
2003	69,37	5,36	25,59	24,64	68,27	5,81	34,95
2004	44,14	24,82	28,71	25,83	49,34	12,15	31,92
2005	58,67	31,42	29,38	31,09	53,32	38,56	41,08
2006	75,22	45,91	44,41	37,23	45,58	40,03	50,05
2007	87,06	52,72	82,13	50,50	46,43	40,65	62,56
2008	81,75	64,11	85,97	44,32	40,15	37,92	62,12
2009	58,15	51,79	68,92	41,72	52,19	53,95	54,96
2010	50,99	75,70	70,67	59,34	42,98	45,50	58,55
2011	72,51	71,50	72,60	62,66	55,71	57,48	66,60
2012	56,95	74,07	40,90	58,06	42,36	69,55	57,11
2013	73,47	87,19	36,61	65,64	15,81	70,29	59,88
2014	73,47	89,42	37,41	65,64	15,81	70,29	60,45
2015	73,47	91,78	38,26	65,64	15,81	70,29	61,06
2016	73,47	94,15	39,11	65,64	15,81	70,29	61,67
Weights	21,95%	19,51%	17,07%	14,63%	14,63%	12,20%	100%

Table 4.13: Core KPIs' scores and KPA's score obtained for the best-case scenario. Source: own elaboration.

Year	Passengers	Aircraft Movements	Origin and Destination Passengers	Freight and Mail Loaded/ Unloaded	Destinations - Nonstop	KPA score
2003	0,00	0,00	0,00	31,29	0,00	5,36
2004	16,73	28,65	15,49	55,88	9,02	24,82
2005	25,02	34,26	23,24	56,04	20,30	31,42
2006	41,92	58,94	40,38	52,92	31,58	45,91
2007	56,40	72,68	55,10	24,15	45,11	52,72
2008	62,10	81,26	61,94	64,51	42,86	64,11
2009	56,74	58,71	57,47	30,32	49,62	51,79
2010	69,34	75,74	69,78	100,00	66,17	75,70
2011	80,65	79,73	81,00	23,25	86,47	71,50
2012	88,67	83,90	89,01	0,00	100,00	74,07
2013	100,00	100,00	100,00	39,36	83,08	87,19
2014	108,66	100,00	100,00	39,36	83,08	89,42
2015	117,88	100,00	100,00	39,36	83,08	91,78
2016	127,99	100,00	100,00	39,36	83,08	94,90
Weights	25,71%	22,86%	20,00%	17,14%	14,29%	100%

Airport 1 performance score increases almost 3% since 2013, yet, that is not enough to break its previous record set in 2011 (see table 15)

Table 4.14: Productivity/Cost-Effectiveness KPIs' scores and KPA's score for the best-case scenario. Source: own elaboration.

Year	Total Cost per Passenger	Total Cost per Movement	Operating Cost per Movement	Aircraft Movements per Gate	Total Cost per WLU	Operating Cost per WLU	Operating Cost per Passenger	Passengers Per Employee	Aircraft Movements per Employee	KPA Score
2003	0,00	39,81	30,16	84,21	10,34	37,93	21,57	0,00	0,00	25,59
2004	27,43	60,34	7,25	100,00	0,00	3,63	0,69	18,14	33,11	28,71
2005	41,30	63,04	0,38	78,85	5,36	0,00	0,00	27,14	39,59	29,38
2006	61,64	87,84	0,00	90,82	25,59	6,37	5,50	45,47	68,11	44,41
2007	84,49	100,00	98,79	97,49	33,70	76,56	94,42	61,19	83,99	82,12
2008	83,98	96,55	97,26	36,58	100,00	100,00	94,12	67,36	93,91	85,97
2009	70,62	64,51	100,00	29,19	57,34	90,19	100,00	52,29	49,27	68,92
2010	87,43	79,40	88,97	0,00	55,15	83,61	94,45	67,78	72,84	70,67
2011	100,00	77,81	75,40	0,97	52,65	78,08	90,68	86,33	89,96	72,60
2012	57,09	0	28,25	1,98	18,80	52,91	63,47	88,09	81,98	40,90
2013	61,51	5,13	3,36	5,88	12,23	27,47	41,96	100,00	100,00	36,61
2014	61,51	5,13	3,36	5,88	12,26	27,47	41,96	117,51	100	38,15
2015	61,51	5,13	3,36	5,88	12,23	27,47	41,96	132,22	100,00	39,44
2016	61,51	5,13	3,36	5,88	12,23	27,47	41,96	146,87	100,00	40,73
Weights	14,29 %	13,19%	12,09%	10,99%	10,99%	10.99%	9,89%	8,79%	8.79%	100%

Table 4.15: KPAs' scores and Airport 1 performance score for the best-case scenario. Source: own elaboration.

Year	Safety and Security	Core	Productivity/ Cost effectiveness	Service Quality	Financial/ Commercial	Environ mental	Airport Score
2003	69,37	5,36	25,59	24,64	68,27	5,81	34,95
2004	44,14	24,82	28,71	25,83	49,34	12,15	31,92
2005	58,67	31,42	29,38	31,09	53,32	38,56	41,08
2006	75,22	45,91	44,41	37,23	45,58	40,03	50,05
2007	87,06	52,72	82,13	50,50	46,43	40,65	62,56
2008	81,75	64,11	85,97	44,32	40,15	37,92	62,12
2009	58,15	51,79	68,92	41,72	52,19	53,95	54,96
2010	50,99	75,70	70,67	59,34	42,98	45,50	58,55
2011	72,51	71,50	72,60	62,66	55,71	57,48	66,60
2012	56,95	74,07	40,90	58,06	42,36	69,55	57,11
2013	73,47	87,19	36,61	65,64	15,81	70,29	59,88
2014	73,47	91,47	38,15	65,64	15,81	70,29	60,98
2015	73,47	95,07	39,44	65,64	15,81	70,29	61,90
2016	73,47	98,65	40,73	65,64	15,81	70,29	62,82
Weights	21,95%	19,51%	17,07%	14,63%	14,63%	12,20%	100%

The smooth growth of the number of passengers ends up failing to provoke a significant increase in Core and Productivity/Cost-Effectiveness KPA's scores (see Tables 4.16 and 4.17).

Table 4.16: Core KPIs' scores and KPA's score obtained for the worst-case scenario. Source: own elaboration.

Year	Passengers	Aircraft Movements	Origin and Destination Passengers	Freight and Mail Loaded/ Unloaded	Destinations - Nonstop	Airport Score
2003	0,00	0,00	0,00	31,29	0,00	5,36
2004	16,73	28,65	15,49	55,88	9,02	24,82
2005	25,02	34,26	23,24	56,04	20,30	31,42
2006	41,92	58,94	40,38	52,92	31,58	45,91
2007	56,40	72,68	55,10	24,15	45,11	52,72
2008	62,10	81,26	61,94	64,51	42,86	64,11
2009	56,74	58,71	57,47	30,32	49,62	51,79
2010	69,34	75,74	69,78	100,00	66,17	75,70
2011	80,65	79,73	81,00	23,25	86,47	71,50
2012	88,67	83,90	89,01	0,00	100,00	74,07
2013	100,00	100,00	100,00	39,36	83,08	87,19
2014	100,67	100,00	100,00	39,36	83,08	87,36
2015	105,10	100,00	100,00	39,36	83,08	88,50
2016	109,60	100,00	100,00	39,36	83,08	89,65
Weights	25,71%	22,86%	20,00%	17,14%	14,29%	100%

Indeed, Core KPA's score almost stagnates between 2013 and 2014, growing only 0,2%, and grows around 1,3% in each of the following two years which is minor compared to the fluctuations observed from 2003 to 2013. Also, Productivity/Cost-Effectiveness KPA's score presents a similar behaviour recording an annual growth of 0,17% in the first year of the forecast and 1,12% in each of the two following years.

Table 4.17: Productivity/Cost-Effectiveness KPIs' scores and KPA's score for the worst-case scenario. Source: own elaboration.

Year	Total Cost per Passenger	Total Cost per Movement	Operating Cost per Movement	Aircraft Movements per Gate	Total Cost per WLU	Operating Cost per WLU	Operating Cost per Passenger	Passengers Per Employee	Aircraft Movements per Employee	KPA Score
2003	0,00	39,81	30,16	84,21	10,34	37,93	21,57	0,00	0,00	25,59
2004	27,43	60,34	7,25	100,00	0,00	3,63	0,69	18,14	33,11	28,71
2005	41,30	63,04	0,38	78,85	5,36	0,00	0,00	27,14	39,59	29,38
2006	61,64	87,84	0,00	90,82	25,59	6,37	5,50	45,47	68,11	44,41
2007	84,49	100,00	98,79	97,49	33,70	76,56	94,42	61,19	83,99	82,12
2008	83,98	96,55	97,26	36,58	100,00	100,00	94,12	67,36	93,91	85,97
2009	70,62	64,51	100,00	29,19	57,34	90,19	100,00	52,29	49,27	68,92
2010	87,43	79,40	88,97	0,00	55,15	83,61	94,45	67,78	72,84	70,67
2011	100,00	77,81	75,40	0,97	52,65	78,08	90,68	86,33	89,96	72,60
2012	57,09	0,00	28,25	1,98	18,80	52,91	63,47	88,09	81,98	40,90
2013	61,51	5,13	3,36	5,88	12,23	27,47	41,96	100,00	100,00	36,61
2014	61,51	5,13	3,36	5,88	12,26	27,47	41,96	100,71	100,00	36,67
2015	61,51	5,13	3,36	5,88	12,23	27,47	41,96	105,36	100,00	37,08
2016	61,51	5,13	3,36	5,88	12,23	27,47	41,96	110,08	100,00	37,50
Weights	14,29 %	13,19%	12,09%	10,99%	10,99%	10.99%	9,89%	8,79%	8.79%	100%

These minimal growths result in a virtual stagnation of Airport 1 performance as shown in Table 4.18.

Table 4.18: KPAs' scores and Airport 1 performance score for the worst-case scenario. Source: own elaboration.

Year	Safety and Security	Core	Productivity/ Cost effectiveness	Service Quality	Financial/ Commercial	Enviromental	Airport Score
2003	69,37	5,36	25,59	24,64	68,27	5,81	34,95
2004	44,14	24,82	28,71	25,83	49,34	12,15	31,92
2005	58,67	31,42	29,38	31,09	53,32	38,56	41,08
2006	75,22	45,91	44,41	37,23	45,58	40,03	50,05
2007	87,06	52,72	82,13	50,50	46,43	40,65	62,56
2008	81,75	64,11	85,97	44,32	40,15	37,92	62,12
2009	58,15	51,79	68,92	41,72	52,19	53,95	54,96
2010	50,99	75,70	70,67	59,34	42,98	45,50	58,55
2011	72,51	71,50	72,60	62,66	55,71	57,48	66,60
2012	56,95	74,07	40,90	58,06	42,36	69,55	57,11
2013	73,47	87,19	36,61	65,64	15,81	70,29	59,88
2014	73,47	87,36	36,67	65,64	15,81	70,29	59,93
2015	73,47	88,50	37,08	65,64	15,81	70,29	60,22
2016	73,47	89,65	37,50	65,64	15,81	70,29	60,51
Weights	21,95%	19,51%	17,07%	14,63%	14,63%	12,20%	100%

4.3 Case II - Aircraft Movements

The second case study applies the same procedures of the Case I, but this time the object study is the number of aircraft movements. Despite Aircraft Movements KPI have been assigned a lower weight than Passengers KPI, the first one could have a direct impact on more indicators than the last one. Considering this, Case II intends to analyse the impact of aircraft movements' growth and compare it with the impact caused by passengers' growth to assess the suitability of the weights allocation on PESA-AGB model and the choice of indicators from the set of KPAs and KPIs provided by ACI.

4.3.1 Hypothesis 1

It is not expected that the first Hypothesis in this case study can show quite telling results. In fact, this first hypothesis just meant to depict the impact of the evolution in the number of aircraft movements, under the "*ceteris paribus*" condition, which is expected to be lower than the impact of the growth in the number of passengers.

The forecasting technique used was the projection of the average growth observed between 2003 and 2013, similarly to what was done when analysing the number of passengers' growth (see subsection 4.2.1). The forecast is shown in Figure 4.12.

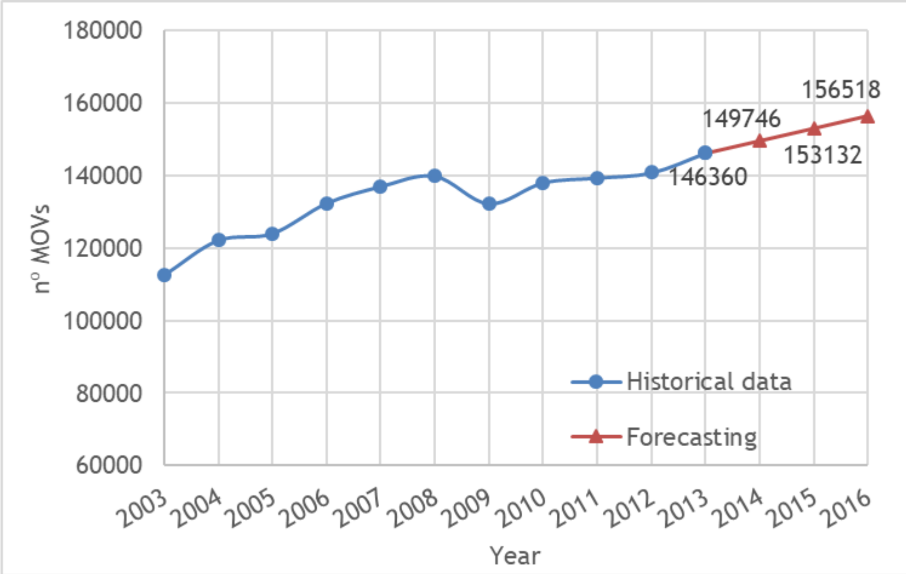

Figure 4.12: Projection of the number of aircraft movements in Airport 1 for the years 2014-2016. Source: own elaboration.

The line representing the forecast confirms the upward trend of the number of aircraft movements at Airport 1 and contains record values which led Aircraft Movements KPI's score to over 100 ones as can be seen in Table 4.19.

Table 4.19: Historical and predicted nos. of aircraft movements and KPA's score (hypothesis I). Source: own elaboration.

Year	Value	Score
2003	112.500	0,00
2004	122.200	16,73
2005	124.100	25,02
2006	132.456	41,92
2007	137.109	56,40
2008	140.016	62,10
2009	132.380	56,74
2010	138.147	69,35
2011	139.497	80,65
2012	140.909	88,67
2013	146.360	100,00
2014	149.746	110,00
2015	153.132	120,00
2016	156.518	130,00

Resulting Core KPA's scores are shown in Table 4.20.

Table 4.20: Core KPIs' scores and KPA's score obtained in Case II. Source: own elaboration.

Year	Passengers	Aircraft Movements	Origin and Destination Passengers	Freight and Mail Loaded/ Unloaded	Destinations - Nonstop	KPA Score
2003	0,00	0,00	0,00	31,29	0,00	5,36
2004	16,73	28,65	15,49	55,88	9,02	24,82
2005	25,02	34,26	23,24	56,04	20,30	31,42
2006	41,92	58,94	40,38	52,92	31,58	45,91
2007	56,40	72,68	55,10	24,15	45,11	52,72
2008	62,10	81,26	61,94	64,51	42,86	64,11
2009	56,74	58,71	57,47	30,32	49,62	51,79
2010	69,34	75,74	69,78	100,00	66,17	75,70
2011	80,65	79,73	81,00	23,25	86,47	71,50
2012	88,67	83,90	89,01	0,00	100,00	74,07
2013	100,00	100,00	100,00	39,36	83,08	87,19
2014	100,00	110,00	100,00	39,36	83,08	89,47
2015	100,00	120,00	100,00	39,36	83,08	91,76
2016	100,00	130,00	100,00	39,36	83,08	94,90
Weights	25,71%	22,86%	20,00%	17,14%	14,29%	100%

It is interesting to observe that using the same method to project future values, the scores obtained for Aircraft Movements KPI are the same obtained as for Passengers KPI in the previous case study, that is, 110 in 2014, 120 in 2015 and 130 in 2016. As expected, Core KPA's scores obtained are slightly lower than in the passengers forecast being compliant with the weights assigned by the experts. This observation is also valid to airport score which grows approximately 0,73% a year (Table 4.21) while in the case Passengers KPI, airports scores grows approximately 0,82% a year.

Table 4.21: KPAs' scores and Airport 1 performance score ontained for Case II. Source: own elaboration.

Year	Safety and Security	Core	Productivity/ Cost effectiveness	Service Quality	Financial/ Commercial	Envirom mental	Airport Score
2003	69,37	5,36	25,59	24,64	68,27	5,81	34,95
2004	44,14	24,82	28,71	25,83	49,34	12,15	31,92
2005	58,67	31,42	29,38	31,09	53,32	38,56	41,08
2006	75,22	45,91	44,41	37,23	45,58	40,03	50,05
2007	87,06	52,72	82,13	50,50	46,43	40,65	62,56
2008	81,75	64,11	85,97	44,32	40,15	37,92	62,12
2009	58,15	51,79	68,92	41,72	52,19	53,95	54,96
2010	50,99	75,70	70,67	59,34	42,98	45,50	58,55
2011	72,51	71,50	72,60	62,66	55,71	57,48	66,60
2012	56,95	74,07	40,90	58,06	42,36	69,55	57,11
2013	73,47	87,19	36,61	65,64	15,81	70,29	59,88
2014	73,47	89,47	36,61	65,64	15,81	70,29	60,33
2015	73,47	91,76	36,61	65,64	15,81	70,29	60,77
2016	73,47	94,04	36,61	65,64	15,81	70,29	61,39
Weights	21,95%	19,51%	17,07%	14,63%	14,63%	12,20%	100%

As in the case of passengers' growth, airport performance score also varies linearly with the number of passengers (see Figure 4.13).

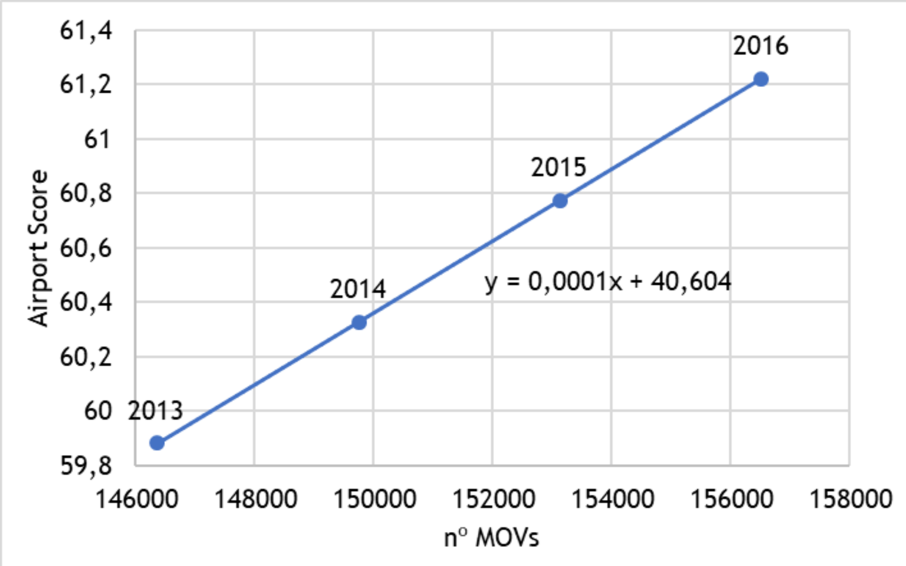

Figure 4.13: Airport Score as a function of aircraft movements (Hypothesis I). Source: own elaboration.

4.3.2 Hypothesis 2

As with the hypothesis presened is subscetion 4.2.1, airport performance score does not register a significant increase comparing to the variations obtained for the years 2003-2013, when varying only the number of aircraft movements. In the present hypothesis, it is verified over which areas does aircraft movements increase have a direct impact. The procedure and criteria applied are the same presented in subsection 4.2.2.

It is easily concluded that changes in the values of aircraft movements per gate and aircraft movements per employee rates due to aircraft movements can be determined without an econometric analysis, observing the metrics of all other indicators. Considering that there were 50 gates and 674 employees at Airport 1 in 2013, variations of both KPIs with the number of aircraft movements are easily determined (see Table 4.22).

Table 4.22: Historical and predicted nos. of aircraft movements per gate and aircraft movements per employee and own KPI's scores at Airport 1 (hypothesis II). Source: own elaboration.

Years	Aircraft Movements per Gate		Aircraft Movements per Employee	
	Values	Scores	Values	Scores
2003	5.114	84,21	172	0,00
2004	5.555	100,00	187	33,11
2005	4.964	78,85	190	39,59
2006	5.298	90,82	203	68,11
2007	5.484	97,49	210	83,99
2008	3.784	36,58	214	93,91
2009	3.578	29,19	194	49,27
2010	2.763	0,00	205	72,84
2011	2.790	0,97	213	89,96
2012	2.818	1,98	209	81,98
2013	2.927	5,88	217	100,00
2014	2.995	8,31	222	111,20
2015	3.063	10,74	227	122,39
2016	3.130	13,16	232	133,59

Despite the number of aircraft movements increase almost every year, Aircraft Movements per Gate KPI's score presents a different evolution; this is due to interventions made at the airport in which gates were added causing a decrease in the rate. From 2013, in line with *ceteris paribus assumption*, the number of gates was assumed to keep unchanged, which along with aircraft movements increase results in an increase of the KPI's score. The same happens for Aircraft Movements per Employee KPI whose score trends are distinct from Aircraft Movements KPI's ones.

The increases predicted for both Aircraft Movements per Gate and Aircraft Movements per Employee KPIs along with the stagnation imposed in the remaining KPIs result in the increase of the productivity of the airport as shown in Table 5. Productivity/Cost-Effectiveness KPA's score increases approximately 11% in 2014, 5% in 2015 and 4% in 2016 breaking with the downward trend observed from 2011 to 2013. These increases boost airport performance score which grew 3,30% until 2016, almost more 1% than in Hypothesis 1, turning over 60, as can also be seen in Table 4.23.

Table 4.23: KPAs' scores and Airport 1 performance score (hypothesis II). Source: own elaboration.

Year	Safety and Security	Core	Productivity/ Cost effectiveness	Service Quality	Financial/ Commercial	Envirom mental	Airport Score
2003	69,37	5,36	25,59	24,64	68,27	5,81	34,95
2004	44,14	24,82	28,71	25,83	49,34	12,15	31,92
2005	58,67	31,42	29,38	31,09	53,32	38,56	41,08
2006	75,22	45,91	44,41	37,23	45,58	40,03	50,05
2007	87,06	52,72	82,13	50,50	46,43	40,65	62,56
2008	81,75	64,11	85,97	44,32	40,15	37,92	62,12
2009	58,15	51,79	68,92	41,72	52,19	53,95	54,96
2010	50,99	75,70	70,67	59,34	42,98	45,50	58,55
2011	72,51	71,50	72,60	62,66	55,71	57,48	66,60
2012	56,95	74,07	40,90	58,06	42,36	69,55	57,11
2013	73,47	87,19	36,61	65,64	15,81	70,29	59,88
2014	73,47	89,47	37,54	65,64	15,81	70,29	60,54
2015	73,47	91,76	38,46	65,64	15,81	70,29	61,20
2016	73,47	94,04	39,38	65,64	15,81	70,29	61,39
Weights	21,95%	19,51%	17,07%	14,63%	14,63%	12,20%	100%

The variation of airport score as a function of aircraft movements is depicted in Figure 4.14, as well as the equation that describes it. The higher slope of line confirms the greater impact of aircraft movements' growth on airport performance.

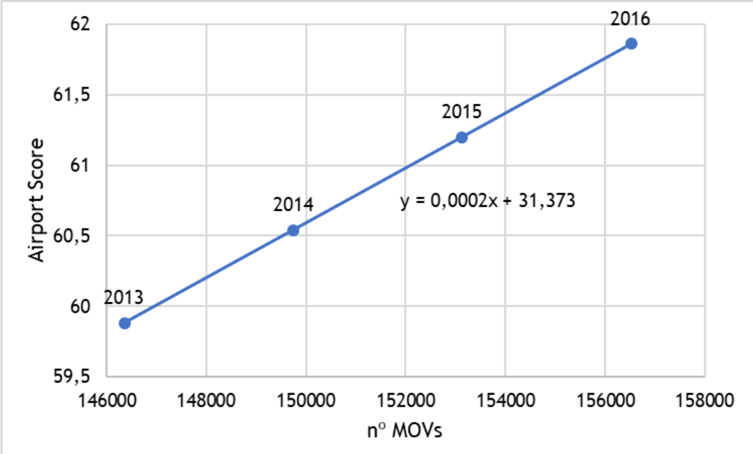

Figure 4.14: Airport Score as a function of aircraft movements (Hypothesis II). Source: own elaboration.

4.3.3 Hypothesis 3

As it was done in the first case study (see subsection 4.2.3), ETS algorithm is used to carry out the forecast with the parameters being set the same way. The forecast, including both upper and lower confidence bounds, is depicted in Figure 4.15. Statistic details of the forecast are presented in Annexe A.5.

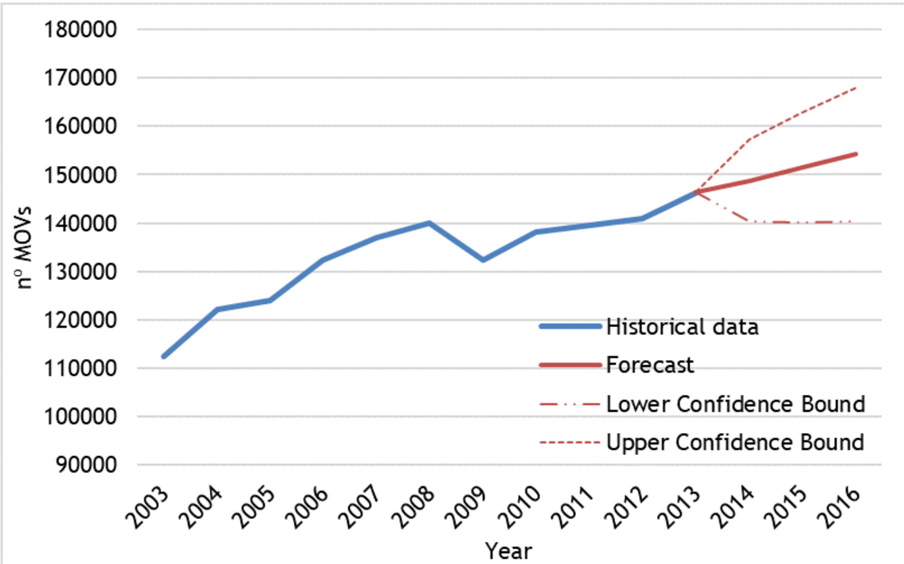

Figure 4.15: Aircraft movements ETS forecast. Source: own elaboration.

The number of aircraft movements and scores obtained for the period 2013-2016 for expected, best-case and worst-case scenarios are shown in Table 4.24.

Table 4.24: Predicted values and scores from aircraft movements' ETS forecast for Airport 1. Source: own elaboration.

Year	History		Expected scenario		Worst-case scenario		Best-case scenario	
	Value	Score	Value	Score	Value	Score	Value	Score
2003	112.500	0,00						
2004	122.200	28,65						
2005	124.100	34,26						
2006	132.456	58,94						
2007	137.109	72,68						
2008	140.016	81,26						
2009	132.380	58,71						
2010	138.147	75,74						
2011	139.497	79,73						
2012	140.909	83,90						
2013	146.360	100,00						
2014			148.807	107,23	140.289	82,07	157.324	132,38
2015			151.514	115,22	140.049	81,36	162.978	149,08
2016			154.221	123,22	140.420	82,46	168.022	163,97

By focusing on the expected scenario it is observed an almost constant increase. Comparing with the trend projection carried out in the second hypothesis (see subsection 4.3.2), there are expected fewer aircraft movements. Still, the performance of this indicator is quite good since the record is surpassed every year. In the best-case scenario, aircraft movements increase is very sharp in 2014 reaching a record higher than the best mark predicted for the expected scenario. Despite this increase being soften in 2015 and 2016, the slope of its curve is one of the higher predicted. Lastly, the worst-case scenario is the only one breaking with the upward trend verified until 2013, presenting a stagnation after a downturn in 2014. However, the numbers observed in the worst-case scenario should not threaten airport sustainability.

Aircraft Movements per Gate rate values and KPI's scores are presented in Table 4.25.

Table 4.25: Aircraft Movements per Gate KPI's values and scores (hypothesis 3). Source: own elaboration.

Year	History		Expected scenario		Worst-case scenario		Best-case scenario	
	Value	Score	Value	Score	Value	Score	Value	Score
2003	5.114	84,21						
2004	5.555	100,00						
2005	4.964	78,85						
2006	5.298	90,82						
2007	5.484	97,49						
2008	3.784	36,58						
2009	3.578	29,29						
2010	2.763	0,00						
2011	2.790	0,97						
2012	2.818	1,98						
2013	2.927	5,88						
2014			2.976	7,64	2.806	1,54	3.146	13,74
2015			3.030	9,58	2.801	1,36	3.260	17,79
2016			3.084	11,52	2.808	1,63	3.360	21,40

Both expected and best-case scenarios follow up the recovery initiated in 2011 with obvious differences in the growth rate. Worst-case scenario shows a decrease in 2014 followed by a stagnation between 2014 and 2016.

The same behaviour is observed for Aircraft Movements per Employee KPI trough the values and scores presented in Table 4.26.

Table 4.26: Aircraft Movements per Employee KPI's values and scores (hypothesis 3). Source: own elaboration.

Year	History		Expected scenario		Worst-case scenario		Best-case scenario	
	Value	Score	Value	Score	Value	Score	Value	Score
2003	172	0,00						
2004	187	33,11						
2005	190	39,59						
2006	203	68,11						
2007	210	83,99						
2008	214	93,91						
2009	194	49,27						
2010	205	72,84						
2011	213	89,96						
2012	209	81,98						
2013	217	100,00						
2014			221	108,09	208	79,93	233	136,25
2015			224	117,04	208	79,13	242	154,95
2016			229	125,99	208	80,36	249	171,40

The impact of these development scenarios on Core and Productivity/Cost-Effectiveness KPAs can be observed in Table 4.27.

Table 4.27: Core and Productivity/Cost-Effectiveness KPAs' scores and Airport 1 performance score (hypothesis 3). Source: own elaboration.

Year	Expected scenario			Worst-case scenario			Best-case scenario		
	Core	Productivity	Airport 1	Core	Productivity	Airport 1	Core	Productivity	Airport 1
2003	5,36	25,59	34,95	5,36	25,59	34,95	5,36	25,59	34,95
2004	24,82	28,71	31,92	24,82	28,71	31,92	24,82	28,71	31,92
2005	31,42	29,38	41,08	31,42	29,38	41,08	31,42	29,38	41,08
2006	45,91	44,41	50,05	45,91	44,41	50,05	45,91	44,41	50,05
2007	52,72	82,13	62,56	52,72	82,13	62,56	52,72	82,13	62,56
2008	64,11	85,97	62,12	64,11	85,97	62,12	64,11	85,97	62,12
2009	51,79	68,92	54,96	51,79	68,92	54,96	51,79	68,92	54,96
2010	75,70	70,67	58,55	75,70	70,67	58,55	75,70	70,67	58,55
2011	71,50	72,60	66,60	71,50	72,60	66,60	71,50	72,60	66,60
2012	74,07	40,90	57,11	74,07	40,90	57,11	74,07	40,90	57,11
2013	87,19	36,61	59,88	87,19	36,61	59,88	87,19	36,61	59,88
2014	88,84	37,52	60,36	83,09	34,37	58,70	94,59	40,66	62,02
2015	90,67	38,52	60,89	82,93	34,28	58,65	98,41	42,75	63,12
2016	92,49	39,52	61,41	83,18	34,42	58,72	101,81	44,61	64,10

In the expected scenario, it is foreseen a slight improvement in Airport 1 performance. More significant increases are observed in the best-case scenario where the percentage annual growth in 2014 is more than 4 times higher than in the expected scenario and around two times higher in the remaining years concerning the forecast. Worst-case scenario shows a slight decrease at the beginning of the forecast period followed by stagnation. Although these scores do not pose a risk to the airport sustainability, it is advisable to take appropriate measures to counter the downward trend caused by the observed development of the number of aircraft movements at Airport 1.

4.4 Case III - Passengers and Aircraft Movements

In the last case study, forecasts passengers and aircraft movements, obtained in subsection 4.3.3 applying ETS method, are used to estimate Airport 1 scores resulting from both indicators' growth. . It is also maintained the assumption that those growths directly influence some indicators.

Since, both Passengers and Aircraft Movements KPIs are now being considered alongside, Core and Productivity/Cost-Effectiveness KPA's reach now stronger variations and, consequently, it will be verified greater airport performance score fluctuations as shown in Table 4.28.

Table 4.28: Core and Productivity/Cost-Effectiveness KPAs' scores and Airport 1 performance score obtained in Case III). Source: own elaboration.

Year	Core	Productivity/ Cost-Effectiveness	Airport 1
2003	5,36	25,59	34,95
2004	24,82	28,71	31,92
2005	31,42	29,38	41,08
2006	45,91	44,41	50,05
2007	52,72	82,13	62,56
2008	64,11	85,97	62,12
2009	51,79	68,92	54,96
2010	75,70	70,67	58,55
2011	71,50	72,60	66,60
2012	74,07	40,90	57,11
2013	87,19	36,61	59,88
2014	91,07	38,32	60,93
2015	95,26	40,17	62,06
2016	99,46	42,02	63,20

Significant Core KPA's score increases are observed. In fact, only with passengers and aircraft movements' expected growths, KPA score obtains annual percentage increases around 4,5% which is between the annual percentage increases verified in 2011 and 2012. Even though,it is too far from the average annual percentage increase verified from 2003 to 2013 of 56,44%. It is important however to note that this average is inflated by the percentage growth of 363% checked in 2004. Similar percentage growth is witnessed by Productivity/Cost-effectiveness KPA.

It is observed that if Airport 1 manages to maintain its performance in the different areas, the air traffic growth will naturally increase its global performance score. Airport performance score is expected to increase 5,54% within three years. However, annual increases are not so significant considering past fluctuations as they are supposed to vary between 1,75% and 1,86% while the average percentage fluctuation verified between 2003 and 2013 is greater than 13%. This cushioning in the performance scores variation can be better visualised in Figure 4.16.

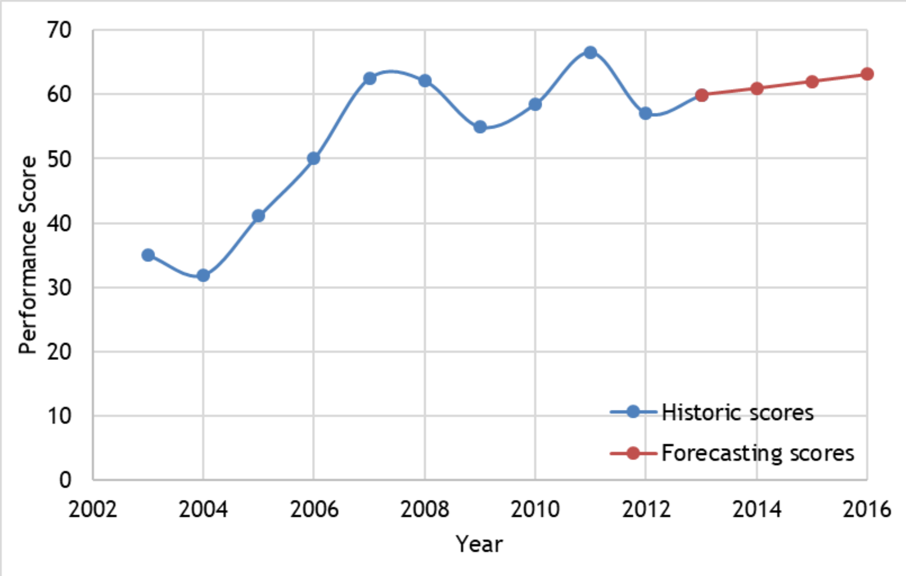

Figure 4.16: Airport 1 performance score variation. Source: own elaboration.

4.5 Conclusion

In this chapter three case studies were conducted where the global airport performance was estimated for passengers and aircraft movements forecasted scenarios. For Case 1 and Case II, three hypotheses were set forward to compare the impact of passengers and aircraft movements growths.

When comparing the results obtained for the first hypothesis in Case I and Case II, it is verified that passengers' growth generates higher scores than aircraft movements' growth despite both indicators obtain same scores, what confirms the higher weight assigned by experts.

The second hypothesis shows different results. Aircraft movements' growth affects directly two KPI's from Productivity/Cost Effectiveness KPA while passengers' growth affects only one KPI from the same performance area. The accumulated weight of Aircraft Movements, Aircraft Movements per Gate and Aircraft Movements per Employee KPIs ends up being greater enough than the accumulated weight of Passengers and Passengers Per Employee KPIs to obtain higher performance scores in Case II rather than in Case I; this means that the assumptions adopted in this hypothesis have a significant impact on airport performance estimation.

In the third hypothesis, same assumptions were thus established. However, it was used ETS to develop the forecasts. When applied by using Microsoft Excel, the resulting forecast allows two growth scenarios to be observed, in addition to the expected one, which corresponds to the confidence bounds. The expected scenarios obtained for the passenger's growth and the aircraft movements' growth foresee steady annual increases, yet, at a lower average growth rate than verified between 2003 and 2013. The best-case scenario predicts a passengers' flow for 2016 slightly higher than the maximum capacity projected for Lisbon airport. Despite these projections not always being extremely accurate and the slight surplus number of passengers can be processed by improving airport efficiency, it is important to remind that an airport operating close to its capacity limit may result in efficiency and safety problems.

In Case III, the Airport 1 performance is estimated for the expected scenarios obtained from the ETS forecast of both passengers and aircraft movements. Scores show that the increase in air traffic (passengers and aircraft movements) does not in itself lead to very significant performance score increases when compared to fluctuations recorded between 2003 and 2013; this means that if Airport 1 managers intend the airport to improve significantly, more than deal with the air traffic growth without losing performance in the various KPAs, the output of some indicators from those areas must be improved.

Chapter 5

Conclusions

5.1 Dissertation Summary

In the process of structuring this work, it was initially defined the study object as being airport performance, due to the increasing demand for air transport and the problems that it causes to the airports, while the main objective was to quantify and predict the development of a specific airport's performance.

Specific targets had to be established to achieve the main goal:

- Determine how to define and measure airport performance;
- Identify the several tools used so far to analyse and measure airport performance and efficiency, as well as to comprehend which indicators are assumed depending on the aspects being analysed;
- Identify suitable forecasting techniques depending on the features and inherent constraints of this study.

In Chapter 2 it is discussed that an airport is a complex system composed of several interconnected subsystems whose managers must deal with external factors and divergent interests of stakeholders. A literature review was carried out to achieve the first two targets. It is shown that most of the studies only address the performance in specific areas such as the commercial or the operational ones. Moreover, it seems there is no agreement in the choice of performance indicators. Since this study addresses global performance, the set of KPIs provided by ACI is adopted. DEA and SFA are by far the most popular techniques in airport performance and efficiency analysis. However, if one intends to model airport performance, only SFA is helpful in addition to OLS based techniques, distance functions or hybrid AHP/DEA models. Also, some MCDA methods have proven to provide accurate results while being applicable in managerial practice.

Chapter 3 provides the literature review on forecasting. Most popular methods include time series techniques and econometric modelling. However, it is also verified that the choice of the most suitable technique may depend on some features such as the time-horizon of the forecast. After considering the different available methodologies and features related to the analysis and forecasting of airport performance, in chapter 4 it was carried out three case studies to assess the impact of passengers and aircraft movements growths on the airport performance, this is done using a MCDA based model (PESA-AGB). Moreover, three hypotheses are set forward to compare both cases under different assumptions. "Passengers" KPI have a greater impact if only its growth is considered. However, when considering the impact on other KPIs directly dependent on the number of Passenger or aircraft movements, the second showed to cause greater variations in airport performance score. It was also applied the ETS technique to make both passengers and aircraft movements' forecasts whose predicted values are used to foresee the airport performance development over these indicators.

This study provides consistent reviews on airport performance and efficiency analysis and air traffic forecasting. Moreover, the case studies performed in this study contributes to both subjects first, by making a sensibility analysis on PESA-AGB model that allows drawing some conclusions about the choice of performance indicators and respective assigned weights, and second, applying ETS methodology to forecast both passengers and aircraft growths.

5.2 Concluding Remarks

Airports were shown to be complex organisations which may have different goals according to its ownership form. Moreover, airports are in the centre of a sphere of influences and must deal with several stakeholders. All this diversity has resulted in a divergence when selecting methodologies and criteria for airport performance analysis.

In this work, it was adopted a set of performance indicators settled internationally by ACI. The weights of each indicator were obtained through an online survey send for more than 500 specialists from the six KPA. As discussed in section 2.3, the introduction of human judgement to this kind of analysis has two effects: by one side, the introduction of flaws inherent to subjective factors; and by another side, it allows to rank several factors by order of importance and allows to assess how new technological or other developments would affect the forecast. Moreover, this study evidences another issue. Despite experts assign a greater importance to the number of passengers rather than to aircraft movements in a direct confrontation between both indicators, when considering the direct impact of each one on other indicators aircraft movements end up having greater impact on airport performance score denoting an inconsistency of the set of indicators or the weights' assignment.

Although this dissertation only presents case studies on Airport 1, further attempts were performed for other benchmarking airports benchmarking. When comparing the evolution of the performance of each airport, there is an issue that becomes evident. Consider for this explanation Airport A and Airport B. If Airport A has fragile history and achieves a new record in some indicator or area, own KPI or KPA achieves a score of 100. If in the same year, airport B records a value above the record in the same KPI or KPA, the score is below 100, getting a lower score than Airport B even if it represents a better performance based on category, dimension or resources of each airport; this means that despite PESA-AGB being a useful tool for self-benchmarking, it may present some flaws for peer-benchmarking.

First attempts of this work consisted of regression analysis. For this, it was tried to obtain a regression line for each indicator and the corresponding equation, with the intent of getting a single equation for airport performance score over time. However, many indicators present a very irregular growth which resulted in trend lines with too much low R squared values for the literature standards. Thus the representativeness of the obtained equations was too low making impossible to derive an equation that could describe the evolution of an airport's performance. Examples comparing the regressions obtained with a quadratic polynomial and a polynomial of degree six for two KPIs are displayed in Annex A.6.

The scoring system of PESA-AGB model was then adopted to quantify airport performance. Equations of airport score as a function of the number of passengers or aircraft movements were obtained for the period corresponding to the *ceteris paribus* assumption. The same equations were tried to be achieved for the previous years, but no valid results were obtained; this is due to the development of other indicators that may have not a significant relationship with airport passengers or aircraft movements but may be explained by other factors instead that would require a profound econometric analysis that is out of the scope of this work.

5.3 Prospects for Future Work

Considering the diversity of scenarios in which airports are managed, and airport performance analysis and forecasting methodologies developed so far, there is still scope for further exploration of these methodologies to improve its effectiveness and contribute to the consistency of the literature on this subject.

Also, the network of airport performance indicators and its explanatory variables can be the object of further investigation. This work addresses only air passengers and aircraft movements, but not only other indicators' impact on airport performance could be assessed as also the variables behind these two indicators' growth could be analysed.

Therefore, due to work developed and the acquired knowledge future steps in this subject's studies should cross the following investigation items:

- To analyse the impact of further KPI's on airport score and to study further correlations between the several KPI's to obtain a broader and more consistent perspective of the anatomy of airport performance;
- To develop an econometric analysis to depict the explanatory variables that have a causal relationship with the several KPI's to obtain a deeper understanding of the factors that affect airport performance;
- To consider other forecasting methodologies that may produce more accurate predictions;
- To consider a process of experts' consultation and/or weights assignment that may lead to a more consistent weight distribution; and
- To embody a quantitative methodology in PESA-AGB model to increase the objectivity of the airport performance evaluation and promote changes that allow more accurate peer-benchmarking.

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Appendix A

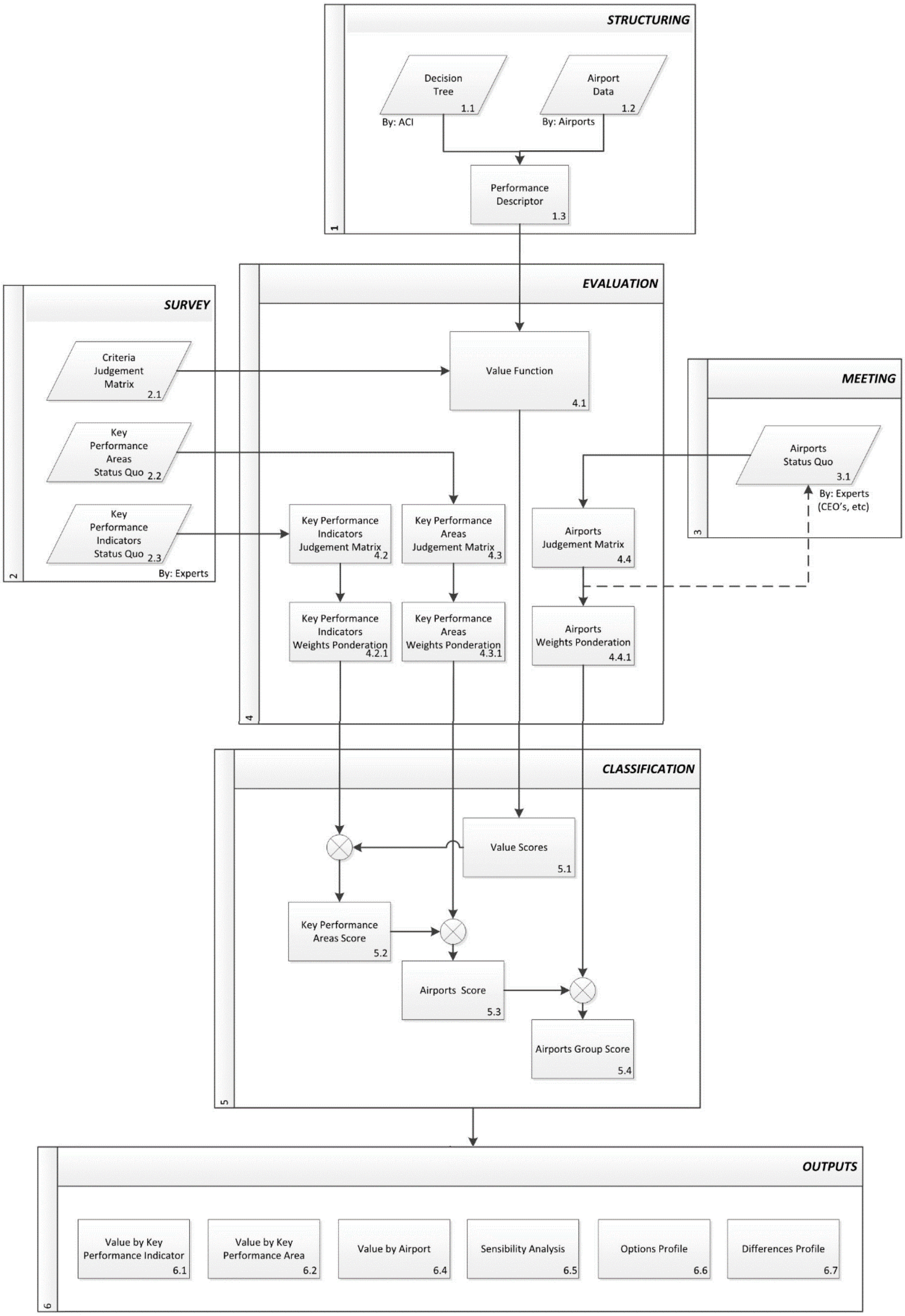
Annexes

A.1 KPI metrics

KPA	KPI	Metric
Core	Passengers	nº PAX
	Origination and Destination Passengers	nº PAX O&D
	Aircraft Movements	nº MOVs
	Freight and Mail Loaded /Unloaded	Metric TONs
	Destinations—Nonstop	nº AIRP non-stop
Safety and Security	Runway Accidents	Accidents / 1000MOVs
	Runway Incursions	Incursions / 1000MOVs
	Bird Strikes	BS / 1000MOVs
	Public Injuries	PInj / 1000MOVs
	Occupational Injuries	OcpInj / 1000HoursWorked
	Lost Work Time from Employee Accidents and Injuries	LWT / 1000HoursWorked
Service Quality	Practical Hourly Capacity	MaxMOVs/hour
	Gate Departure Delay	ΣΔGTj / nº Flights
	Taxi Departure Delay	ΣΔTTj / nº Flights
	Customer Satisfaction	A-100-90 % B-90-70 % C-70-50 % D-50-30 % E- 30-0 %
	Baggage Delivery Time	ΣΔBDTj / nº Flights
	Security Clearing Time	ΣΔSCTj / nº PAX
	Border Control Clearing Time	ΣΔBCCTj / nº PAX
	Check-in to Gate Time	Σ (ΔTj x PAXj) / Σnº PAX
Productivity/ Cost Effectiveness	Passengers Per Employee	nº PAX / nº EMP
	Aircraft Movements per Employee	nº MOVs / nº EMP
	Aircraft Movements per Gate	nº MOVs / nº GATE
	Total Cost per Passenger	EUROS / nº PAX
	Total Cost per Movement	EUROS / nº MOVs
	Total Cost per WLU	EUROS / WLU
	Operating Cost per Passenger	EUROSop / nº Pax
	Operating Cost per Movement	EUROSop / nº MOVs
	Operating Cost per WLU	EUROSop / WLU
Financial/ Commercial	Aeronautical Revenue per Passenger	REV Euros / nº PAX
	Aeronautical Revenue per Movement	REV Euros / nº MOVs

KPA	KPI	Metric
	Non-Aeronautical Operating Revenue as Percentage of Total Operating Revenue	NonAeroOp Euros / TotalOp Euros (%)
	Non-Aeronautical Operating Revenue per Passenger	NonAeroOp Euros / nº PAX
	Debt Service as Percentage of Operating Revenue	Debt Euros / OP Euros (%)
	Long-Term Debt per Passenger	LT Debt Euros / nº PAX
	Debt to EBITDA Ratio	Debt Euros / EBITDA
	EBITDA per Passenger	EBITDA Euros / nº PAX
Environmental	Carbon Footprint (TONS/PAX)	GHG / nº PAX
	Waste Recycling	Waste recycling (%)
	Waste Reduction Percentage	Waste reduction (%)
	Renewable Energy Purchased by the Airport (%)	REP (%)
	Utilities/Energy Usage per Square Meter of Terminal	KWh / m2
	Water Consumption per Passenger	H2O (lts) / nº PAX

A.2 PESA-AGB Model Flowchart



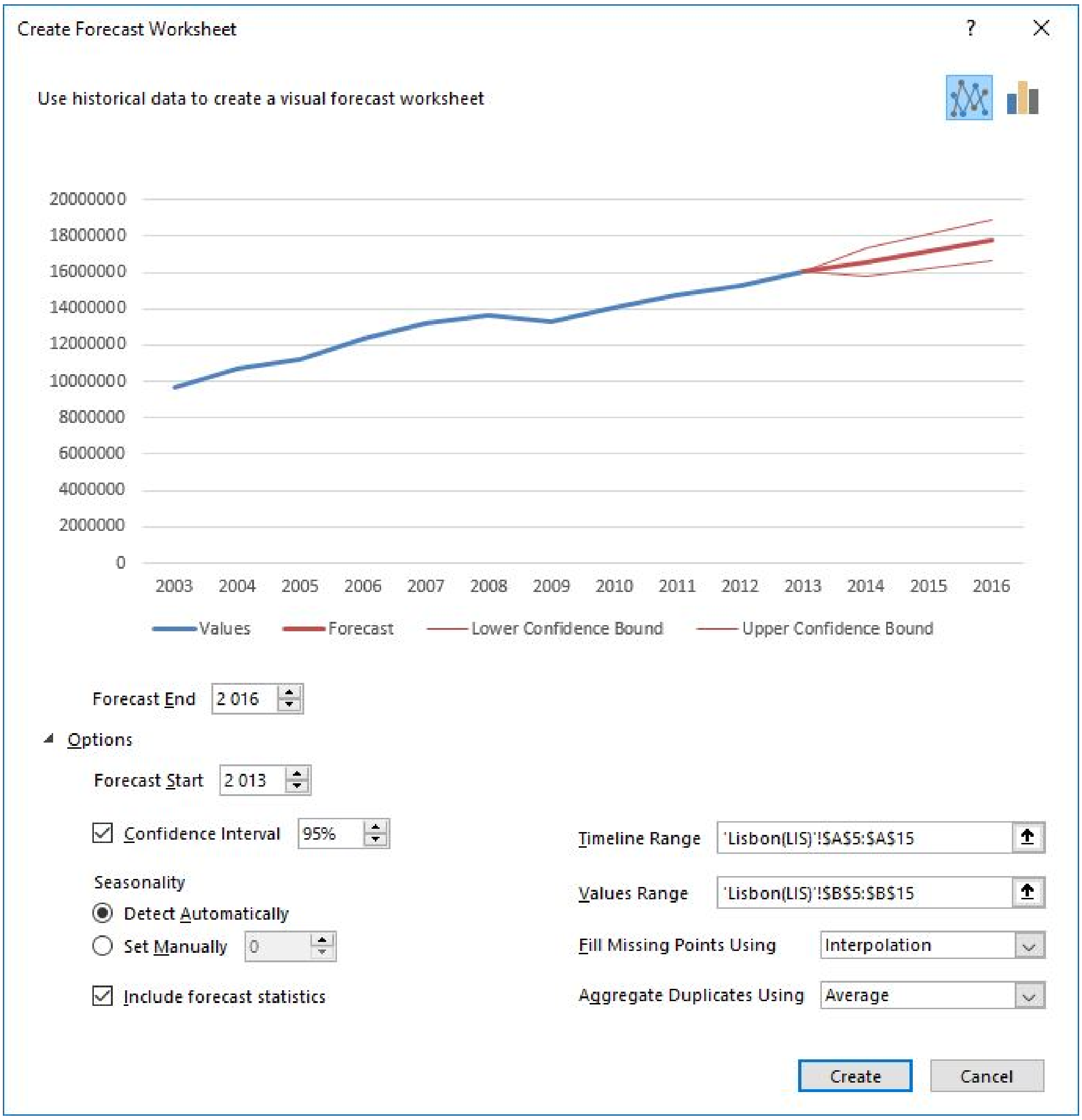
A.3 Database

	Core					Safety and Security					
	Passengers	Origination and Destination Passengers	Aircraft Movements	Freight and Mail Loaded /Unloaded	Destinations—Nonstop	Runway Accidents	Runway Incursions*10	Bird Strikes	Public Injuries	Occupational Injuries*100	Lost Work Time from Employee Accidents and Injuries
	nºPAX	nº PAX O&D	nº MOVs	Metric TONs	nº AIRP non-stop	Accidents / 1000MOVs	Incursions / 1000MOVs	BS / 1000MOVs	PInj / 1000MOVs	OcpInj / 1000Hours Worked	LWT / 1000Hours Worked
2003	9636400	9502000	112500	95766	74	0,000	0,059	0,410	0,489	0,5330	7,740
2004	10705000	10510000	122200	100075	78	0,000	0,063	0,760	0,532	1,0205	9,638
2005	11234700	11014000	124100	100104	83	0,000	0,056	0,813	0,540	0,8590	4,134
2006	12314314	12129411	132456	99557	88	0,000	0,077	0,444	0,113	0,5447	2,516
2007	13239756	13087453	137109	94515	94	0,000	0,062	0,372	0,102	0,6353	3,433
2008	13603620	13532562	140016	101158	93	0,000	0,062	0,264	0,393	0,5596	2,910
2009	13261203	13241861	132380	95595	96	0,000	0,062	0,690	0,332	1,5080	1,889
2010	14066534	14042901	138147	105304	102	0,000	0,076	0,561	0,217	1,3503	5,944
2011	14788480	14772503	139497	94356	108	0,000	0,061	0,712	0,100	0,9223	4,164
2012	15301176	15294210	140909	90282	112	0,000	0,080	0,657	0,248	0,7551	2,467
2013	16024950	16009049	146360	97179,3	107	0,000	0,060	0,690	0,098	0,7541	5,944
Bons	16024950	16009049	146360	105304	112	0	0,056	0,264	0,0983609	0,5330	1,89
2	13895433,33	13840032,67	135073,33	100296,667	99,33333	0,002	0,064	0,447	0,2455363	0,8580	4,47
3	11765916,67	11671016,33	123786,67	95289,3333	86,66667	0,004	0,072	0,630	0,3927118	1,1830	7,06
Neutros	9636400	9502000	112500	90282	74	0,006	0,080	0,813	0,5398872	1,5080	9,64

	Service Quality								Productivity/Cost Effectiveness									
	Practical Hourly Capacity	Gate Departure Delay	Taxi Departure Delay	Customer Satisfaction	Baggage Delivery Time	Security Clearing Time	Border Control Clearing Time	Check-in to Gate Time	Passengers Per Employee	Aircraft Movements per Employee	Aircraft Movements per Gate	Total Cost per Passenger	Total Cost per Movement	Total Cost per WLU	Operating Cost per Passenger	Operating Cost per Movement	Operating Cost per WLU
	MAxMOVs/hour	ΣΔGTj / nFlights	ΣΔTTj / nFlights	A-100-90 % B-90-70 % C-70-50 % D-50-30 % E- 30-0 %	ΣΔBDTj / nFlights	ΣΔSCTj / nPAX	ΣΔBCCTj / nPAX	Σ (ΔTj x PAXj) / ΣnPAX	PAX / EMP	MOVs / EMP	MOVs / GATE	TCost / PAX	TCost / MOVs	TCost / WLU	OP Cost / Pax	OP Cost / MOVs	OP Cost / WLU
2003	39,00	12,30	3,20	65,40	27,30	25,60	8,60	22,40	14757	172	5114	19,47	1667,56	18,47	4,96	424,67	4,70
2004	41,00	14,40	3,50	67,20	25,40	26,40	9,00	19,70	16394	187	5555	18,27	1600,65	19,29	5,46	478,72	5,77
2005	38,00	13,20	2,10	65,90	27,00	24,30	7,80	23,00	17205	190	4964	17,58	1591,86	18,87	5,48	496,23	5,88
2006	42,00	10,10	2,90	67,00	31,10	26,60	6,70	25,30	18858	203	5298	16,25	1511,07	17,27	5,35	497,20	5,68
2007	43,00	9,90	2,00	67,80	24,90	24,30	10,10	21,80	20275	210	5484	15,24	1471,46	16,64	3,19	307,98	3,48
2008	39,00	11,50	1,40	68,70	34,00	25,70	9,30	17,50	20832	214	3784	15,26	1482,69	11,42	3,20	310,58	2,39
2009	37,00	10,90	1,90	66,70	24,00	25,00	7,80	22,30	19473	194	3578	15,84	1587,10	14,77	3,05	305,93	2,85
2010	38,00	9,80	2,50	70,80	22,50	20,50	8,30	23,10	20870	205	2763	15,11	1538,58	14,95	3,19	324,68	3,15
2011	44,00	10,50	1,70	71,80	21,50	22,70	12,40	21,60	22543	213	2790	14,56	1543,76	15,14	3,28	347,75	3,41
2012	42,00	14,00	1,50	72,20	17,50	26,30	9,50	18,90	22702	209	2818	16,55	1797,26	17,81	3,94	427,91	4,24
2013	45,00	12,20	2,00	74,10	18,00	25,10	10,10	20,00	23776	217	2927	16,26	1780,54	18,33	4,46	488,64	5,03
Bons	45,00	9,80	1,4	74,1	17,5	20,50	6,7	17,5	23776	217	5555	14,56	1471,46	11,41537	3,05	305,93	2,39
2	42,33	11,33	2,1	71,2	23	22,53	8,6	20,1	20770	202	4624	16,20	1580,06	14,0396	3,86	369,68	3,55
3	39,67	12,87	2,8	68,3	28,5	24,57	10,5	22,7	17763	187	3693	17,83	1688,66	16,66382	4,67	433,44	4,72
Neutros	37,00	14,40	3,5	65,4	34	26,60	12,4	25,3	14757	172	2763	19,47	1797,26	19,28804	5,48	497,20	5,88

	Financial/Commercial								Environmental					
	Aeronautical Revenue per Passenger	Aeronautical Revenue per Movement	Non-Aeronautical Operating Revenue as	Non-Aeronautical Operating Revenue per	Debt Service as Percentage of	Long-Term Debt per Passenger	Debt to EBITDA Ratio	EBITDA per Passenger	Carbon Footprint (TONS/PAX)	Waste Recycling	Waste Reduction Percentage	Renewable Energy Purchased by the	Utilities/Energy Usage per Square	Water Consumption per Passenger
	REV / PAX	REV / MOVs	NonAeroOp REV / TotalOp VER (%)	NonAeroOp REV / PAX	Debt / OP Ver (%)	LT Debt / PAX	Debt/EBITA	EBITAD/PAX	GHG/PAX	%water recicled	Waste red (%)	REP (%)	KWh/m^2	H2O (Lit)/PAX
2003	9,60	822,22	0,322	4,21599	0,33	9,02	2,54	3,55	0,00035	5,78	-3,31	24,20	555,38	40,00
2004	8,73	765,14	0,328	3,98010	0,37	12,79	4,00	3,20	0,00031	7,57	-0,55	26,10	581,42	39,60
2005	8,41	761,48	0,340	4,06112	0,36	17,98	5,01	3,59	0,00029	10,17	27,63	28,00	604,08	31,10
2006	7,76	720,99	0,344	3,87561	0,33	18,44	4,89	3,77	0,00026	9,39	-14,53	29,90	417,73	33,00
2007	7,23	698,35	0,349	3,74633	0,29	18,02	4,38	4,12	0,00024	11,48	8,69	31,80	452,55	39,00
2008	7,08	687,42	0,348	3,68472	0,30	20,64	5,04	4,09	0,00024	14,56	-0,26	33,70	481,31	39,00
2009	7,24	725,19	0,351	3,87812	0,33	20,69	4,50	4,59	0,00023	19,46	-3,95	48,80	513,02	32,10
2010	6,86	698,36	0,350	3,68908	0,31	19,96	4,53	4,41	0,00022	23,95	-11,84	53,00	589,15	37,80
2011	6,78	718,81	0,347	3,61068	0,23	19,22	3,82	5,04	0,00022	30,84	-2,68	56,00	571,16	35,90
2012	6,59	715,90	0,355	3,62119	0,29	13,61	3,67	3,71	0,00021	19,11	6,17	59,00	448,15	32,30
2013	6,29	689,24	0,358	3,57327	0,32	52,84	14,92	3,54	0,00019	13,33	9,78	73,10	520,30	30,60
Bons	9,60	822,22	0,358	4,21599	0,23	9,02	2,54	5,04	0,0001903	30,84	27,63	73,1	417,73	30,60
2	8,50	777,29	0,346	4,00175	0,28	23,63	6,67	4,42	0,0002422	22,49	13,58	56,8	479,85	33,73
3	7,40	732,36	0,334	3,78751	0,32	38,24	10,80	3,81	0,0002941	14,13	-0,48	40,5	541,96	36,87
Neutros	6,29	687,42	0,322	3,57327	0,37	52,84	14,92	3,20	0,000346	5,78	-14,53	24,2	604,08	40,00

A.4 ETS Forecast Software Parameters



A.5 ETS Forecast Statistics

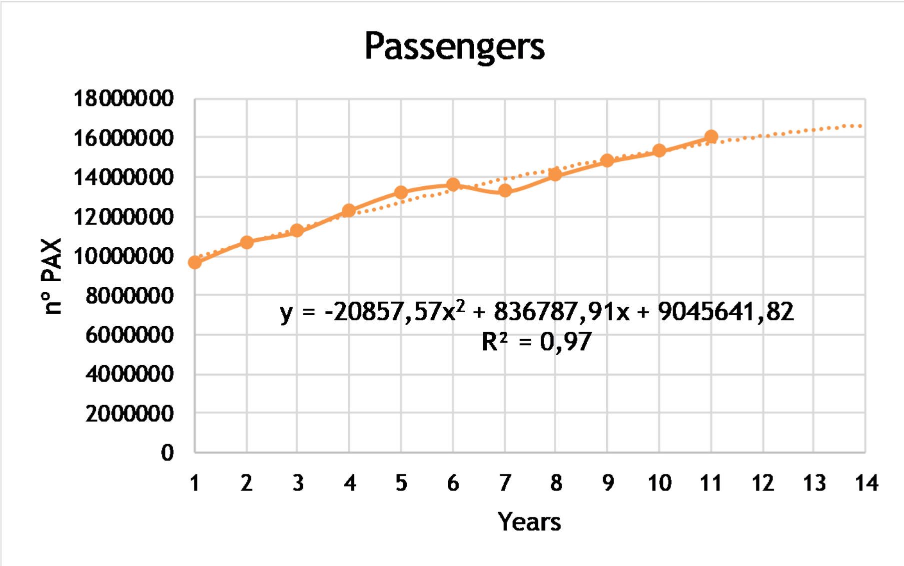
Passengers ETS forecast statistics. Source: own elaboration.

Statistics	Value
Alpha	1,00
Beta	0,25
Gamma	0,00
MASE	0,33
SMAPE	0,01
MAE	223080,41
RMSE	252245,76

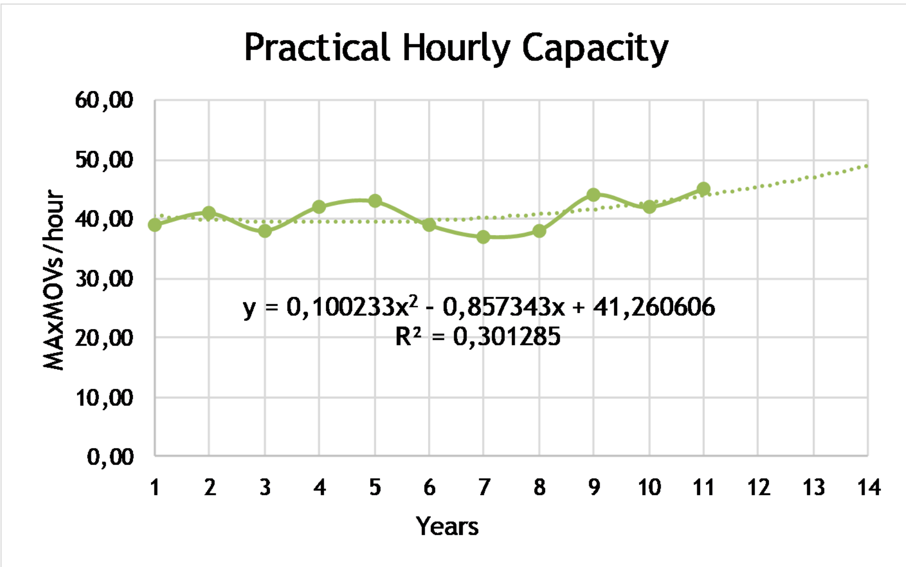
Aircraft movements ETS forecast statistics. Source: own elaboration.

Statistics	Value
Alpha	0,90
Beta	0,00
Gamma	0,00
MASE	0,31
SMAPE	0,01
MAE	1800,02
RMSE	252245,76

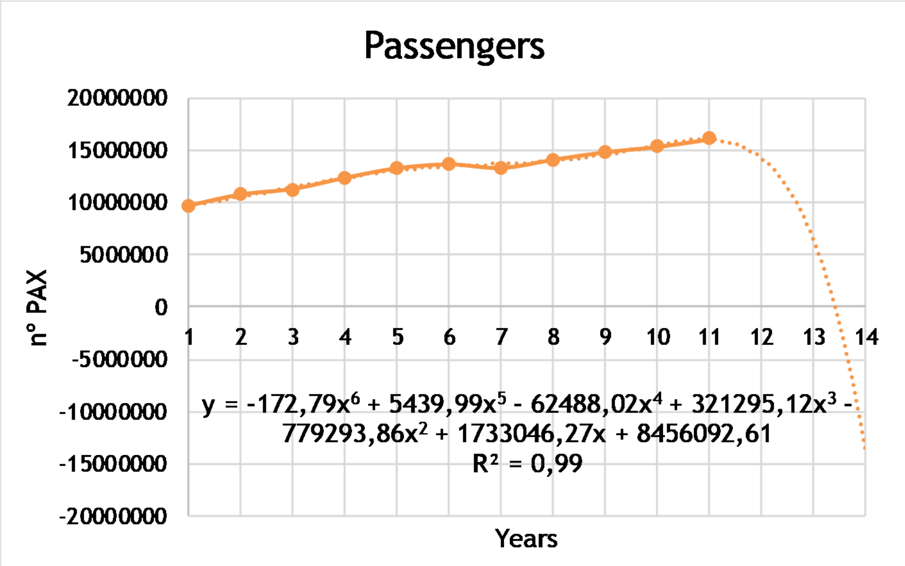
A.6 Regression Analysis Attempts



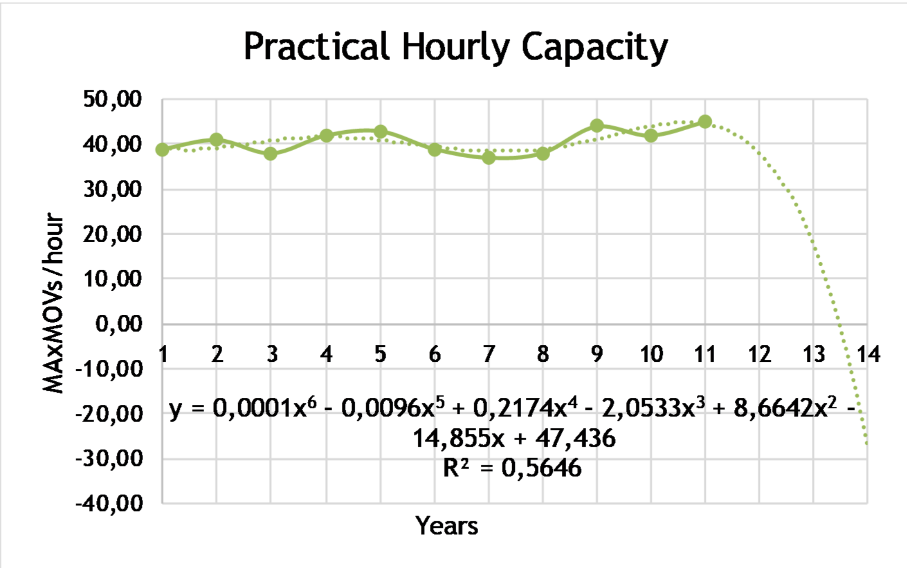
Passengers' trendline and forecast obtained with a quadratic polynomial. Source: own elaboration.



Practical hourly capacity trendline and forecast obtained with a quadratic polynomial. Source: own elaboration.



Passengers' trendline and forecast obtained with a polynomial of degree six. Source: own elaboration.



Practical hourly capacity trendline and forecast obtained with a polynomial of degree six. Source: own elaboration.

A.7 Publications' Abstracts

Intellectual Capital and Regional Development:
New Landscapes and Challenges for Planning the Space
2017 JULY 6-7
UBI, COVILHÃ, PORTUGAL
24th APDR CONGRESS
UNIVERSIDADE BEIRA INTERIOR
APDR

MODELAÇÃO E PREVISÃO DO DESEMPENHO DE AEROPORTOS

MODELLING AND FORECASTING AIRPORT PERFORMANCE

Nuno Valente[1], Maria E. Baltazar [2], Jorge Silva[3]

[1] Universidade da Beira Interior, Aerospace Sciences Department (DCA-UBI) Covilhã, Portugal
CERIS CESUR, Instituto Superior Técnico, Universidade de Lisboa, Lisboa, Portugal
nunorafav@gmail.com
[2] Universidade da Beira Interior, Aerospace Sciences Department (DCA-UBI) Covilhã, Portugal
CERIS CESUR, Instituto Superior Técnico, Universidade de Lisboa, Lisboa, Portugal
mmila@ubi.pt
[3] Universidade da Beira Interior, Aerospace Sciences Department (DCA-UBI) Covilhã, Portugal
CERIS CESUR, Instituto Superior Técnico, Universidade de Lisboa, Lisboa, Portugal
jmrs@ubi.pt

ABSTRACT

Airports are an essential part of air transport system, providing infrastructures to enable the transfer of passengers and freight between the land surface and air vehicles, to store and maintain aircraft and to accommodate other service providers needful to air transportation. Moreover, airports have strategic importance to the regions they serve as they bring wealth, employment opportunities, promote regional tourism and encourage economic development.

This paper addresses performance and efficiency of three Portuguese airports with the model development that describes and forecasts it.

An Ordinary Least Squares (OLS) based model has been developed to assess and compare three Portuguese benchmark airports' performances. Key Performance Areas (KPAs) and Key Performance Indicators (KPIs), from which airport performance is defined, are identified based on literature. Lastly, a forecasting is performed based on the model obtained. Forecasts effectiveness is assessed, and necessary adjustments are made. This adjustment may help airport managers to develop management strategies and to project its results.

Keywords: *airport performance, forecasting, modelling*

Airport Performance Analysis and Forecasting

Nuno Valente[1, 2, *], Maria E. Baltazar[1, 2], Jorge Silva[1, 2]

[1]Universidade da Beira Interior, Aerospace Science Department (DCA-UBI), Rua Marquês d'Ávila e Bolama, 6201- 001, Covilhã, Portugal.

[2]CERIS, CESUR, Instituto Superior Técnico, Universidade de Lisboa, Av. Rovisco Pais 1, 1049-001, Lisboa, Portugal

*Corresponding author: nunorafav@gmail.com

Co-authors email: mmila@ubi.pt; jmiguel@ubi.pt

Abstract

Airports are an essential part of air transport system, providing infrastructures to enable the transfer of passengers and freight between the land surface and air vehicles, to store and maintain aircraft and to accommodate other service providers needful to air transportation. Moreover, airports have strategic importance to the regions they serve as they bring wealth, employment opportunities, promote regional tourism and encourage economic development.
Air traffic has been growing at a high rate and airports are currently facing congestion in its infrastructures, threatening its operability. Due to capacity constraints, airport performance has been the subject of an increasing volume of empirical research in recent years.
This paper addresses the impact of passengers and aircraft movements on the airport performance through a sensibility analysis of the estimated global performance of a fictitious airport, representative of a Portuguese hub airport, through a multi criteria decision analysis (MCDA) model. It also intended to carry out forecasts of passengers and aircraft movements using a decomposition method for the same airport and predict its global performance.
The conducted forecast, along with the literature review, may contribute to assess its adequacy to a certain intended use and to depict the diversity of forecasting tools. Furthermore, it may help to assess the appropriateness of performance indicators choice and the weights assignment.

Keywords: *Airport Performance, Forecasting, MCDA, Exponential Smoothing*