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Airport Benchmarking
The Key Performance Area of Safety

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Dedicatory

This thesis is dedicated to my parents. For their endless love, support and encouragement throughout my life.

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First and foremost, I have to thank my parents for their love and support throughout my life. Thank you both for giving me the strength to carry on and pursue my dreams. My big brother deserves my wholehearted thanks as well.

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List of Publications

Articles produced as a result of this dissertation research in annexe 4:

1. **Airport Performance and Efficiency Assessment: A New Approach**
   Maria E. Baltazar, João Jardim, Pedro Alves, Paulo Marchão & Jorge Silva (2014). 18th ATRS World Conference.

2. **Determination and Evaluation of the Airport Catchment Area**
   Pedro Alves, Paulo Marchão, Maria E. Baltazar, Pedro Almeida & Jorge Silva (2014). 18th ATRS World Conference.

3. **Global Decision Analysis Model for Airport Performance Management**
   Maria E. Baltazar, Paulo Marchão, Francisco Fernandes & Jorge Silva (2015). 3 EJIL

4. **Airport Performance Management, Hinterland Impact, and Global Decision Analysis Model**
   Maria E. Baltazar, Paulo Marchão, Francisco Fernandes & Jorge Silva (2015). 12th Aviation Student Research Workshop

5. **Airport Benchmarking Process and the Key Performance Area of Safety/Security**
   Paulo Marchão, Maria E. Baltazar, Tiago Rosa, Jorge Silva (2015). AIRDEV II - 2nd International conference of the Airport Development Series, 4-6 November, Bangalore (India).

6. **The Airport as a Catalytic Element of the Regional Development in the Hinterland**
   Pedro Alves, Maria E. Baltazar, Paulo Marchão, Jorge Silva & Vasco Reis (2015). AIRDEV II

7. **Airport Benchmarking Process and the Key Performance Area of Safety**
   Paulo Marchão, Maria E. Baltazar, Tiago Rosa, Jorge Silva (2017). Case Studies on Transport Policy - Special issue "Airport Development (AIRDEV-2015)", (Manuscript submitted for publication).

8. **Airport Benchmarking Issues. The Key Performance Area of Safety**
   Paulo Marchão, Maria E. Baltazar, Tiago Rosa, Jorge Silva (2017).21ST ATRS WORLD CONFERENCE (Manuscript submitted for publication).

Resumo

A utilidade do processo de *benchmarking* de aeroportos é amplamente reconhecida num mundo onde a competição entre aeroportos se esta a tornar uma realidade cada vez mais presente. Logo há uma necessidade por um consenso mais amplo para estabelecer e construir bases de dados confiáveis para medir a *performance* de aeroportos e consequentemente o desenvolvimento e implementação de melhores e mais precisos sistemas de gestão da mesma.

Existem vários estudos focados na avaliação comparativa, mas sobretudo baseados em fatores económicos e de produtividade. No entanto há uma escassez de estudos focados na *performance* do aeroporto como um conjunto de áreas que devem ser abordadas numa verdadeira análise global.

Por meio de análise multicritério de apoio à decisão (*multiple-criteria decision analysis-MCDA*), aplicada à área de segurança operacional e no modelo desenvolvido designado por PESA-AGB (*Performance Efficiency Support Analysis- Airport Global Benchmarking*) por sua vez baseado na metodologia MACBETH (*Measuring Attractiveness by a Categorical Based Evaluation Technique*) pretende-se avaliar a *performance* de 3 aeroportos fictícios (O aeroporto A com características semelhantes ao Aeroporto de Lisboa com grande número de movimentos e também considerado o principal aeroporto português, o Aeroporto B, semelhante ao aeroporto do Porto com características próprias de um aeroporto de companhias aéreas de baixo custo e transporte de carga e por último o aeroporto C com semelhanças ao aeroporto de Faro, marcado pela sazonalidade da sua procura) e em dois processos distintos, numa análise comparativa por grupos de aeroportos pertencentes ao mesmo grupo, e numa análise comparativa de cada aeroporto ao longo de um período de 11 anos.

A *performance* da área de segurança é feita comparando classificações obtidas entre os aeroportos (*peer-benchmarking*) e através dos resultados obtidos por cada aeroporto nos últimos anos (*self-benchmarking*), demonstrando-se assim a utilidade e flexibilidade da ferramenta para os agentes com interesses ligados à infraestrutura aeroportuária.

Como um importante resultado constatou-se que a Área de Desempenho de Segurança tem o maior peso e, portanto, é a área mais importante em relação ao desempenho do aeroporto, de acordo com a pesquisa feita levando em conta as opiniões dos especialistas.

Os acidentes em pista como indicador de performance de segurança ocupam o lugar de maior importância e maior peso dentro dos indicadores de performance de segurança.

Através da análise da performance constatou-se que os aeroportos A, B e C têm desempenho médio a excelente na área de segurança com uma evolução positiva de uma maneira geral a partir de 2007 e com piores performances no ano de 2004.

Como outputs do modelo utilizado encontraram se medidas que permitem a análise de *performance* na área de Segurança. Com este tipo de avaliação deverá ser possível um melhor entendimento de como os aeroportos, infraestruturas de grande complexidade, lidam com as questões de segurança num processo de análise comparativa.

Palavras-chave

Análise Multicritério de Apoio à Decisão; Desempenho Aeroportuário; MACBETH; Segurança.

Resumo Alargado

Introdução

Esta secção resume, em língua portuguesa, o trabalho de investigação desta dissertação. É descrito o enquadramento da dissertação, é feita uma abordagem ao conceito de benchmarking, é explicado o modelo MCDA aplicado à área de Segurança, são analisados 4 casos de estudo, e termina com a apresentação das principais conclusões. Por fim são enunciadas algumas linhas de investigação para trabalhos futuros.

Enquadramento

Numa infraestrutura complexa como um aeroporto, uma das principais preocupações é a forma de melhorar o seu desempenho. Este é um assunto bastante problemático; a maioria das análises de desempenho de um aeroporto tenta fornecer dados objetivos para a gestão de recursos e o desempenho financeiro.

De igual modo, a motivação para a avaliação do desempenho de aeroportos está relacionada com a necessidade de melhores políticas públicas, pois com o advento da liberalização do comércio e privatizações dos serviços à escala mundial gerou-se uma intensificação da concorrência nos mercados mundiais, tornando-se assim ainda mais importante que os aeroportos ofereçam serviços de qualidade da forma mais eficiente e em todas as dimensões operacionais do aeroporto. A análise de desempenho permite a oportunidade para avaliar aeroportos individualmente ou grupos de aeroportos em relação às melhores práticas da indústria.

Também entre os aeroportos o processo de benchmarking assume uma importância cada vez maior, pois a competição entre eles está a tornar-se uma realidade cada dia mais presente. Logo há uma necessidade por um consenso mais amplo para estabelecer e construir bases de dados confiáveis para avaliar o desempenho de aeroportos e consequentemente o desenvolvimento e implementação de melhores e mais precisos sistemas da sua gestão.

Existem vários estudos focados na avaliação comparativa ou benchmarking, mas sobretudo baseados em fatores económicos e de produtividade. No entanto verificou-se uma escassez de estudos focados no desempenho do aeroporto entendido como um conjunto de áreas que devem ser abordadas numa verdadeira análise global.

Este trabalho foca-se numa dessas áreas, nomeadamente no desempenho da segurança, proporcionando assim a oportunidade de avaliar com o benchmarking aeroportuário, individualmente ou por grupos de aeroportos, indo assim ao encontro do interesse crescente por esta matéria demonstrado por operadores, companhias aéreas, reguladores, empresas de consultoria e analistas financeiros. Também desta forma, e aplicando uma metodologia MCDA, será possível avaliar a utilidade de uma ferramenta que pode ser valiosa para a gestão aeroportuária, ajudando a identificar falhas de desempenho através da comparação com os *standards* e as melhores práticas da indústria. Esta comparação com as melhores práticas da indústria reflete-se neste trabalho com a auscultação a vários especialistas na área aeroportuária em geral, e na de segurança em particular. Desta forma é possível complementar o melhor entendimento global da segurança dentro da estrutura aeroportuária, fazendo frente aos desafios crescentes no sistema de transporte aéreo e detetando variações no seu desempenho.

Casos de estudo

O principal objetivo será então o de conseguir uma avaliação do desempenho da Área de Segurança do Aeroporto, através dos Indicadores de Segurança considerados mais relevantes que a constituem. Para tal serão analisados quatro casos de estudo, tanto no desempenho de aeroportos individualmente ao longo de vários anos, como também englobando uma análise de desempenho entre aeroportos do mesmo grupo.

Para tal usou-se o modelo PESA-AGB (*Performance and Efficiency Support Analysis for Airport Global Benchmarking)* baseado em Macbeth (Measuring Attractiveness by a Categorical Based Evaluation Technique) em três aeroportos, A, B e C, (Aeroporto A com características semelhantes ao Aeroporto de Lisboa com grande número de movimentos e passageiros e também considerado o principal aeroporto português, o Aeroporto B, semelhante ao aeroporto do Porto com características próprias de um aeroporto de companhias aéreas de baixo custo e transporte de carga e por último o aeroporto C com semelhanças ao aeroporto de Faro, marcado pela sazonalidade da sua procura) com características distintas e que podem representar as principais infraestruturas aéreas portuguesas ao longo de 11 anos (2003-2013).

Principais conclusões

- A Área de Desempenho de Segurança tem o maior peso e, portanto, é a área mais importante em relação ao desempenho do aeroporto, de acordo com a pesquisa feita com a opiniões dos especialistas.
- Os acidentes em pista ocupam o lugar de maior importância dentro dos indicadores de performance de segurança, com 21,57% de peso, já que os especialistas consideram que esse indicador tem um grande impacto na área de segurança de qualquer aeroporto. A menor preocupação para os especialistas é o Tempo de Trabalho Perdido por Acidentes e Lesões dos Empregados com o valor de 11,76%.
- No Self-Benchmarking do Aeroporto A, podemos perceber que os acidentes de pista têm a maior pontuação ao longo desses anos. O melhor ano para a Área de Desempenho de

Segurança foi em 2007 e o pior de 2004 com uma pontuação abaixo de 50. A partir da análise do quadrante, pode-se mostrar que, tanto para a Pontuação do Aeroporto quanto para a Área de Segurança, a maior parte dos anos neste estudo tem bons registos, apenas 2004 tem uma performance mais fraca.

- Em relação ao aeroporto B, semelhante ao aeroporto do Porto, o ano com melhor classificação para a Área de Desempenho de Segurança foi 2008 seguido de perto por 2011 e o pior 2004. A partir da análise de quadrantes, pode-se mostrar que, tanto para a Pontuação do Aeroporto quanto para a Área de Segurança, a maior parte dos anos neste estudo tem bons registos, com os anos 2007-2013 com desempenho excecional e os anos 2003-2006 um desempenho médio.
- Para o aeroporto C, semelhante ao aeroporto de Faro, o melhor ano no desempenho global da área de segurança é 2013, e o pior é 2009, no entanto, sendo o pior relativamente, tem uma pontuação média de 59,48. A análise do quadrante revela os anos 2007-2013 com um desempenho igualmente excecional e os anos 2003-2006 com desempenho médio.
- Em relação à análise de Peer-Benchmarking dos scores da SKPA e das pontuações globais dos 3 aeroportos, podemos fazer algumas pressuposições. Há uma relação sobre as Pontuações de Desempenho de Segurança dos aeroportos, anos 2004 e 2010, por exemplo, têm pontuações de avaliação mais baixas em termos de Desempenho de Segurança no Peer Group, esta é uma conclusão importante, pois talvez possam correlacionar crise económica ou outro tipo de acontecimento externo e suas repercussões na Área de segurança de um aeroporto.
- Os outputs do modelo PESA-AGB permitem identificar ações na área de segurança e monitorizar os resultados da Área de Segurança alcançados pelos aeroportos para que as partes interessadas possam acompanhar o desempenho e os valores ao longo do tempo.Com base nessa informação, é possível obter um perfil de valor da Área de Segurança Operacional dividido em três principais zonas de desempenho, evidenciando: um limite superior ao "bom"; a zona de conformidade entre linhas "boas" e "neutras" e uma zona de não conformidade abaixo da linha "neutra". Ou seja, a partir de um perfil de valor de Segurança do aeroporto, é possível observar quais são as opções com o melhor perfil e quais são os que exigem intervenção. Além disso, uma análise de quadrante permite observar o verdadeiro impacto da SKPA nos scores gerais do aeroporto.

Perspetivas de trabalhos futuros

Para trabalho futuro e para reforçar o impacto da área de segurança e respetivos indicadores no desempenho geral do aeroporto, outras abordagens deveriam ser feitas em complemento:

- Delinear diferentes cenários que testarão a sensibilidade do modelo;

- Expandir o modelo a outros aeroportos de características operacionais distintas;
- Aplicar o modelo a mais indicadores nesta área, bem como a outros que contemplem também a segurança contra atos ilícitos;
- Desenvolver uma aplicação, com base TIC, que permita a avaliação em tempo real do impacto dos indicadores de segurança no desempenho quer da própria área, quer no do aeroporto em geral.

Abstract

The utility of an airport benchmarking process is widely recognised in a world where competition between airports is becoming a reality. Therefore, there is a need for a broad consensus to establish and construct reliable databases for measuring airport performance and consequently the development and the implementation of even more accurate performance management systems. A wide number of studies that focus on airport benchmarking - but mainly based on economic and productivity performance indicators are done and can be found in the literature. However, there is a lack of studies that focus on the airport performance in a holistic form, set in different areas for a truly global analysis.

A Multi-Criteria Decision Analysis (MCDA) approach applied to Safety key performance area from PESA–AGB (Performance Efficiency Support Analysis – Airport Global Benchmarking) model. This model is based on MACBETH (Measuring Attractiveness by a Categorical Based Evaluation Technique) methodology is used to evaluate its impact on the overall performance of three airports; and under two distinct processes, peer and self-benchmarking - along eleven years.

The Safety area performance analysis is done describing four case studies, where a self-benchmarking analysis was conducted for three airports, A, B and C, with distinctive characteristics, each one representing the main Portuguese air infrastructures: Airport A is considered the largest one in terms of number of passenger and movements, related to Lisbon airport; Airport B mainly a Low-Cost Carrier (LCC) and Cargo one, resembling Oporto airport; and finally Airport C, an LCC oriented one with seasonality peaks along the year resembles the Faro airport. The last case study englobes the three airports in a peer-benchmarking analysis.

As an important result, it was found that the Safety Performance Area has the greatest weight and therefore is the most important area in relation to airport performance, according to research done considering the opinions of experts.

Through the performance analysis, it was found that airports A, B and C have medium to excellent performance in the security area, with a positive evolution in general since 2007 and with worse performances in 2004.

The results evidence the importance of this type of evaluation to understand how airports deal with Safety issues and how this key performance area may impact in any benchmarking process, and on the overall evaluation of such complex transport infrastructure too.

Keywords

Airport Benchmarking; MACBETH; Multi-Criteria Decision Analysis; Safety.

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List of Acronyms

A-CDM	Airport Collaborative Decision Making.
ACI	Airports Council International.
ACT	Autoridade para as Condições de Trabalho.
ADREP	Accident and Incident Data Reporting.
AHP	Analytic Hierarchy Process.
ANAC	Autoridade Nacional da Aviação Civil.
APU	Auxiliary Power Unit.
ASRS	Aviation Safety Reporting System.
ATFCM	Air Traffic Flow and Capacity Management.
ATM	Air Traffic Management.
ATRS	Air Transport Research Society.
CAA	Civil Aviation Authority.
CAST	Commercial Aviation Safety Team.
CBR	Case-Based Reasoning.
CDM	Collaborative Decision Making.
CFIT	Controlled flight into terrain.
CICTT	CAST/ICAO Common Taxonomy Team.
DEA	Data Envelopment Analysis.
EASA	European Aviation Safety Agency.
EU	European Union.
FAA	Federal Aviation Administration.
GB	Goal Programming.
HRC	High-risk accident occurrence categories.
IATA	International Air Transport Association.
IBIS	ICAO Bird Strike Information System.
ICAO	International Civil Aviation Organization.
JAR	Joint Airworthiness Requirements.
KPA	Key Performance Area.
KPI	Key Performance Indicator.
LCC	Low-Cost Carrier.
LOC-I	Loss of Control in Flight.
LPPs	Linear Programming Problems.
MACBETH	Measuring Attractiveness through a Category-Based Evaluation Technique.
MAUT	Multi-Attribute Utility Theory.
MCDA	Multi-Criteria Decision Analysis.
OSH	Occupational safety and health.
PESA-AGB	Performance and Efficiency and Analysis Airport Global Benchmarking.

RS	Runway Safety related events.
SFA	Stochastic Frontier Analysis.
SKPA	Safety Key Performance Area.
SKPI	Safety Key Performance Indicator.
SMART	Simple Multi-Attribute Rating Technique.
SMS	Safety Management Systems.
SPI	Safety Performance Indicator.
TFP	Total Factor Productivity.
UK	United Kingdom.
USA	United States of America.
WLU	Work Load Unit.

Chapter 1

Introduction

1.1. Motivation

What is the main concern that leads to research in safety performance evaluation in airports and who is interested in the outcomes of these studies?

When handling with a complex infrastructure like an airport, one of the main concerns is how to improve its performance; this is a very problematic subject as most performance analysis of an airport tries to supply objective data for resource management and financial performance and compares it. In consequence, identifies the standard and best practices for the services. These studies are helpful for different groups of stakeholders and airports users. For example, there are airlines companies interested in airport performance those studies. There are also economic factors related to the airport and others, like regulation at state, European and world level, that would improve the local infrastructure performance.

Another reason for the performance evaluation of airports is the necessity for better public policies facing the advent of commercialisation and privatisation worldwide. With competition intensifying at the world markets, it became more necessary for airports to provide quality service in a more efficient way and impacting on all the operational dimensions of the airport. The performance analysis allows the opportunity to evaluate and measure airports individually or groups of airports compared to the best practices in the industry. Consequently, operators, airlines, regulators, consulting companies and financial analysts show an increased interest in this kind of information.

The performance analysis is necessary also for the managers; they help to identify the flaws in their projects by comparison with standards. So, in that way, it helps in gaining a better understanding of the problems in the transportation system; and so detecting variances in performance.

Another reason that motivates this study is the relative uniqueness of airports, as all the airports differ in modus operandi and are also very challenging to try to evaluate those differences. Maybe, for this motive, there is a shortage of studies that measure the performance of Portuguese airports [1],[2].

At a global level, those studies are based mainly on international reports such as Air Transport Research Society (ATRS) and Airports Council International (ACI) that publish performance data in airports of different sizes and owners.

Most of the studies focus on the productivity and financial aspects and usually use methodologies based on partial performance indicators, like Total Factor Productivity (TFP) or Data Envelopment Analysis (DEA). This study is focused in the key performance area of safety in a more general view of the complexity of an infrastructure like an airport; and so, this study includes a broader and not so driven input/output view of this fundamental and important area in commercial aviation.

1.2. Object and Objectives

The object of this thesis is Airport Safety Area. The main objective is to assess the performance of the Airport Safety Area using the PESA-AGB model. This model is based on Measuring Attractiveness by a Categorical Based Evaluation Technique (MACBETH); this model was applied in three airports, A, B and C, with distinctive characteristics representing the main Portuguese air infrastructures along 11 years (2003- 2013):

This analysis is done describing four case studies, where in the first three a self-benchmarking analysis was made, Airport A is considered the largest one in terms of number of passenger and movements, related to Lisbon airport; Airport B mainly a Low-Cost Carrier (LCC) and Cargo one, resembling Oporto airport; and finally, Airport C, an LCC oriented one with seasonality peaks along the year resembles the Faro airport. The last case study englobes the three airports in a peer-benchmarking analysis.

1.3. Dissertation Structure

The dissertation is divided into six chapters, that can be summarised as follows.

The first chapter is the work introduction and presents the motivation, the object and objectives, and the dissertation structure.

The second chapter presents a state of the art and literature review in airport safety, analysing the trends in total numbers and rates, framing the current situation regarding the main categories of accidents and, also, looks at the existent mechanisms at the regulation level and others to improve, or maintain the current rates.

The third chapter is a state of the art and literature review over airport benchmarking and performance evaluation, as well as an overview of safety areas and indicators best practices and legislation. It also includes a methodology overview and comparison, used in the decision-making of airports, as long as advantages and disadvantages of the commonly used models.

The fourth chapter describes the method with a short description of Multi-Criteria Decision Analysis (MCDA), namely Measuring Attractiveness through a Category-Based Evaluation Technique (MACBETH) approach, describing the mathematical foundations as well as the strengths and downsizes of the methodology. Lastly, there is a description of the model adaptation for the assessment of the Safety Key Performance Area and Indicators, called PESA-AGB, including all the steps necessary for the performance evaluation.

The fifth chapter contains the case studies where is applied the methodology referenced in chapter four to assess the airport safety performance and efficiency for three different airports with different characteristics and complexities. The assessment of those infrastructures that belong to the same airport group is done firstly individually along 11 years as a self-benchmark and then comparing between themselves as a peer-benchmark along the same years.

Chapter six presents a brief dissertation summary and some concluding remarks and finally proposes insights for the development of future research in this area.

Chapter 2

Airport Safety

2.1. Introduction

Despite accidents in aviation making headlines all over the world, aviation is arguably the safest mode of mass transportation [3], and the technological development over the years has provided outstanding safety records for commercial aviation [4]. While the quest for zero accidents or serious incidents and the achievement of absolute control is a good demand, they are in fact unachievable goals in an open and dynamic operational context. Accidents and non-predicted events will invariably happen, and the probable cause for that will be a Safety failure of some kind [5].

A more realistic objective of Safety would be to bring under control, in aviation operational contexts, all variables that can be hasty wrong or damaging outcomes. A definition of Safety would be as according to International Civil Aviation Organization (ICAO) “The state in which the possibility of harm to persons or of property damage is reduced to, and maintained at or below, an acceptable level through a continuing process of hazard identification and safety risk management” [5] (pp.2-1).

Therefore, Safety risk must nonetheless improve its rates, and safety policies must be implemented at a predictive level, and from that perspective, this area is enhanced through organisational structure and processes that identify possible failure conditions. Corrections or mitigations are implemented to reduce ongoing failures and avoid accidents. Over time, these efforts have become essential to formalising Safety Management Systems (SMS). An SMS is made up of a proactive, systematic, and prescriptive set of guidelines, policies, and practices for managing safety at an airport, airline, or general aviation-related operation. The Civil Aviation Authority (CAA) defines SMS as a “formal, top-down business-like approach to managing safety risk. It includes systematic procedures, practices, and policies for the management of safety (including safety risk management, safety policy, safety assurance, and safety promotion)” [6] (pp.2).

Besides that, Aviation organisations must satisfy regulations, including requirements of management systems, e.g., safety quality, environment, and occupational safety. Standards for quality, environment and occupational health and safety [7] and [8] have been integrated with each other to enable airports to align or integrate the various management systems in case they wish to do so [9]. The common requirements for air navigation service providers, allow organisations to combine the different management systems into one, so it is vital to understand how SMS’s interact with them.

Nevertheless, the operational experience with measuring the effectiveness of safety management systems is insufficient, and there are many questions yet to be answered on measuring safety performance, demonstrating compliance with safety management regulations and the relation with quality management and safety culture. In our case, there is a merge between causes of hazards related to safety and causes of hazards related to occupational safety [10].

2.2. Accident Database and Accident Rates in Commercial Aviation

Statistical data of Commercial air transport acknowledge that flight safety has increased and that are fewer accidents worldwide since 1959 through 2015 [4]. Therefore, it is one of the reasons society still regards air transportation as a secure way of travel, and its growth continues to demonstrate it. Still, when accidents happen, it makes headlines in the news all over the world, reminding people of the potentially catastrophic consequences; and for that, safety is a crucial component of the commercial aviation model, meaning that accidents risk per flight must continue to decrease.

Therefore, given the importance of accidents in aviation, and given the purpose it supports, a safety performance evaluation of accidents was made in commercial aviation and its evolution over the years, to assert the actual context of safety occurrences at the moment.

Occurrences reporting in commercial aviation are kept by the Accident and Incident Data Reporting (ADREP) database, operated and maintained by International Civil Aviation Organization (ICAO); the ADREP database receives, stores, and provides States with occurrence data that will assist them in validating safety. In this context, the term ‘occurrence’ includes both accidents and incidents.

According to ICAO´s Aircraft accident and incident investigation, Annex 13 [11] (pp.1) the definition of an accident is described as follows:

> “Accident. An occurrence associated with the operation of an aircraft which takes place between the time any person boards the aircraft with the intention of flight until such time as all such persons have disembarked, in which:

a) a person is fatally or seriously injured as a result of:
   - being in the aircraft, or
   - direct contact with any part of the aircraft, including parts which have become detached from the aircraft, or
   - direct exposure to jet blast,

except when the injuries are from natural causes, self-inflicted or inflicted by other persons, or when the injuries are to stowaways hiding outside the areas normally available to the passengers and crew; or:

b) the aircraft sustains damage or structural failure which:

— adversely affects the structural strength, performance or flight characteristics of the aircraft, and

— would normally require major repair or replacement of the affected component,

except for engine failure or damage, when the damage is limited to the engine, its cowlings or accessories; or for damage limited to propellers, wing tips, antennas, tires, brakes, fairings, small dents or puncture holes in the aircraft skin; or

c) the aircraft is missing or is completely inaccessible.

Note 1. For statistical uniformity, only, an injury resulting in death within thirty days of the date of the accident is classified as a fatal injury by ICAO.

Note 2. An aircraft is considered to be missing when the official search has been terminated, and the wreckage has not been located".

The analysis for accidents of fixed-wing aircraft in commercial aviation was taken from Boeing Company database occurrence reporting, and the resulting curve of some fatal accidents per year is given in Figure 2.1.

Since 1960 annual fatal accident rates have continued to decrease, currently, worldwide fatal accident rates are just over 0.010 per million for the US and Canada, and 0.035 for the rest of the world; there is a decrease in the number of accidents from 1990.

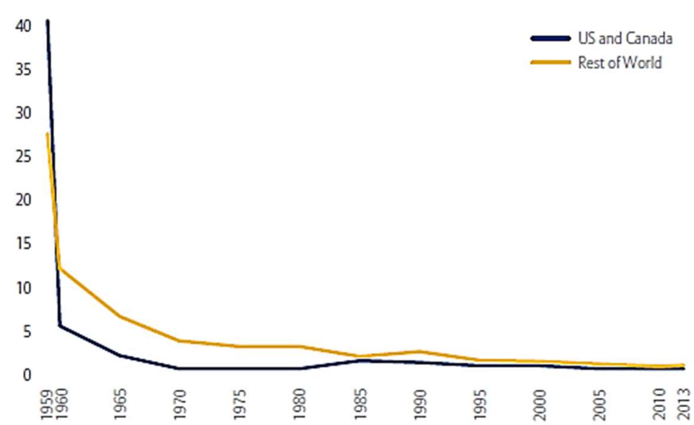

Figure 2.1 - Worldwide annual fatal accident rates per 1 million departures.
Source: Boeing Co. Statistical Summary [4].

Figure 2.2 - Number of passengers carried and fatalities per passengers carried data. Source: IATA / Industry Economic Performance [12].

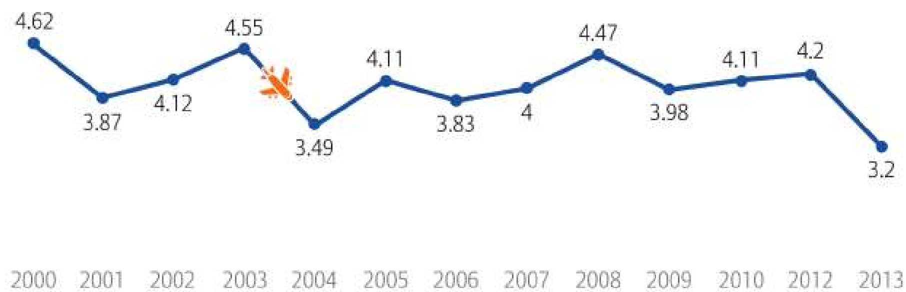

Figure 2.3 - Global accident rate per million departures; scheduled commercial air transport. Source: Allianz Global Corporate & Specialty [13].

Using the same flight selection criteria, analysing the number of passengers carried in the more recent period (2006–2015) as shown in Figure 2.2, we can see that besides the passenger's numbers steadily increasing, there is an inverse trend in the number of fatalities.

The calculated accident rates in Figure 2.3 are obtained by dividing the number of accidents for scheduled flights in each year by the total number of scheduled flights for that year; the curve in Figure 2.3 indicates that the accident rate hovered around four accidents per one million departures in the last two decades.

2.2.1 Taxonomy

ICAO and the Commercial Aviation Safety Team (CAST), including states and industry leaders, have jointly commissioned the CAST/ICAO Common Taxonomy Team (CICTT). CICTT includes experts from several air carriers, aircraft manufacturers, engine manufacturers, pilot associations, regulatory authorities, transportation safety boards, ICAO, and members of Canada, the European Union - France, Italy, the Netherlands, the United Kingdom and the United States [14]. CICTT is co-chaired by one representative each from ICAO and CAST. The objective is to enhance aviation safety through the development and promotion of common terminology, definitions, and taxonomies used to describe aviation safety events [14].

International adoption of these standard descriptors harmonises the value of aviation safety information by facilitating the sharing and analysis of safety information. [14] defines specific occurrence categories that apply both to incidents and to accidents, and groups them in six classes (Table 2.1).

Table 2.1 - Operational grouping of categories.

Airborne	
ABRUPT MANOEUVRE	AMAN
AIRPROX/TCAS ALERT/LOSS OF SEPARATION/NEAR MIDAIR COLLISIONS/MIDAIR COLLISIONS	MAC
MAC	
CONTROLLED FLIGHT INTO/TOWARD TERRAIN	CFIT
FUEL RELATED	FUEL
GLIDER TOWING RELATED EVENTS	GTOW
LOSS OF CONTROL – INFLIGHT	LOC–I
LOSS OF LIFTING CONDITIONS EN-ROUTE	LOLI
LOW ALTITUDE OPERATIONS	LALT
UNINTENDED FLIGHT IN IMC	UIMC
Aircraft	
FIRE/SMOKE (NON-IMPACT)	F-NI
SYSTEM/COMPONENT FAILURE OR MALFUNCTION (NON-POWERPLANT)	SCF–NP
SYSTEM/COMPONENT FAILURE OR MALFUNCTION (POWERPLANT)	SCF–PP
Ground Operations	
EVACUATION	EVAC
FIRE/SMOKE (POST-IMPACT)	F–POST
GROUND COLLISION	GCOL
GROUND HANDLING	RAMP
LOSS OF CONTROL – GROUND	LOC–G
RUNWAY EXCURSION	RE
RUNWAY INCURSION – ANIMAL	RI–A
RUNWAY INCURSION – VEHICLE, AIRCRAFT OR PERSON	RI–VAP
Miscellaneous	
BIRD	BIRD
CABIN SAFETY EVENTS	CABIN
EXTERNAL LOAD RELATED OCCURRENCES	EXTL
OTHER	OTHR
SECURITY-RELATED	SEC
UNKNOWN OR UNDETERMINED	UNK
Non-aircraft-related	
AERODROME	ADRM

ATM/CNS	ATM
Takeoff and Landing	
ABNORMAL RUNWAY CONTACT	ARC
COLLISION WITH OBSTACLE(S) DURING TAKE-OFF AND LANDING	CTOL
UNDERSHOOT/OVERSHOOT	USOS
Weather	
ICING	ICE
TURBULENCE ENCOUNTER	TURB
WIND SHEAR OR THUNDERSTORM	WSTRW

Source: [14].

2.2.2 High-risk accident occurrence categories

An analysis that englobes all type of accidents in commercial aviation proves itself useful, and the conclusion that accidents rates are diminishing is good news for commercial aviation. However, it is important to address the safety of the airport system, so a more detailed approach to the various accident categories will shed some light over the main categories involved. ICAO identified three high-risk accident occurrence categories (HRC):

- runway safety-related events (RS);
- loss of control in-flight (LOC-I);
- controlled flight into terrain (CFIT).

Runway safety-related events include ICAO's accident occurrence categories: Abnormal Runway Contact, Birdstrike, Ground Collision, Ground Handling, Runway Excursion, Runway Incursion, Loss of Control on Ground, Collision with an obstacle(s), Undershoot / Overshoot, Aerodrome [15].

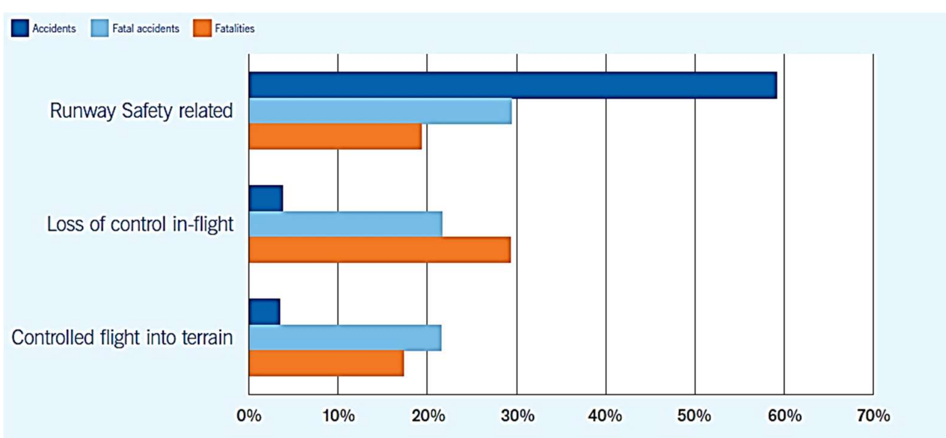

Figure 2.4 - Percentage of high-risk accident occurrence categories in all accidents: 2005–2010.

Source: [4].

Figure 2.4 illustrates that Runway safety accidents represent 59% of all accidents, accounting for 29% of all fatal accidents and 19% of all related fatalities reported between 2005 and 2010. While the loss of control in-flight occurrence category represents only 4% of all accidents, this category is of significant concern as it accounts for 22% of all fatal accidents and 29% of all fatalities. Similarly, accidents related to controlled flight into terrain account for only 3% of all accidents but represent 22% of all fatal accidents and 17% of fatalities.

2.2.3 Runway Incursions

A runway incursion is an occurrence where an unauthorised aircraft, vehicle or person is on a runway; this adversely affects runway safety, as it creates the risk that an aeroplane is taking off or landing will collide with the object. The Procedures for Air Navigation Services — Air Traffic Management (ATM) [16] (pp.1-15) defines a runway incursion as: “Any occurrence at an aerodrome involving the incorrect presence of an aircraft, vehicle or person on the protected area of a surface designated for the landing and take-off of aircraft.” Being aware that this “incorrect presence” may be a consequence of a failure of a pilot to comply with a valid ATM clearance or their compliance with an inappropriate ATM clearance [17].

For Figure 2.5 and Figure 2.6 both runway incursions categories are shown. One for vehicles, aircraft or persons and the other for animals in the perimeter; as the curves illustrates there is no clear tendency over the recent period, with a maximum of 8 times per million flights for the two categories and an average of 0.05 times per million flights.

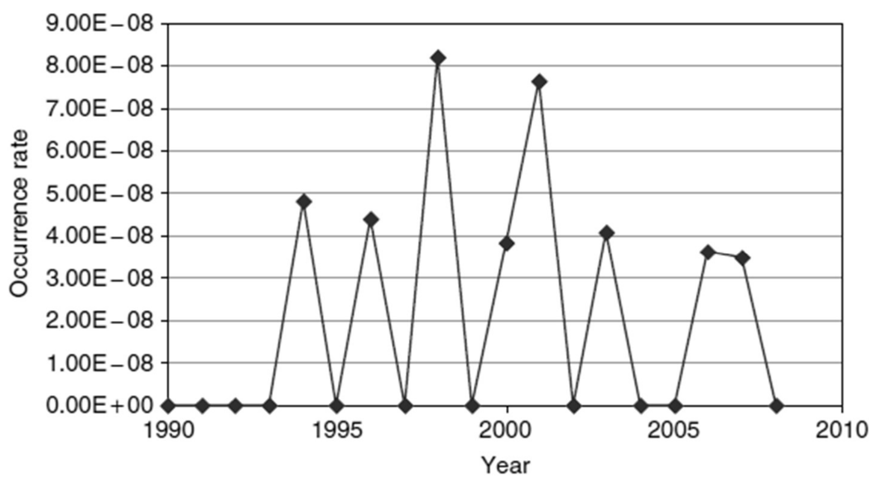

Figure 2.5 - Occurrence rates for runway incursion – vehicle, aircraft or person.
Source: [15].

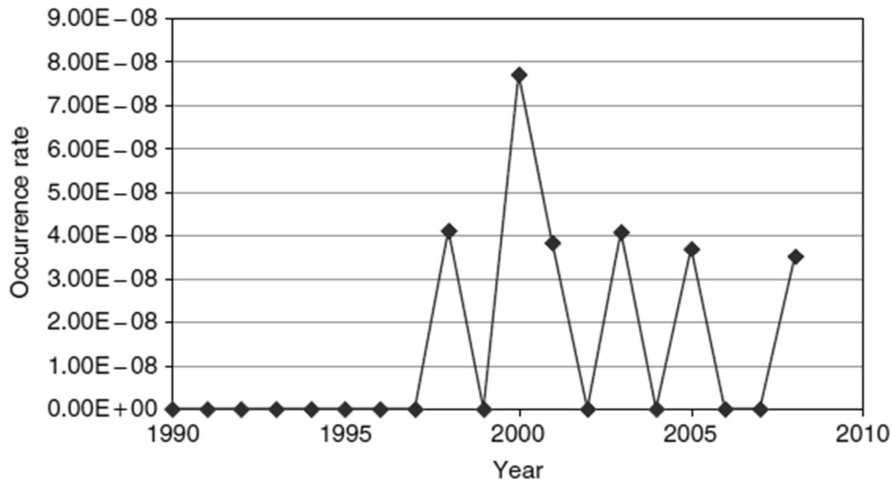

Figure 2.6 - Occurrence rates for runway incursion – animal.

Source [15].

2.3. Bird Strikes

A bird strike is strictly defined as a collision between a bird and an aircraft which is in flight or on a take-off or landing roll. The term is often expanded to cover other wildlife strikes - with bats or ground animals.

Unfortunately, Bird Strikes are a quite common hazard and can be a major risk to aircraft safety. Particularly in the case of smaller aircraft, substantial damage may be sustained to the aircraft structure and all aircraft in general, especially jet-engine ones, are susceptible to the risk of having loss of thrust due to suction of birds into engine air intakes, and this has led to catastrophic consequences resulting in several fatal accidents; nowadays, bird strikes have resulted in the loss of at least 231 lives and 42 aircraft in civil aviation [18].

Bird strikes may arise during any phase of flight but are most probably during the take-off, initial climb, approach and landing phases due to the greater numbers of birds in flight at lower levels [19]; that is why this is of utmost importance for airport wildlife management. Since most birds fly mainly during the day, most of this kind of incidents occur during daylight hours as well.

One of the most significant potential hazards at airports is the collision between aircraft and wildlife which may result in damage to the aircraft or even its structural failure (e.g. engine failure from the suction of birds). Although wildlife strikes are most commonly associated with birds, mammals such as deer, coyotes, or stray dogs wandering the runways can be a significant hazard to aircraft operational safety.

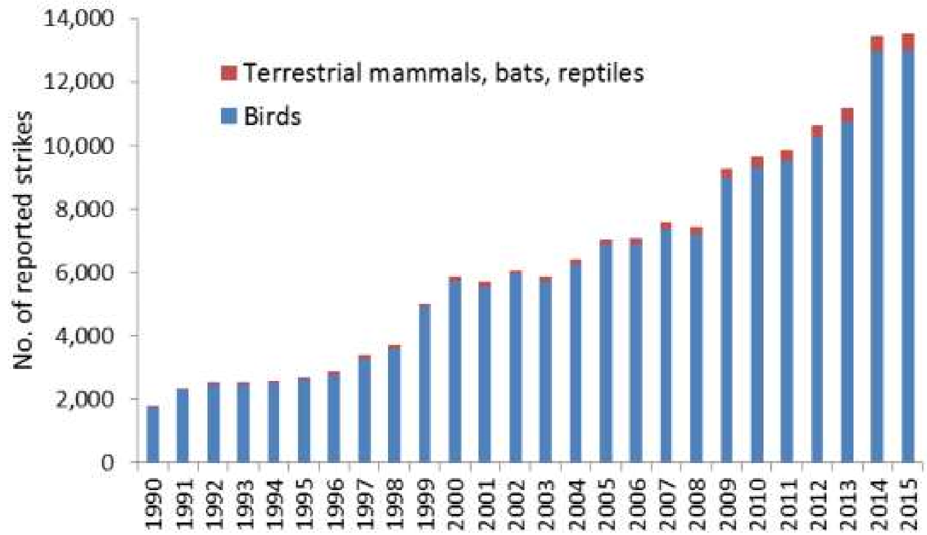

Figure 2.7 - Number of reported wildlife strikes with civil aircraft, USA, 1990–2015. Source: [20].

As depicted in Figure 2.7, from 1990 to 2015, 166,276 strikes involved birds (160,894), terrestrial mammals (3,561), bats (1.562), and reptiles (259). The trend is positive, probably due to a combination of factors including air traffic growth, reporting due to improved wildlife management implementation and bird population growth.

As 90% of all bird and mammal strikes occur at or near airports [21], the single most significant contributor to the reduction of associated risk is a well-managed and supported science-based, wildlife-management program. The civil aviation authority should ensure that any procedures in the airport certification manual relating to bird/wildlife control are developed and implemented as part of the aerodrome SMS [21].

So, Airport and aerodrome operators should [22]:

- monitor and manage aerodrome-wildlife habitats and food sources that may result in hazards;
- monitor the management of off-aerodrome land use and wildlife food sources related to hazards;
- manage wildlife hazards at and near aerodromes, and implement programs to control the presence of birds and mammals; and
- conduct training programs for wildlife-management personnel.

The ICAO Annex 14 [23] requires States to assess the bird/wildlife strike hazard on, and in the vicinity of, an aerodrome. This could be implemented through the establishment of a national procedure for recording and reporting bird/wildlife strikes to aircraft and the collection of information on the presence of birds/wildlife in the vicinity of the aerodrome which constitutes a potential hazard to aircraft operations. This Annex also requires States to collect and forward bird/wildlife strike reports to ICAO for inclusion in the ICAO Bird Strike Information System (IBIS). The IBIS system consists of the reporting forms and subsequently computer storage of strike reports and analysis of strike data. Data collected by IBIS may be used by States that do not have computerised bird/wildlife strike, data collection systems, to evaluate their efforts to control bird/wildlife strikes at airports with similar bird/wildlife ecology.

2.4. Regulation

International air transport developed and became more complex over the past half century, as well its regulation too. "Regulation is the giving of authoritative direction to bring about and maintain a desired degree of order. All regulation involves regulatory process, various patterns of activity by people interacting to establish and maintain some desired result for the subject or entities being regulated. Similarly, all regulation involves regulatory structure, i.e. the organisations or other entities involved and the legal framework (such as licences, regulations and agreements). Finally, "all regulation involves regulatory content, the particular subjects being regulated (such as market access, pricing and capacity)" [24] (pp.III).

A specialised agency of the United Nations, the International Civil Aviation Organization (ICAO) was created in 1944 to promote the safe and orderly development of international civil aviation throughout the world [25]. At a global level, ICAO is the organisation that regulates operating procedures for international aviation and issues, which is, all standards and recommended practices in every detail. However, with the advent of ICAO, and the following standards defined by this organisation, national regulation did not become unnecessary. Many aspects of aviation are subject to national requirements, and in the case of Portugal, the national authority for civil aviation, Autoridade Nacional da Aviação Civil (ANAC), acts accordingly with the European Joint Airworthiness Requirements (JAR) and subsequent European Aviation Safety Agency (EASA) Regulations.

National regulations on aircraft design, operations and maintenance are still much more accurate and detailed than their international counterpart, while for air traffic management, air navigation services and airports the contrary is true. At the beginning of commercial aviation, air traffic management didn't exist. Pilots had to maintain separation with other aircraft by sight and consequently, the increase of air traffic resulted in an increasing number of mid-air collisions too; thus national Civil Aviation Authorities started to protect their flight regions with air traffic controllers assisting pilots to maintain safe operations. The role of ICAO then was to harmonise operations and to set standards for equipment. These flight regions making part of the CAAs became under control with either regulation or oversight of ATM related safety issues. Hence, when there was an ATM related safety problem, those flight regions had to find and solve it, lacking the presence of an independent national observer. Only during the 1990s, developments started to introduce safety management system principles, and the separation of the regulation, the oversight and the service provision from each other.

Similar difficulties also apply regarding the relations between airport operators and regulation/ oversight.

Thus ICAO's, the main activities can be summarised as follows [26]:

- Harmonizing global regulatory framework by developing policies and guidance as those contained in the Policy Guidance on the Economic Regulation of International Air Transport [27];
- Serving as a global forum for cooperation and concerted actions, providing practical solutions to address challenges of emerging regulatory challenges of global importance, such as market access, air carrier ownership and control, consumer protection, competition, assurance of essential services, and trade in services;
- Enhancing transparency of aviation through dissemination and exchange of information on States' policies and practices, air service agreements, taxes, and industry trends and developments; and
- Facilitating States' air services negotiations and business-to-business networking among States, international organisations, aviation industry, tourism, and other stakeholders.

2.5. Safety Management Systems

The main function in Airport Operations is to establish the airport in a safe, secure, and efficient manner. A significant factor contributing to this achievement has been the development of Airport Operations in implementing safety-related policies and practices. Over the last decades, these efforts have become essential to formalising a highly-detailed Safety Management System. An SMS is made up of a proactive, systematic, and prescriptive set of guidelines, policies, and practices for managing safety at an airport, airline, or related operation. The International Civil Aviation Organization, defines SMS as “A system to assure the safe operation of aircraft through efficient management of safety risk. This system is designed to continuously improve safety by identifying hazards, collecting and analysing data and continuously assessing safety risks. The SMS seeks to proactively contain or mitigate risks before they result in aviation accidents and incidents. It is a system that is commensurate with the organisation's regulatory obligations and safety goals” [28] (pp.5-1).

Proactive systems for managing aviation safety are nowadays a major concern for the aviation industry. In 2005, the International Civil Aviation Organization recommended that all aviation authorities must implement SMS regulatory structures and has provided resources to assist with implementation, including the ICAO Safety Management Manual [5]. Unlike the occupational safety focus of SMS in another industry, the ICAO focus is to use SMS for managing aviation safety. With aviation's reality low percentage of accidents, to continue to make safety improvements, there must be a proactive approach to managing safety that focuses on the control of procedures and to make safety a fully integrated part of the airport operation. Consequently, SMS is being adopted in many areas of commercial aviation throughout the world.

SMS are becoming a worldwide industry standard in aviation. Commercial airlines, corporate operators, helicopter operators, and other stakeholders in aviation have implemented SMS in their operations. An SMS is built, featuring a formal, top-down, business-like approach to managing safety, on four fundamental principles or framework according to ICAO Annex 19 Appendix 2 Framework for a Safety Management System [29] and its implementation shall be corresponding with the size of the organisation and the complexity of the services provided:

- Safety policy and objectives:
  - Management commitment and responsibility;
  - Safety accountabilities;
  - Appointment of key safety personnel;
  - Coordination of emergency response planning;
  - SMS documentation.

- Safety risk management:
  - Hazard identification;
  - Safety risk assessment and mitigation.

- Safety assurance:
  - Safety performance monitoring and measurement;
  - The management of change;
  - Continuous improvement of the SMS.

- Safety promotion:
  - Training and education;
  - Safety communication.

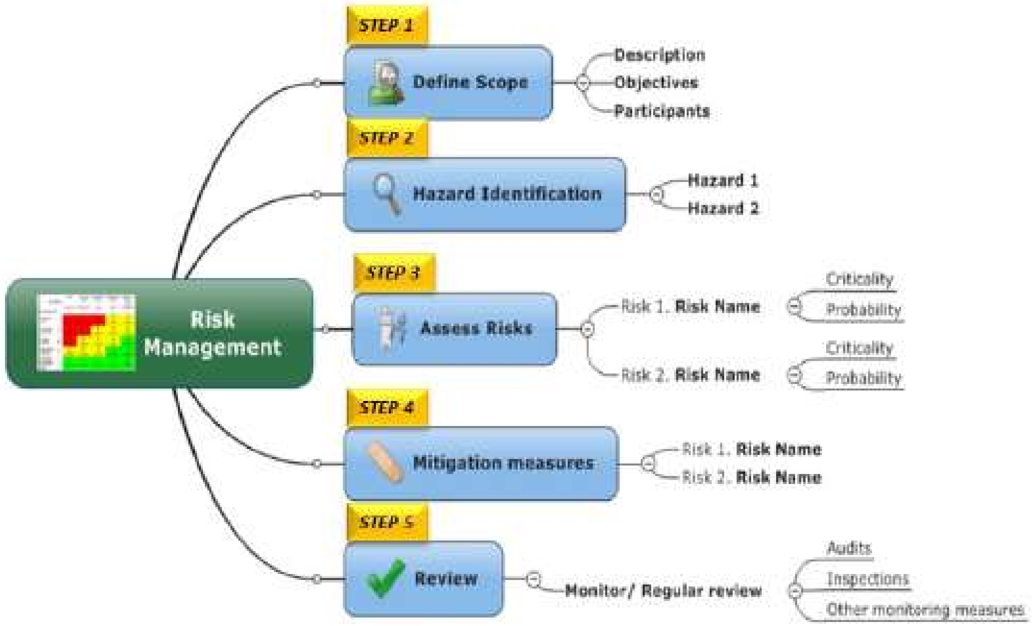

Figure 2.8 - ICAO SMS safety risk management framework.
Source: [30].

Figure 2.8 depicts one of the most important components of ICAO´s SMS Framework, the Safety Risk Management.

2.6. Occupational Health and Safety

There is a distinction between operational safety (or just safety) at an airport and occupational safety. The focus of safety in an aviation organisation is in operation and the types of occurrences that can contribute to a catastrophic accident. The emphasis of occupational safety is to the health and safety of employees or other workers; these types of threats are directly related to individual employees and typically address risks of various types of physical injuries, including slips, falls, struck-by incidents, physical strains, electrocution, and vehicle incidents. However, there might be an intersection between causes of hazards related to operational safety and causes of hazards related to occupational safety [9].

Occupational safety issues should be involved in an airport safety management system that integrates other related aspects of airport safety. Occupational health and safety management strategies applicable to airport operators depend on the employment associated with the workers, many of them employed by airlines or ground services providers. Therefore, may only be applied to contractual arrangements or partnership with third parties.

Occupational health and safety issues associated with airport operation primarily include the following [31]:

Noise

Airport ground service personnel may be potentially exposed to extremely high levels of noise from taxiing aircraft, the operation of aircraft auxiliary power units (APUs), and ground service vehicles. As most of these noise sources cannot be prevented, control measures should include the use of personal hearing protection by exposed personnel and implementation of work rotation programs to reduce cumulative exposure.

Physical Hazards

Airport ground service personnel may be exposed to a diversity of physical risks depending on the specific worker function. The most significant occupational hazards include strains due to carrying heavy loads, repetitive motions from luggage and cargo handling activities, and aircraft service operations; collisions with moving ground service vehicles or cargo, or taxiing aircraft; and exposure to weather elements. Workers may also be exposed to jet engine hazards.

Chemical Hazards

Ground service providers may be exposed to chemical hazards, as of contact with fuels and other chemicals, such as those used in de-icing and anti-icing. Fuels may present a risk of exposure to volatile organic compounds via inhalation or skin contact during normal use or in the case of spills. It may also present a riskless frequent of fire and explosions.

Health and safety at work are one of the areas where the *European Union* (EU) has committed, with a legal framework trying to cover the maximum number of risks with the least number of regulations.

Also the European Commission works with the European Agency for Health and Safety at Work and the European Foundation for the Improvement of Living and Working Conditions; to disseminate information, offers guidance and promotes healthy working environments. One of the most important legal act is the European Framework Directive (1989/391/EEC) [32], that establishes general principles for managing safety and health, such as responsibility of the employer, rights/duties of workers, using risk assessments to improve company processes continuously, and workplace health and safety representation.

In the Portuguese case those issues are addressed by the Working Conditions Authority (ACT) under the administration of the State Ministry of Labour, Solidarity and Social Safety but with administrative autonomy in all the mainland territory. ACT's key task is to encourage the development of working conditions, by promoting the policies on the prevention of occupational hazards and the compliance with the labour standards and the laws concerning the health and safety at work in all the private activity sectors. As a tripartite body, ACT works with social partners to enable sharing of best practice in *Occupational safety and health* (OSH) and to promote the European campaigns.

Health and safety are broadly considered across the air transport industry to have improved over the last ten years, as the number of accidents and incidents is believed to have reduced [33], also revealing a favourable trend.

2.7. Safety Culture

Numerous definitions of safety culture exist in safety literature. [34] (pp.4), for example, defined it as “shared values and beliefs that interact with an organisation's structures and control systems to produce behavioural norms”. The Advisory Committee for Safety in Nuclear Installations, subsequently adopted by the UK Health and Safety Commission [35], defined it as the product of individual and group values, attitudes, competencies, and patterns of behaviour; thus, determine the commitment to; and the style and proficiency of, an organisation's health and safety programmes. Organisations with a positive safety culture are characterised by communications founded on mutual trust, by shared perceptions of the importance of safety, and confidence in the efficacy of preventative measures [35].

Safety risk is managed by a Safety Management System, which considers several dimensions as well as safety culture [36]. In contrary with other high-risk industries, the frequency of catastrophic accidents per exposure in civil aviation ranks among the lowest, outperforming, for instance, the railways, chemical industry and healthcare, only comparable to nuclear industry [37]. The most important difference between civil aviation and other industries lies not so much in the management and practices but especially in differences in safety culture.

The efficiency of a safety management system depends on how well it is implanted in the core of the organisation — how things are done — so that a positive safety culture is generated and maintained in an ongoing manner [38].

The relationship between safety management systems and safety culture has been discussed widely in the safety literature of high-tech and high-risk industries including aviation. Regulators also take an interest in the function of safety management systems, and safety culture in ensuring safety. A “good” safety culture is attained in the aviation industry by crew training and by non-punitive incident reporting that offers protection to the sources of the information. Non-punitive confidential incident reporting started in earnest in 1976 with the NASA-operated Aviation Safety Reporting System (ASRS) in the United States of America (USA) [15], soon followed in the rest of the world. In Europe, any operational interruption, defect, fault or any other irregular circumstance that has or may have influenced flight safety and has not resulted in an accident or serious incident must be reported [39].

In Europe, although safety culture in aviation often is at a high level, there are still areas for improvement [40], and thus continuing the emphasis of ICAO and EASA on the introduction of safety management systems, by aviation service providers that support a strong safety culture. An optimistic attitude towards safety culture is a means to progress an actual implementation of an SMS, while processes, procedures, documentation and communication are ways to support safety and thus to improve safety culture as Figure 2.9 depicts.

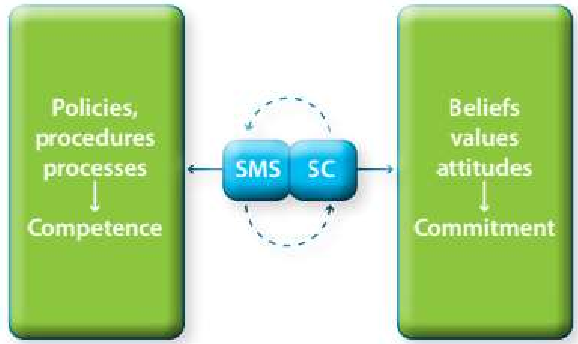

Figure 2.9 - Inter-dependency between SMS and Safety Culture.
Source: [40].

2.8. Conclusion

The literature review in this chapter over safety statistics from open access sources and terminologies for accidents and incidents has shown that occurrence rates of accidents since the beginning of commercial aviation have declined over the years. However, in relation to Take-Off, Landing and Ground Operations that may involve airport authority and subsequently airport safety performance, and in comparison, with other categories, the major source of accidents still occurs in this phase; covering the main airport related accident types like Runway Excursions, Ground Handling, Abnormal Runway Contact, and Ground Collision. In the case of Runway Incursions – vehicle/aircraft/person one of the most important safety indicators there is no identifiable trend over the last years.

In relation to Bird Strikes, there is also a growing trend number of incidents, probably due to a combination of factors including air traffic growth, better reporting due to improved wildlife management implementation and bird population growth.

As for Regulation, ICAO is the main body that regulates operating procedures for international aviation and issues, which is, all standards and recommended practices in every detail. Although still many aspects are subject to national requirements, the national authority for civil aviation, ANAC, acts accordingly with the European Joint Airworthiness Requirements (JAR) and subsequent European Aviation Safety Agency (EASA) Regulations.

Over the last years, a significant factor contributing Airport Safety has been the implementation of SMS, (prescriptive set of guidelines, policies, and practices for managing safety at an airport, airline, or related operation), the efficiency of a safety management system depends on how well it is implanted in the core of the organisation — how things are done — so that a positive safety culture is generated and maintained in an ongoing manner.

With the expectable air traffic growth in the next decades and to continue to maintain good records in occurrence rates and good overall safety in commercial aviation, safety regulation, but also Safety Management Systems and Safety culture must continue to be implemented and optimised.

Chapter 3

Airport Benchmarking

3.1. Introduction

In this chapter is made a state of the art and literature review regarding airports benchmarking to assess airport performance and efficiency evaluation, including an overview of the related methodologies, to provide an outline of the current trends and practical experience of airport benchmarking. Moreover, the most common efficiency indicators relating to airport safety are described and the way they can provide an actual performance assessment.

3.2. Airport Benchmarking

Airports are complex sets of businesses, and different airports operate in very different physical, financial, and governance environments. it is essential to compare similar sets of businesses working in a similar environment, to make useful comparisons among airports [10]. Performance measurement is of crucial importance in management activity, both at the operational level of the individual airport and at the wider system level [41]. Since the last decades, there's been an increased interest in Airport Benchmarking, with the recognition of its importance for day to day business and operational management, regulatory bodies, Government and other stakeholders such as passengers and airlines [41]. This interest has been simulated in the development of actual performance measurement practices and benchmarking studies, inside and outside of the airport sector. Also, airport management is facing the government agencies requests, which consider airport is benchmarking as support to form or adjust regulations and to create legislation [42], to improve it.

ACI [10] describes benchmarking as an economic standard by which business performance is measured, comparing productivity and efficiency, evaluating specific processes, policies and strategies to assess overall organisational performance. The airport's strategic objectives are evaluated to measure the performance of its functions, and the best practices for possible incorporation into the organisation's procedures are identified, to increase efficiency, quality and customer satisfaction. Some examples according to [41] of different purposes to which performance data may be used include:

- Government – for economic and environmental regulation;
- Airline – so they can compare costs/performance across airports;
- Airports managers – to run their own business;
- Passengers – to assess how well they are served as consumers;
- Owners/shareholders – to assess business performance and the return on their investment.

Airports have long-leaved their role as infrastructure; nowadays are considered an industry which encompasses a broad range of business, competencies and skills, together with the implementation of effective management and business techniques that also includes benchmarking. Airports are now in a much more competitive environment, under enormous pressure to find out about the performance of their competitors through benchmarking. This situation is due to airline competition, brought by liberalization in the USA and Europe. An increasingly competitive airline industry which is operating in a much costlier environment; and is keener than ever before to identify any airport, which is being inefficiently managed or which is not providing the desirable quality of service [43].

Airport benchmarking can be divided into two types: Internal (or self-benchmarking) — where an airport compares its performance with itself over time; and external (or peer benchmarking) — where an airport compares its performance against other airports, either at a specific year or over a time period.

Benchmarking is a management tool to monitor improvements in performance and is an effective way to identify unsound practices, analysing if they can be eliminated, as well as what are the best practices and if they can be incorporated into an organisation [10].

3.2.1 Performance and Efficiency Evaluation

Airports are multidimensional organisations whose efficiency's hard to measure based on a single criterion, due to variances in terminal layout, runway configurations, passengers origin and destination, and hub versus non-hub status, make assessments between airports even more challenging [44].

Overall Airports importance in the movement of people and cargo in a globalised world has led to an increased interest in the efficiency of airports in nowadays economics [45]. Additionally, airline competition brought about by deregulation and privatisation has evidenced this reality and positioned airports in a much more competitive environment. Thus, airports are now under pressure to improve their efficiency relative to competitors [46].

The evaluation of airport performance can be classified into two main types: the efficiency evaluation approach and the productivity evaluation approach. The main difference between efficiency and productivity lies in the concept of available outputs [47]. While productivity considers real outputs, efficiency considers the maximum potential output that can be produced with the available inputs. Efficiency, consequently, frequently relies on comparisons with others. However, the terms efficiency and productivity are often used interchangeably, even though the meaning of these two terms is not the same. The fact that changes in productivity are due to changes in efficiency, among other factors, may have influenced the consideration that both terms were equivalent [47].

According to [48], core processes for airports are the production process and airside and landside service provisions, described by:

- Production process: this process transforms a set of quasi-fixed inputs and variable inputs to provide runway and terminal capacity. Airport authorities use these inputs to provide services at the existing capacity levels of airport infrastructure. Poor utilisation of input resources can result in significant quantities of waste inputs which will quickly increase costs;
- Airside service processes: the airport provides runway capacity for aircraft movement; this capability is treated both as one of the produced outputs (for production process) and as an input (for airside service process) to provide services for aircraft movement;
- Landside service processes: terminal capacity can be regarded as an intermediate product that is produced by the production process and consumed in the production of air passenger movement and shippers' cargo volume.

Figure 3.1 depicts the operational framework regarding the relations between the airport's inputs and outputs.

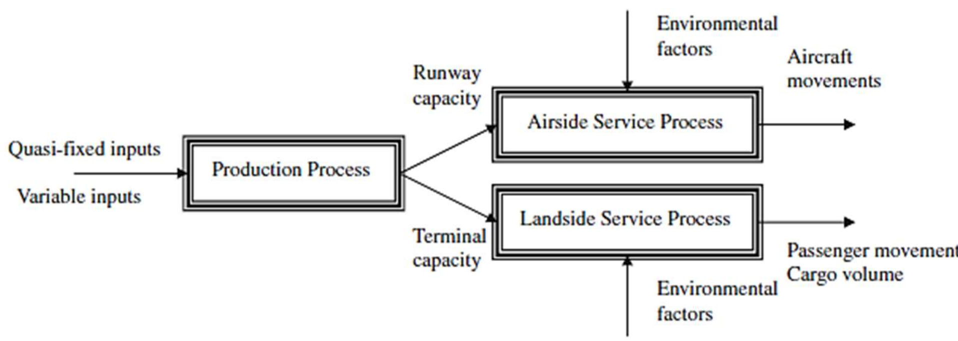

Figure 3.1 - Operational framework of airport service.
Source: [48].

3.2.2 Areas and Indicators

Airports performance efficiency has been traditionally compared to their peers [49], but now they realise the usefulness for benchmarking with other airports to improve their competitive level through identification and adoption of best common practices [50]. So, a way of comparing them was through performance indicators. however, this poses some problems, as airports have different performance indicators, due to various conditions associated with airport operations, i.e. aviation activities, business, location constraints. For instance: larger airports are likely to focus on various indicators than smaller ones; airports with large developable land areas will concentrate on different indicators than high constrained airports in the major urban areas; and privatized airports on various financial performance indicators, than non-profit government-owned airports. Regarding which indicators are most important and each airport characteristics, managers will have a vital position to adopt which indicators are most significant, and how many indicators the airport should monitor; moreover, as new problems arise, this set of indicators can change [10].

The development of good performance indicators that reflect managerial performance is critical in all forms of benchmarking. Dependent on the degree of outsourcing undertaken by the airport, the unit operating cost of airports can change. As the management of airports operates in different ways, some will do some activities themselves, such as ground handling, car parking and retailing, while other airports may outsource the same services. Therefore, one airport's operating costs may be higher just because it handles in more services than other airports, and so may not be an appropriate reflection of bad performance [51].

Airports choose a diversity of approaches in classifying Key Performance Areas that comprise the major activities in airport management. According to ACI, some airports use only three Key Performance Areas, and others use 15 or more. As an example, ACI uses the following six Key Performance Areas [10]:

- Safety and Security – these are the most important airport responsibilities, and therefore they are categorised separately;
- Service Quality – this increasingly important area reflects the evolution of airport management from having a primary focus on facilities and operations to having a strong customer service focus in an increasingly competitive environment;
- Productivity/Efficiency – these measures are closely related/overlapping measures of an airport's performance. They are sometimes separated into productivity measures, which track output on a non-cost basis — e.g., passengers per airport employee or departures per gate — and efficiency measures, which track output on a cost basis — e.g., total or operating cost per passenger;
- Financial/Commercial – this includes measures relating to airport charges, airport financial strength and sustainability, and the performance of individual commercial functions;
- Environmental – this evolving area has become a strong focus for airport management striving to minimise environmental impacts;
- Core – these are the core measures used to characterize and categorize airports, such as the number of passengers and operations. Although airports may have little control over these core indicators, especially in the short term, they are important indicators of overall airport activity, and important drivers and components of other indicators.

As others examples of published airport key performance indicators, Transportation Research Board [52] made other lists. Moreover, the International Air Transport Association (IATA) made lists in the perspective of passengers that includes data from 57 of the world's major airports.

3.2.3 Safety Performance Indicators

As a good working SMS does not guarantee a reduction of a number of accidents and other incidents, a key component of the SMS model is the use of performance indicators to assess the effectiveness of safety programs.

The concepts of performance indicators and performance targets are neither new nor exclusive to aviation or transportation operations safety. They have been used outside transportation operations safety; for instance, they have been commonly used by economists as a way to measure the "health" status of an economy [53]. Transportation safety has adopted these notions and changed them to measure the "health" status of safety.

In SMS, these are called *Safety Performance Indicators (SPIs)*. *ICAO Annex 19* [5] (pp.xii*)*, defines an SPI as "a data-based safety parameter used for monitoring and assessing safety performance." It measures whether a system is operating by the goals of the safety program and not only to simply acknowledge regulatory requirements. Using SPIs represents a change from traditional data collection and analysis methods to the development of mechanisms that continuously monitor safety risks, detect emerging safety risks, and determine any necessary corrective actions [53].

Rockwell [54] identified the following characteristics of a "good" measure of safety performance:

- Quantifiable and permitting statistical inferential procedures;
- Valid or representative to what is to be measured;
- Provide minimum variability when measuring the same conditions;
- Sensitive to change in environmental or behavioural conditions;
- Cost of obtaining and using measures is consistent with the benefits;
- Comprehended by those in charge with the responsibility of using them.

Two main types of SPIs are common in classifications adopted by different transportation industries: lagging SPIs and leading SPIs. Lagging SPIs also known as "Outcome SPIs" are defined as "Metrics that measure safety events that have already occurred including those unwanted safety events you are trying to prevent" [55] (pp.5). Lagging indicators reflect adverse consequences that the organisation aims to prevent and they are also valuable for aggregate, long-term trending, either for specific occurrence types or locations. Because lagging SPIs reflect safety outcomes, they can be used to assess the effectiveness of safety measures, actions, or initiatives and are a way of validating the safety performance of the system. An aviation example of a high-severity lagging SPI would be the number of runway excursion accidents/10.000 landings.

Leading SPIs known as "Process SPIs" defined by "Metrics that provide information on the current situation that may affect future performance" [55] (pp.6). Thus, measure conditions that have the potential to become or contribute to either a high severity/low probability negative outcome, or a lower severity/higher probability outcome, but which have not realised such potential. The focus of leading SPIs is on anticipating emerging weaknesses and vulnerabilities to determine the need for action, or on monitoring the extent to which specific activities required for safety are performed [56]. Some examples of SPI leading indicators in aviation SMS programs are:

- The percentage of changes to Standard Operating Procedures that have been subject to hazard identification and safety risk management;
- The extent to which work is carried out by Standard Operating Procedures.

3.2.4 Methodologies

Complex Infrastructures like Airports provide a challenge in establishing an appropriate performance measurement system. Performance measurement is a critical management activity, both at the operational level of an airport and at a wider system level. The advent of commercialisation and privatisation of airports and related services requires a correct assessment to provide quality services efficiently in all the operational dimensions of the airport [57].

There are several studies that reflect various airport management areas, but usually, and in their majority, have an economical and productivity emphasis. Moreover, these studies focus on capacity utilisation and effectiveness of the resources available, factors like pricing [58], [59], service quality [60], [61], unit cost such as total cost per Work Load Unit (WLU) [62] and Total Factor Productivity (TFP) [63]–[65]. Consequently, how to deal with this various factors that involves many stakeholders, not only airports but others, such as regulators and airlines that share economic interests in airport performance is not an easy task.

The performance analysis of an airport is then monitored using performance indicators in the different areas besides safety, so a benchmarking study of an airport or group of airports in an established set of indicators, and the major benefits taken from these types of studies are of major significance for stakeholders [66].

A literature review of airport benchmarking made by [67] and [47] has been made comprising a broad range of performance areas and activities, parametric stochastic frontier analysis [68], [69] as well as a price index and total factor productivity [70].

Data Envelopment Analysis (DEA), a nonparametric method in operations research and economics for the estimation of production, is nevertheless the most frequent choice. [44],

[69], and [70], used it in Portugal, Spain, Australia, USA, United Kingdom (UK), Taiwan airports and as well as in other airports around the world [72], [73].

Baltazar et al. [73] used and compared the results, of two multidimensional tools: a MCDA/MACBETH one and DEA that were based on three Iberian airports, two in Portugal (Lisbon and Ponta Delgada) and one in Spain (Barcelona). The preliminary results evidenced how MACBETH approach seems to be an auspicious one when compared with those (DEA based) traditionally in use. Mainly, because MACBETH appears to be more realistic than DEA, and it can be easily applied in managerial practice, including in the process all related stakeholders.

MacLean et al. [36] also address benchmarking airports with specific safety performance measures but weren't found any studies mentioning airport safety in a MCDA analysis [36]. Rosa [74], made an overview of these methodologies represented in Figure 3.2.

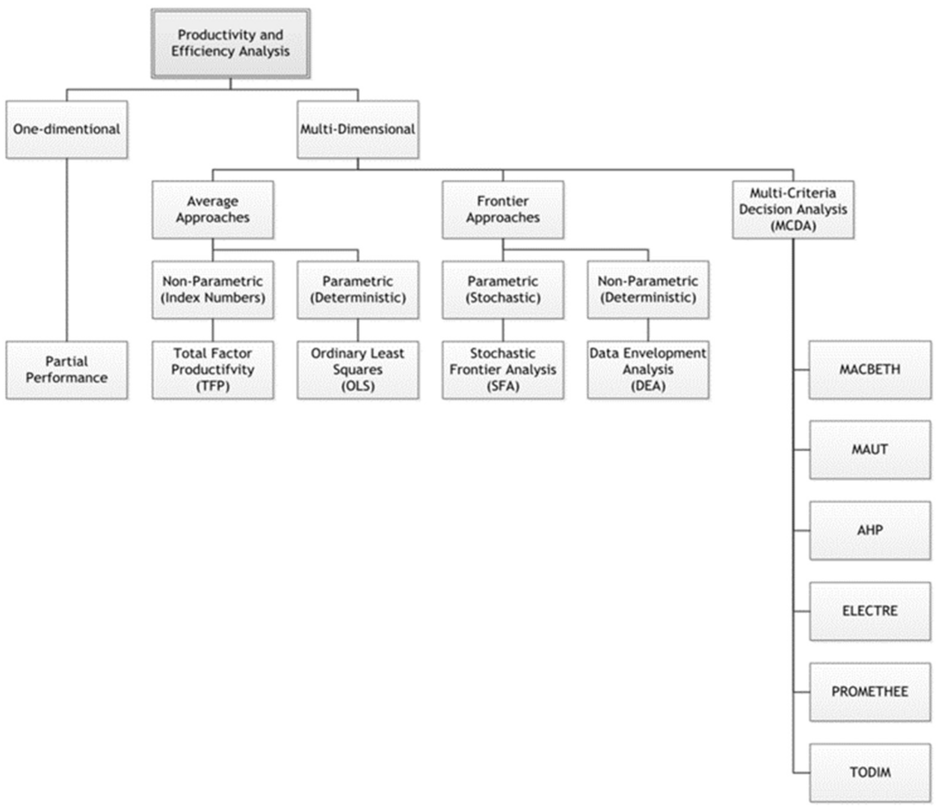

Figure 3.2 - Overview of benchmarking methodologies.
Source: Rosa [74].

Also, Table 3.1 depicts a review of the main methodologies applied until 2011 for airport performance assessment and the frequency of the use of each method according to [47]. Table 3.1 asserts that the majority of methodologies were based on DEA and combinations of DEA with TFP and SFA, only one of the studies used Multi-Criteria Analysis.

Table 3.1 - Methodologies applied until 2011 for airport performance assessment and the frequency of each method.

	Partial measures	MCDA	Frontier analysis	Parametric approach	SFA	Non-Parametric approach	DEA	TFP	Combination [1]	Other research methods	Total
1997	-	-			-		1	1	-	-	2
1998	-	-			-		-	-	-	-	0
1999	-	-			-		2	-	-	-	2
2000	1	-			-		1	-	-	-	2
2001	-	-			-		2	-	1	-	3
2002	1	-			-		1	-	1	1	4
2003	-	-			-		2	1	1	-	4
2004	-	1			-		3	1	1	1	7
2005	-	-			-		-	-	-	-	0
2006	-	-			-		1	1	1	1	4
2007	-	-			-		1	-	-	-	1
2008	-	-			2		3	1	1	-	7
2009	-	-			1		2	-	1	2	6
2010	-	-			1		2	-	3	2	8
2011	-	-			1		2	-	1	1	5
Total	2	1			5		23	5	11	8	55

Source: [47].

Table 3.2 describes the most common methodologies used in airport performance assessment with their main weakness [47].

Table 3.2 – Methodologies used in airport benchmarking, characterisation and weakness.

Methodology		Weakness
Partial Measure	Uses partial ratio data to carry out performance comparison of the target sample in single dimension such as on financial and cost performance of an airport.	Focuses on certain fields of airport performance. The evaluation result of this method would not be able to provide a more comprehensive assessment of an airport's performance.

[1] Combinations include: DEA and TFP; DEA and SFA; SFA and TFP

Methodology		Weakness
Multi-Criteria Decision Analysis (MCDA)	Employing this approach can be divided into two main steps: the first step is to acquire relative weights, and the second step is to rank the options. This method first selects evaluation indicators through expert survey or interview, and then chooses optimal solution based on those selected indicators.	Because the selection of indicators is based on expert's experience and their judgment, the result may be affected by subjective factors.
Total Factor Productivity (TFP)	In economies, TFP is a variable which accounts for effects in total output not caused by inputs. TFP allows for measuring cost efficiency and effectiveness and for distinguishing productivity differences in airport performance. This technique can also be used for investigating the impact of variations of input and output price on an airport's performance.	TFP requires an aggregation of all outputs into a weighted output index and all inputs into a weighted input index using pre-defined weights which can be biased.
Stochasticc Frontier Analysis (SFA)	SFA, sometimes referred to as econometric frontier approach, is one of the main parametric approaches used by researchers to evaluate efficiency.	Although the parametric approaches consider the effect error, which is not seen in non-parametric approach, the parametric methods still face challenges on separating random error from efficiency.
Data Envelopment Analysis (DEA)	DEA is a non-parametric approach, which requires no assumptions about the functional form and calculates a maximal performance measure for each airport relative to all other airports.	The key drawback of the technique is that it does not allow for random error in the data, assuming away measurement error and luck as factors affecting the outcome, which implies that the measured inefficiency is likely to be overstated.

Source: [47].

From the analysis of these methods to assess performance and efficiency, MCDA was elected to apply in this study. Thus, this statement reinforced by previous studies done by José Braz [75], João Jardim [2], Tiago Rosa [76] and Baltazar [77], that also applied MCDA as a tool for airport benchmarking.

3.3. Decision Making in Airports

Stakeholders may have different decisions because of the absence of information or the receiving of information that has diverging meaning to different partners. Addressing these limitations individually will bring improvements but to tackle the overall complexities of airports a new concept was created, called Airport CDM or Airport Collaborative Decision Making (A-CDM). A-CDM has an objective to provide Air Traffic Flow and Capacity Management (ATFCM) at airports by reducing delays, increasing the predictability of events and improving the utilisation of resources, and so improving operational efficiency in various areas of performance including safety.

The decision-making by the Airport CDM Partners is facilitated by the sharing of accurate and timely information and by adapted procedures, mechanisms and tools [78]. Airport CDM Partners have a shared objective, to maintain a safe and efficient air transport service for the benefit of passengers and cargo. To achieve this objective there are many supporting objectives. Figure 3.3 represents supporting objectives and airport services involved.

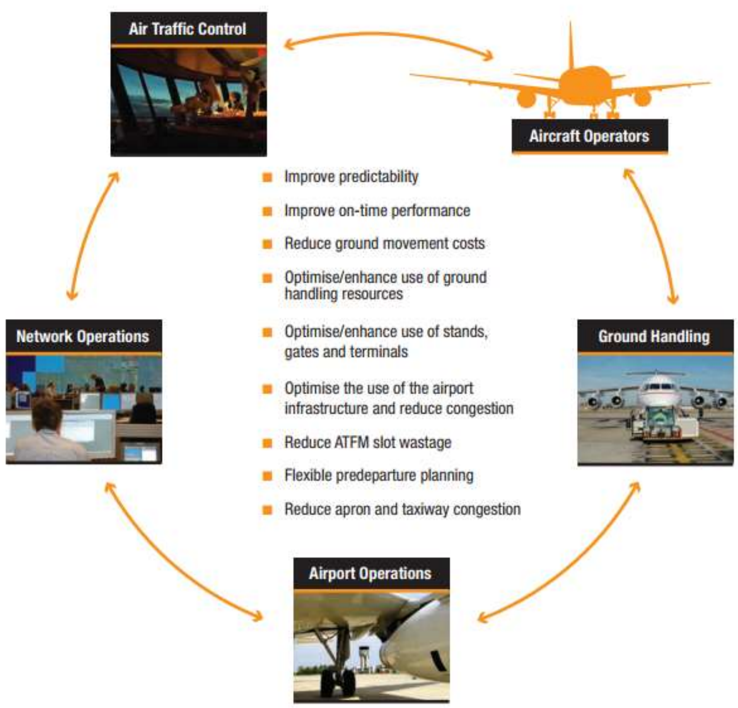

Figure 3.3 - Airport collaborative decision-making objectives and airport services involved. Source: [78].

Performance of a CDM Airport will be measured not only against its previous performance as self-benchmarking but also regarding the performance of the entire airport network. It is therefore significant that the performance indicators, and the methods for measuring them, are consistent at European level. The objectives and related performance indicators are divided into two categories [78]:

- Generic objectives and performance indicators, applicable to all airport partners and corresponding to four main improvement areas, e.g. safety, efficiency, environment, and capacity;
- Specific improvement objectives and performance indicators defined for each airport partner, including the Network Operations. Each specific objective is linked to at least one global objective.

3.4. Conclusion

Performance benchmarking is an essential part of the unceasing improvement of an organisation's effectiveness and productivity. From an airport's outlook, it links objectives to the requirements of customers, stakeholders and to the airport itself. Whether an airport is looking to improve its internal operations or to become more competitive on an industry-wide basis, understanding best practices and utilising them is essential to future prosperity and development, properly.

After a literature review on benchmarking methodologies most frequently used in airports performance assessment and weighing the advantages and disadvantages of each method, the decision to use the multicriteria approach was the one that better addresses the requirements for this study. Multicriteria Decision Analysis helps to integrate a broad set of key performance indicators in the critical area of safety, that encompass various degrees of particularities and complexities, with experts' experience and their judgment, even though the result may be affected by subjective factors.

Chapter 4

Airport Safety Assessment Model

4.1. Introduction

In this chapter is presented and discussed the literature review on Multi-Criteria Decision Analysis, or MCDA, as a valide methodology that can be applied to several complex environments as, for example, those of our case studies. It is most applicable to solve problems that are characterised by choices among alternatives mainly because of several interesting characteristics; such as: to help to focus on what is important; it is logical and consistent, and it is easy to use [79].

Among several MCDA tools, it was chosen chose MACBETH as the one that fits the requirements for addressing the variety and complexity of airport safety benchmarking. Thus, a model was built to assess airport performance and efficiency in the Safety Key Performance Area (SKPA) and Safety Key Performance Indicators (SKPIs).

4.2. Multi-Criteria Decision Analysis

Over the last decades, Multi-Criteria Decision Analysis has been used in many different application areas and has been improved significantly, as several methods have been developed, with small differences to previously existing approaches, creating new branches of research [79].

In general, the MCDA process can be divided into different steps, starting with the identification of a problem, which will then be structured. This step includes the definition of a decisive goal, the identification of stakeholders, uncertainties, criteria and alternatives. The next step is the model building, in which alternatives and criteria are explicitly defined, and values are determined through preference modelling and measurement tasks using specific methodology(ies). The model is then ready to be used to support the decision-making process analysing the sensitivity and the robustness of the results. Last but not the least, a plan for further action may be developed [80].

Several MCDA methodologies have been developed over the last decades, to improve the quality of decisions involving multiple criteria, making choices more explicit, rational and efficient. The objective is to compare a structured process from different perspectives, identifying objectives and creating alternatives [81]. According to Velasquez and Tester [79] literature review, the observed advantages and advantages, as well as areas of application for each method, are those summarised in

Table 4.1.

Table 4.1 – MCDA methodologies characterization.

Method	Advantages	Disadvantages	Areas of Application
Multi-Attribute Utility Theory (MAUT)	Takes uncertainty into account; can incorporate preferences.	Needs much input; preferences need to be precise.	Economics, finance, actuarial, water management, energy management, agriculture.
Analytic Hierarchy Process (AHP)	Easy to use; scalable; hierarchy structure can easily adjust to fit many sized problems; not data intensive.	Problems due to the interdependence between criteria and alternatives; can lead to inconsistencies between judgment and ranking criteria; rank reversal.	Performance-type problems, resource management, corporate policy and strategy, public policy, political strategy, and planning.
Case-Based Reasoning (CBR)	Not data intensive; requires little maintenance; can improve over time; can adapt to changes in the environment.	Sensitive to inconsistent data; requires many cases.	Businesses, vehicle insurance, medicine, and engineering design.
Data Envelopment Analysis (DEA)	Capable of handling multiple inputs and outputs; efficiency can be analysed and quantified.	Does not deal with imprecise data; assumes that all input and output are exactly known.	Economics, medicine, utilities, road safety, agriculture, retail, and business problems.
Fuzzy Set Theory	Allows for imprecise input; takes into account insufficient information.	Hard to develop; can require numerous simulations before use.	Engineering, economics, environmental, social, medical, and management.
Simple Multi-Attribute Rating Technique (SMART)	Simple; allows for any weight assignment technique; less effort by decision makers.	The procedure may not be convenient considering the framework.	Environmental, construction, transportation and logistics, military, manufacturing and assembly problems.
Goal Programming (GP)	Capable of handling large-scale problems; can produce infinite alternatives.	It is ability to weight coefficients; typically needs to be used in combination with other MCDM methods to weight coefficients.	Production planning, scheduling, healthcare, portfolio selection, distribution systems, energy planning, water reservoir management, scheduling, wildlife management.
ELECTRE	It takes uncertainty and vagueness into account.	Its process and outcome can be difficult to explain in layman's terms; outranking causes the strengths and weaknesses of the alternatives to not be directly identified.	Energy, economics, environmental, water management, and transportation problems.
PROMETHEE	Easy to use; does not require the assumption that criteria are proportionate.	Does not provide a clear method by which to assign weights.	Environmental, hydrology, water management, business and finance, chemistry, logistics and transportation, manufacturing and assembly, energy, agriculture.

Method	Advantages	Disadvantages	Areas of Application
Simple Additive Weighting (SAW)	Ability to compensate among criteria; intuitive to decision makers; the calculation is simple does not require complex computer programs.	Estimates revealed do not always reflect the real situation; result obtained may not be logical.	Water management, business, and financial management.
Technique for Order Preference by Similarity to Ideal Solution (TOPSIS)	Has a simple process; easy to use and program; the number of steps remains the same regardless of the number of attributes.	Its use of Euclidean Distance does not consider the correlation of attributes; difficult to weight and keep the consistency of judgment.	Supply chain management and logistics, engineering, manufacturing systems, business and marketing, environmental, human resources, and water resources management.

Source: [79].

In addition to the MCDA mentioned above methodologies, Carlos Bana e Costa, Jean-Claude Vansnick, and Jean-Marie De Corte presented another one based on the additive utility model. A result is a tool called MACBETH (Measuring Attractiveness by a Categorical Based Evaluation Technique). Braz [75], Jardim [2], Baltazar [77] and Rosa [74] chose MACBETH as a MCDA tool that complied and suited all the requirements for addressing the variety and complexity of performance areas and indicators for airport performance assessment.

4.2.1 Measuring Attractiveness by a Categorical Based Evaluation Technique (MACBETH)

Bana et al. [82] stated that the MACBETH method used in this model is a decision-making evaluation method of options within multiple criteria methodologies. The main distinction among other Multiple Criteria Decision Analysis (MCDA) methods and MACBETH are that this only needs qualitative judgments about the difference of attractiveness between two elements at a time, to generate numerical scores for the options in each criterion and to weight the criteria. In simple words, the MACBETH approach tries to answer the following questions [83]:

- How can we build an interval scale of preferences on a set of actions without forcing evaluators to produce direct numerical representations of their preferences?
- How can we coherently aggregate these qualitative evaluations using an additive utility model?

Thus, the MACBETH decision aid process involves the construction of a quantitative assessment model. A value scale for each criterion and weights for the criteria are constructed from the evaluator’s semantic judgments. The options value scores are subsequently aggregated additively to calculate the overall value scores that reflect their attractiveness considering all the criteria.

MACBETH is a Humanistic, an Interactive, and a Constructive tool [84]. When the evaluator judgements are set, their consistency is verified, and corrections may be needed to avoid inconsistencies if they arise. Then MACBETH develops a quantitative evaluation from evaluator's qualitative judgements. For this quantitative assessment model, a value scale is calculated for each criterion and its weights. Value scores are subsequently aggregated additively considering all the criteria to calculate the overall value scores thus reflecting their attractiveness [85]. At first, and to make the result more robust, it is necessary to obtain a massive data collection about the study object so a decision group can have a global view of the decisions to be taken. Next step is to create a decision tree with nodes, that is, a decision model. Nodes correspond to indicators that are going to be considered; each decision maker defines each indicator attractiveness in the tree. MACBETH have seven attractiveness difference qualitative categories: no difference, very weak, weak, moderate, strong, very strong, and extreme [86]. As presented by Bana e Costa [87], MACBETH has a complex mathematical formulation. This formulation can be observed in Annex 1.

4.3. Performance and Efficiency Support Analysis for Airport Global Benchmarking (PESA – AGB)

PESA-AGB (Performance and Efficiency Support Analysis for Airport Global Benchmarking) model was developed by Baltazar [77] to assess airports performance and efficiency in each Key Performance Area (KPA). and each Key Performance Indicator (KPI). This model is based on the MACBETH mathematical foundations, and it consists in a five-step arrangement (Figure 4.1): Structuring (Step 1); Survey and Meeting (Step 2); Evaluation (Step 3); Classification (Step 4); and Outputs (Step 5).

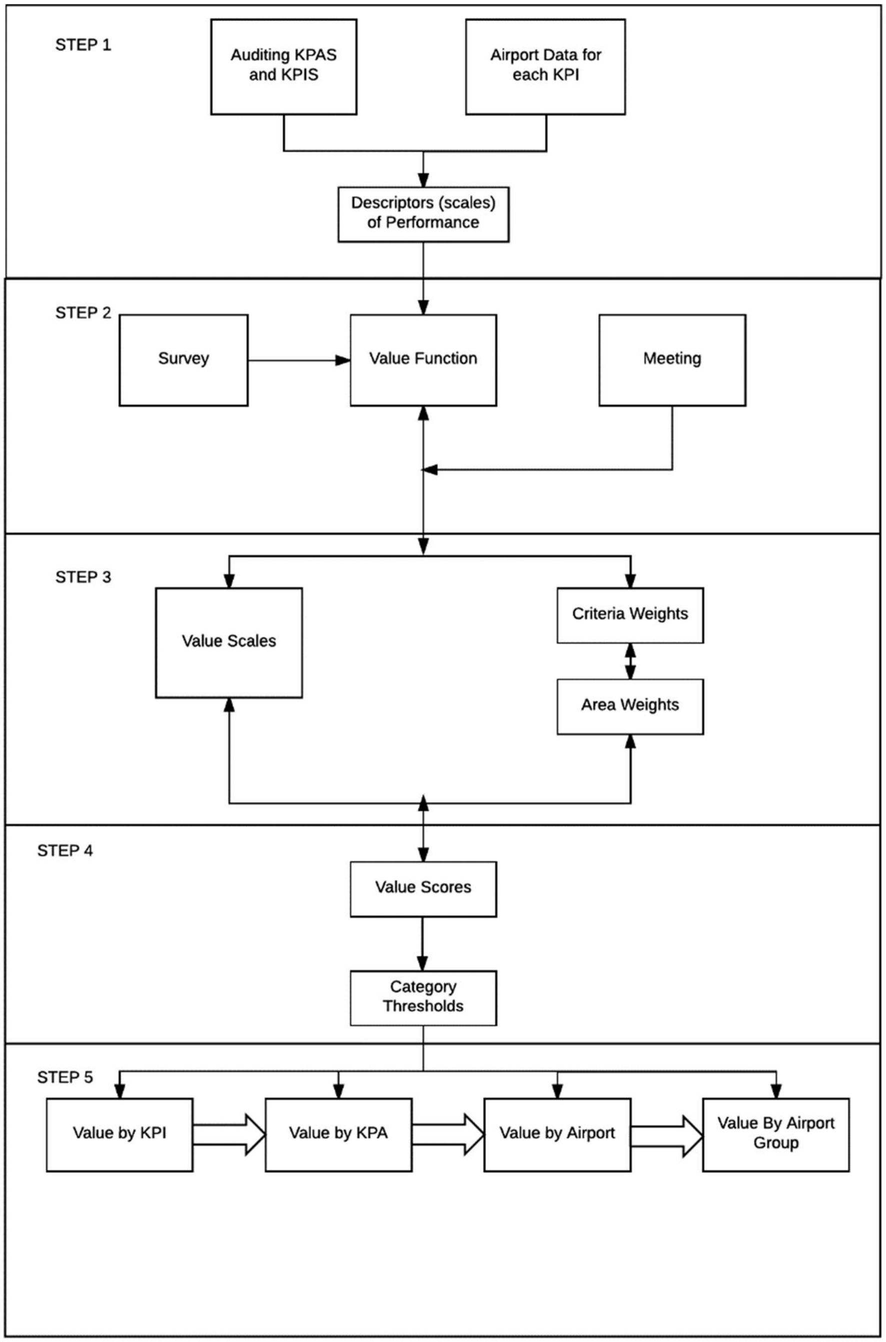

Figure 4.1 - Steps for building the PESA-AGB multi-criteria model.

Source: [82].

4.3.1 The Safety Performance Area and Safety Indicators

To produce a performance ranking in an eleven-years interval, the **first step** consists in collecting a vast amount of airport data from public infrastructures (ANA Aeroportos,[89]–[106]) and the definition of the decision tree according to ACI [107].

The decision tree of PESA-AGB model consists six KPA's: Core, Safety, Service Quality, Productivity/Cost Efficiency, Financial/Commercial, and Environmental. Each KPA is associated with several KPI's - a total of forty-two items as referred by [77]. This study besides been part of the PESA-AGB model that encompasses various key performance areas of the airport, it is only focused on the Safety KPA and the related Safety KPIs as defined by ACI.

Safety KPA comprises critical airport functions which sometimes overlap. Safety indicators are used to track airfield safety issues as well as safety issues involving other airport sectors, including roadways and general employee safety [107]. This KPA is described by six KPIs as in Table 4.2. Thus, runway accidents, runway incursions, bird strikes, public injuries, occupational injuries and lost work time from employee accidents and injuries, where the key performance indicators considered for the safety area. Other key performance areas and key performance indicators have been taken into account in the PESA-AGB original model to evidence a more integrated performance analysis of the distinct aspects that constitute the airport but this study main focus is to demonstrate safety performance impact and importance on the overall performance of the airport/group of airports.

Table 4.2 - ACI safety performance indicators.

Key Performance Indicators in Safety and Security in the last 11 years
Runway Accidents: Aircraft accidents involving a runway per thousand aircraft movements (take-offs and landings are counted separately), measured over the course of a year.
Runway Incursions: Number of occurrences per thousand movements involving the incorrect presence of an aircraft, vehicle, or person on the protected area of a surface designated for the landing and take-off of aircraft, measured over the course of a year.
Bird Strikes: Number of incidents per thousand movements, involving bird strikes, which are collisions of airborne animals (usually birds, but also including bats) with aircraft, measured over the course of a year.
Public Injuries Number, of public injuries per thousand passengers, measured over the course of a year
Occupational Injuries: Occupational injuries to airport authority employees per thousand hours worked.
Lost Work Time from Employee Accidents and Injuries: Lost time due to employee accidents and injuries, measured per thousand hours worked.

Source:[107].

With those Key Performance Indicators now it is possible to construct the value decision tree, and with the collected data from airports, we can define the performance descriptors. These descriptors translate the information needed for effective performance and evaluation assessment. Table 4.3 is an example of a performance descriptor for Runway Incursions. With the data collected for every KPI defined in the decision tree, a performance descriptor with four levels (L1, L2, L3 and L4) is built. Table 4.3 describes the process of creating a performance descriptor too.

Table 4.3 - a performance descriptor for Runway Incursions.

Level	Description
L4(Good)	The year with the lowest number of incursions per thousand movements for the last 11 years
L3	The 1/3 of the difference between the best and the worst value of [incursions/1.000movs] for the last 11 years.
L2	The 2/3 of the difference between the best and the worst value of [incursions/1.000movs] for the last 11 years.
L1(Neutral)	The year with the highest number of incursions per thousand movements for the last 11 years

Performance descriptors are as performance scales; four reference levels of accomplishment describe the airport performance on each criterion and consequently the airport performance profile on Safety. For all the performance descriptors were established two reference levels – the "good" and the "neutral" ones and additionally two intermediate levels for each KPI. "Good" was set as the best level of performance in the last 11 years indicating that no improvement is required in the respective criterion; the "neutral" was set as the worst level of performance in the last 11 years. That is, it is neutral regarding need for improvement (because it ensures regular working conditions), but below this level action is recommended to improve, at least until the "neutral" level is achieved.

The **second step** represents the collection of expert's judgments through survey and/or meetings.

An online survey was prepared by NIT research group and was sent to more than five hundred experts in several key performance areas. The survey was applied in 2015 [108] and obtained a total of 81 answers. Note that PESA-AGB model does not rely on the number of answers but the quality of the answers and its relevance to each case under study. Nevertheless, the survey consisted of the following six steps:

(i) Welcome message;
(ii) Experts personal information: name, email and professional expertise;
(iii) To rank KPA's by relevance order, from 1 (least relevant) to 6 (most relevant). Different KPA's could be assigned with the same rank;
(iv) To choose KPA field of expertise;
(v) To rank KPI's of the KPA selected in (iv) by relevance order, from 1 (least relevant) to 6 (most relevant). Different KPI's could be assigned with the same rank;

(vi) To fill all KPI's judgement matrix. For each judgement matrix six questions were asked, so that: A refers to KPI best option; D refers to KPI worst option; B and C were intermediate values equally distributed between A and D. To answer these questions six semantic attractiveness difference categories were proposed: "very weak", "weak", "moderate", "strong", "very strong" or "extreme", so that:

a) Question 1. AD - A is more attractive than D. The difference is…?
b) Question 2. AC - A is more attractive than C. The difference is…?
c) Question 3. BD - B is more attractive than D. The difference is…?
d) Question 4. AB - A is more attractive than B. The difference is…?
e) Question 5. BC - B is more attractive than C. The difference is…?
f) Question 6. CD - C is more attractive than D. The difference is…?

From the application of the survey, we obtain three outputs: criteria judgement matrix, key performance indicators status quo, and key performance areas *status quo*.

Meetings are a process used by this model to get experts opinions in assessing airports performance too. These meetings consist of a key players gathering, who wish to analyse and solve an important issue related to their organization, assisted by an impartial facilitator; who is a specialist in decision analysis and works as a process consultant, using a model of relevant data and judgements created on the spot to assist the group to think more clearly about the related issue [77]. A *status quo* scale is created using expert's answers statistical average.

Finally, survey and meeting results are introduced in PESA–AGB model as inputs of **step 3**. **Step 4** is a judgement matrix construction for each KPI. With the judgments matrix created KPI weight ponderation is determined. **Step 5** uses the performance descriptions and weight ponderation to obtain the KPI score for each option (year). Step 5 produces a large variety of outputs which allows monitoring performance over time. These outputs consist of performance profiles, sensibility analysis, options and difference profiles, and scores for KPIs, KPA, airports (internal benchmarking) and airport groups (external benchmarking). Annex 2 [109] describes a step by step example on how to obtain Safety KPI scores using PESA-AGB model.

4.4. Conclusion

In this chapter, a literature review was made encompassing the various existing MCDA methods, and its characterisation: advantages, disadvantages and areas of application.

About airport benchmarking DEA is still the most used methodology for assessing performance, but in the specific case of airport safety area, it was not found in the literature any use of multi-criteria decision analysis method/tool to evaluate its performance and efficiency.

From an adjustment of a MACBETH tool called PESA-AGB model and using ACI indicators, the six Safety Key Performance Indicators of the Safety Key Performance Area were incorporated in that model to allow a performance assessment. MACBETH mathematical foundations and PESA-AGB model were both explained step by step in Annex 1 and Annex 2, respectively.

The methodology considered in this chapter is then able to be applied in the subsequent chapter 5 for the self and peer benchmarking case studies.

Chapter 5

Case Studies

5.5 Introduction

5.6 Self-Benchmarking

5.6.1 Airport A

5.6.2 Airport B

5.6.3 Airport C

5.7 Peer-Benchmarking

5.8 Conclusion

5.1. Introduction

This chapter, describes four case studies, where a self-benchmarking analysis was conducted for three airports, A, B and C, with distinctive characteristics, each one representing the main Portuguese air infrastructures: Airport A is considered the largest one in terms of number of passenger and movements is related to Lisbon airport; Airport B mainly a Low-Cost Carrier (LCC) and Cargo one, resembles Oporto airport; and finally Airport C, an LCC oriented one with seasonality peaks along the year resembles the Faro airport. Finally, is presented the last case study that encompasses the three airports as group for a peer-benchmarking analysis.

All the performance evaluations take place in an eleven-year time span and data collected for this study were retrieved from ANA airports reports.

5.2. Self-Benchmarking

With the MACBETH approach and the PESA-AGB model implemented, the ranking of all the Safety Performance Indicators was made possible, as well as the scores for each year; in this case, each year representing an option.

Table 5.1, Table 5.2 and Table 5.3 present the value scores for each KPI in a year, including the weights given by experts for each of them. Finally, and going up in the decision tree, the score of the Safety Performance Area for each year is accessed too.

The airport is divided in 6 KPA, and the SKPA weight of Safety is 21,95% according to the survey made with the expert's opinion. This value is in line with the expectations for the Safety Area, as it reflects the primary concerns of stakeholders and major repercussions it can have if any kind of failure happens.

Also, the KPA of Safety is divided into 6 SKPI, and the relative weights vary between 11.76% and 21.57% as Figure 5.1 depicts. Without surprise, Runway Accidents takes leading place with 21.57%, as experts consider that this indicator has a major impact in the safety area of any airport. The least concern for stakeholders is Lost Work Time from Employees Accidents and Injuries with the value of 11.76%. Runway Incursions, Bird Strikes, Public Injuries and Occupational Injuries stand in the intermediate weights of importance with 19.61%, 17.65%, 15.69% and 13.73% respectively.

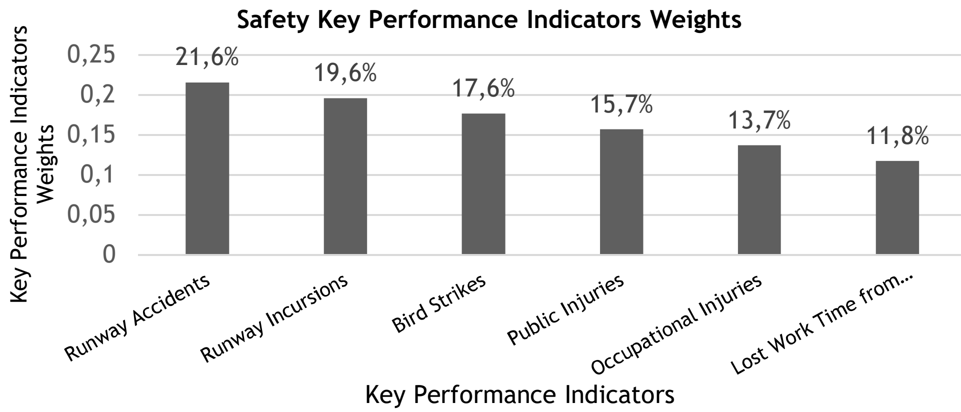

Figure 5.1 – Safety key performance indicators weights.
Source: Annex 3.

The lower the weight means that variations in a KPI in a certain year, will have a smaller impact in overall airport score for the Safety Area.

In Table 5.1 regarding Airport A the Safety Key Performance Area achieves the best value in 2007, with the overall score of 87.06, due to the fact that almost all Indicators have scores above 80, with Runway Incursions having the lowest score of 71.86. The worst year was 2004 with a score of 44.14.

In Table 5.2 regarding Airport B the maximum score was achieved in 2008 with 87.65 and the worst (as in Airport A) in 2004.

In Table 5.3, and looking at 2013, the Safety Key Performance Area achieves the score of 84.6 and the apparent reason for this is that in 2013 all indicators of Safety contributed with high scores and none of them with significant variance. Inversely in the year 2009, a closer look reveals a poor score in various performance indicators such as Bird Strikes, and Occupational Injuries, for example; and analysing a trend from a managerial perspective we can imagine that proactive action would be taken to improve the score. However, in 2010 nevertheless, Birds Strikes and Occupational Injuries remain with a low score, perhaps indicating a need to address the problem separately.

Table 5.1 - Summary of the scores obtained for Airport A scores for KPIs and KPA along 11 years.

	Runway Accidents	*Runway Incursions*	*Bird Strikes*	*Public Injuries*	*Occupational Injuries*	*Lost Work Time E.A.I.*	*Safety Key Performance Area Score*
2003	100.00	85.10	73.41	9.90	100.00	24.50	69.37
2004	100.00	70.21	9.65	1.55	49.99	0.00	44.14
2005	100.00	100.00	0.00	0.00	66.57	71.03	58.67
2006	100.00	12.28	67.21	95.67	98.80	91.91	75.22
2007	100.00	71.86	80.33	98.91	89.51	80.08	87.06
2008	100.00	73.88	100.00	28.55	97.27	86.83	81.75
2009	100.00	74.18	22.40	40.28	0.00	100.00	58.15

	Runway Accidents	*Runway Incursions*	*Bird Strikes*	*Public Injuries*	*Occupational Injuries*	*Lost Work Time E.A.I.*	*Safety Key Performance Area Score*
2010	100.00	16.50	45.90	65.41	16.17	47.67	50.99
2011	100.00	79.29	18.40	99.42	60.07	70.65	72.51
2012	100.00	0,00	28.42	56.59	77.22	92.55	56.95
2013	100.00	81.79	22.40	100.00	77.32	47.67	73.47
Weights	21.57%	19.61%	17.65%	15.69%	13.73%	11.76%	100%

Source: Annex 3.

Table 5.2 - Summary of the scores obtained for Airport B scores for KPIs and KPA along 11 years.

	Runway Accidents	*Runway Incursions*	*Bird Strikes*	*Public Injuries*	*Occupational Injuries*	*Lost Work Time E.A.I.*	*Safety Key Performance Area Score*
2003	100.00	85.10	66.90	0.00	84.84	24.50	64.59
2004	100.00	70.21	29.45	15.61	87.65	0.00	55.01
2005	100.00	100.00	23.77	21.36	91.23	71.03	69.60
2006	100.00	12.28	63.26	34.02	92.92	91.91	64.04
2007	100.00	71.86	70.97	51.32	94.39	80.08	78.61
2008	100.00	73.88	88.45	80.10	96.25	86.83	87.65
2009	100.00	74.18	100.00	57.64	0.00	100.00	74.57
2010	100.00	16.50	69.98	76.51	98.85	47.67	68.33
2011	100.00	79.29	70.94	100.00	98.41	70.65	87.14
2012	100.00	0.00	3.53	89.06	98.21	92.55	60.53
2013	100.00	81.79	0.00	91.89	100.00	47.67	71.35
Weights	21.57%	19.61%	17.65%	15.69%	13.73%	11.76%	100%

Source: Annex 3.

Table 5.3 - Summary of the scores obtained for Airport C scores for KPIs and KPA along 11 years.

	Runway Accidents	*Runway Incursions*	*Bird Strikes*	*Public Injuries*	*Occupational Injuries*	*Lost Work Time E.A.I.*	*Key Performance Area Score*
2003	100.00	85.10	62.08	0.00	84.79	24.50	63.73
2004	100.00	70.21	95.01	8.01	87.60	0.00	65.38
2005	100.00	100.00	100.00	25.10	91.15	71.03	83.63
2006	100.00	12.28	65.28	55.15	92.61	91.91	67.67
2007	100.00	71.86	58.50	87.60	94.09	80.08	82.06
2008	100.00	73.88	48.34	82.42	95.57	86.83	80.85
2009	100.00	74.18	17.50	54.27	0.00	100.00	59.48
2010	100.00	16.50	87.32	80.59	98.80	47.67	72.02
2011	100.00	79.29	0.00	91.35	98.64	70.65	73.29
2012	100.00	0.00	70.95	78.47	98.25	92.55	70.77
2013	100.00	81.79	67.84	100.00	100.00	47.67	84.60
Weights	21.57%	19.61%	17.65%	15.69%	13.73%	11.76%	100%

Source: Annex 3.

5.2.1 Airport A

The PESA-AGB model allows to perform sensitivity analyses. All changes on scores and weights are instantaneously reflected in all other dependent scores. Sensitivity analysis is consisted by consistently varying a specific criterion weight and subsequently adjusting the difference equally over the remaining criteria. The results of sensitivity analysis for the most important criterion, in this case, the Safety Key Performance Area, (having highest weight) is displayed in Figure 5.2. It shows the sensitivity analysis relating to the weight of the Safety Key Performance Area of the Airport; this kind of study allows the transformation of the options scores and the potential actions to be observed if the weight of the Safety Key Performance Area (SKPA) is changed. In this case, we can see the current weight (on the horizontal axis) of 21,95% for the SKPA of Airport A.

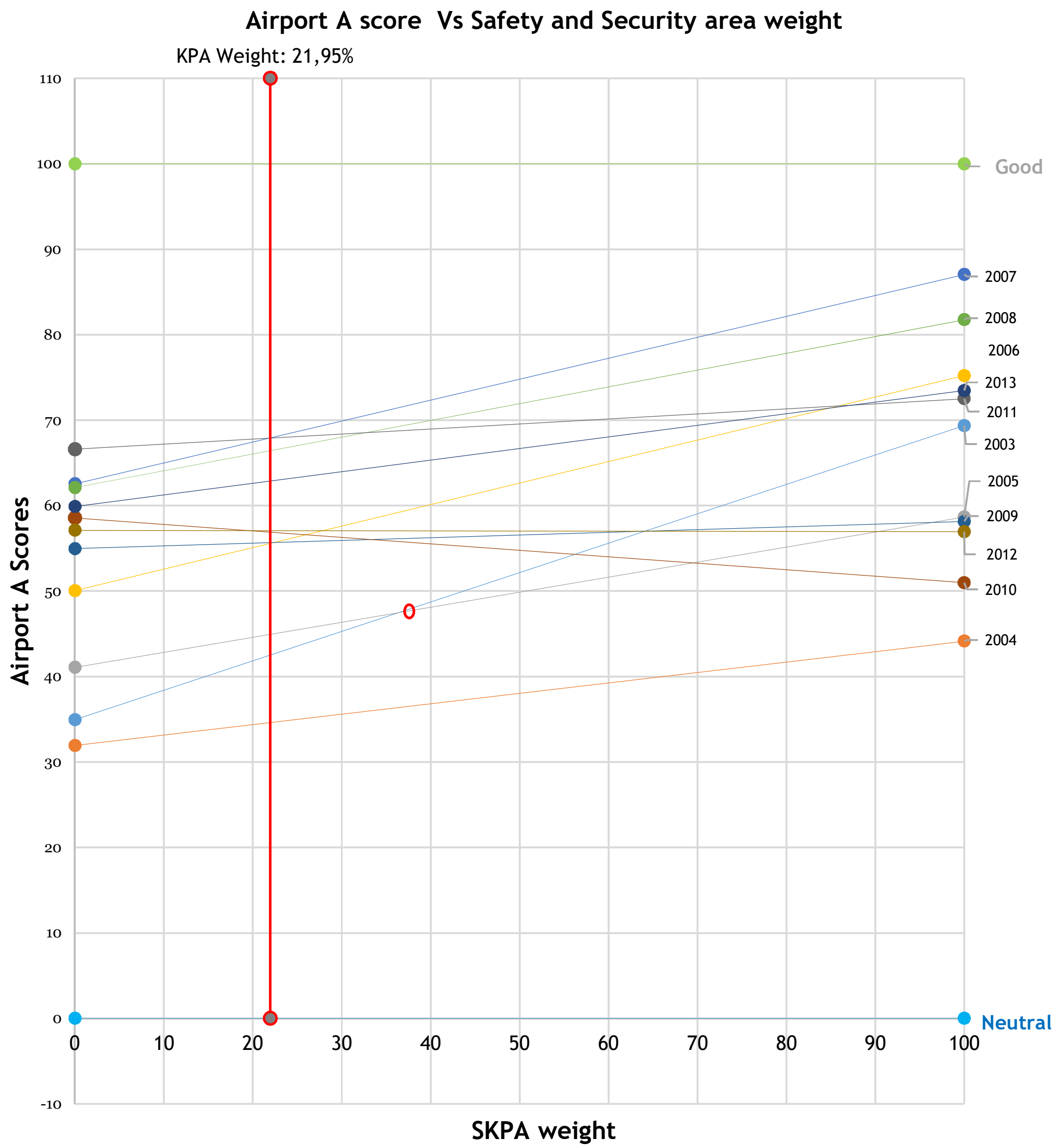

Figure 5.2 - Sensitivity analysis of SKPA weight for Airport A.

Source: Annex 3.

If the weight of the SKPA varies, the options, representing the years (on the vertical axis) vary their ranking too; in this case, there is a direct relation for most of the years, meaning that a decrease or increase of the area weight is directly associated with the year scoring. However, for years 2010 and 2012, there is an inverse relation, meaning that if the weight for the SKPA decreases, the scoring for that year will increase. In the managerial perspective, the sensitivity analysis can be a handy tool. This is because it permits a critical assessment of the value scores in the context of the globality of the Safety Area; as another example, if the experts' board would decide a change of the SKPA weight from 21,95% to, for instance, to 40%, in that case, the year of 2005 would have a poorer score than the year 2003, thus exchanging relative scoring position.

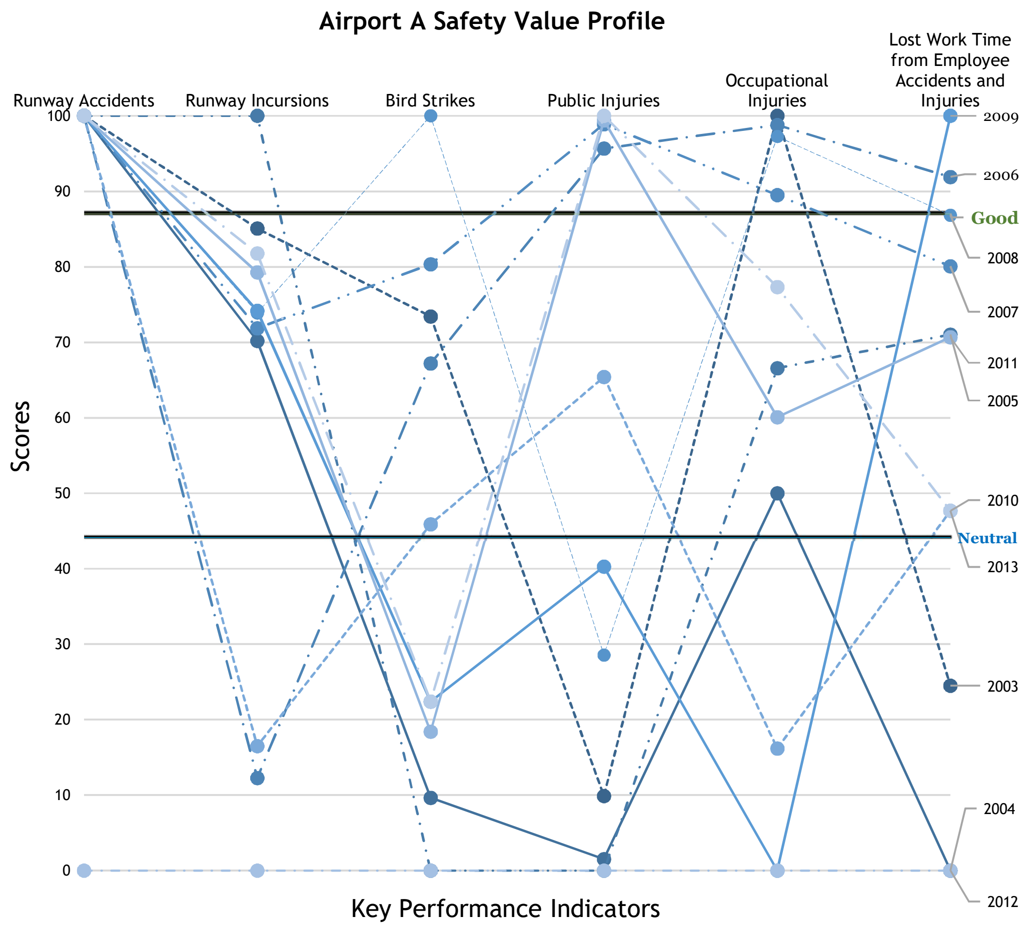

Figure 5.3 - Safety value profile for Airport A.

Source: Annex 3.

Other outputs include the Safety Area performance profile for 2003-2013 options (Figure 5.3). This analysis will allow the comparison of the scores over the years for various indicators and makes easy to identify areas that deserve more attention from the stakeholders.

In the Safety Value profile for Airport A, we can define three major zones of achievement for the performance of an indicator: the exceed threshold (over the green line) that comprises 87 to 100 scores; the compliance zone (between the green and the horizontal blue lines) - 44 to 86 scores and the non-compliance zone (under the horizontal blue line) - 0 to 43 scores.Thus, for airport A Safety Value Profile, it's possible to observe that the option 2007 for example has profile with good performance overall, having all the indicators above the neutral level, in the compliance and the exceed threshold zone; the option 2004 has by far the worst profile, with indicators like Bird Strikes, Public Injuries and Occupational Injuries in the non-compliance zone requiring from the safety management a necessity to improve all the above-mentioned indicators.

Figure 5.4 evidences another PESA-AGB output, that is, the impact of the SKPA scores in the Airport A overall score. 2006, 2007 and 2008 are fitted with the regression line, but all the others are far from the mean.

Figure 5.4 - Linear regression between airport an overall score and its safety KPA score.
Source: Annex 3.

Moreover, from the managerial point of view it is possible to group the options under evaluation in quadrants, as follows:

- Quadrant 1 (Q_1): years with a **high** SKPA scores and **high** airport overall scores - 2006 2007, 2008, 2009, 2010, 2011, 2012 and 2013;
- Quadrant 2 (Q_2): years with a **low** SKPA scores and **high** airport overall scores - none;
- Quadrant 3 (Q_3): years with a **low** SKPA scores and **low** airport overall scores - 2004;
- Quadrant 4 (Q_4): years with a **high** SKPA scores and **low** airport overall scores - 2003 and 2005.

The quadrant analysis allows to observe a genuine impact of the SKPA in the airport overall scores: Q1 demonstrates a clear impact on the safety performance area.

5.2.2 Airport B

Figure 5.5 looks at Airport B. The weight of the Safety Key Performance Area (SKPA) remains the same as for Airport A, that is 21,95%.

As in airport A, the tendency remains the same: if the weight of the SKPA varies, there is a direct relation for most of the years, meaning that a decrease or increase of the area weight is directly associated with the year scoring. Also for years 2010 and 2012, there is an inverse relation, meaning that if the weight for the SKPA decreases, the scoring for those years will increase.

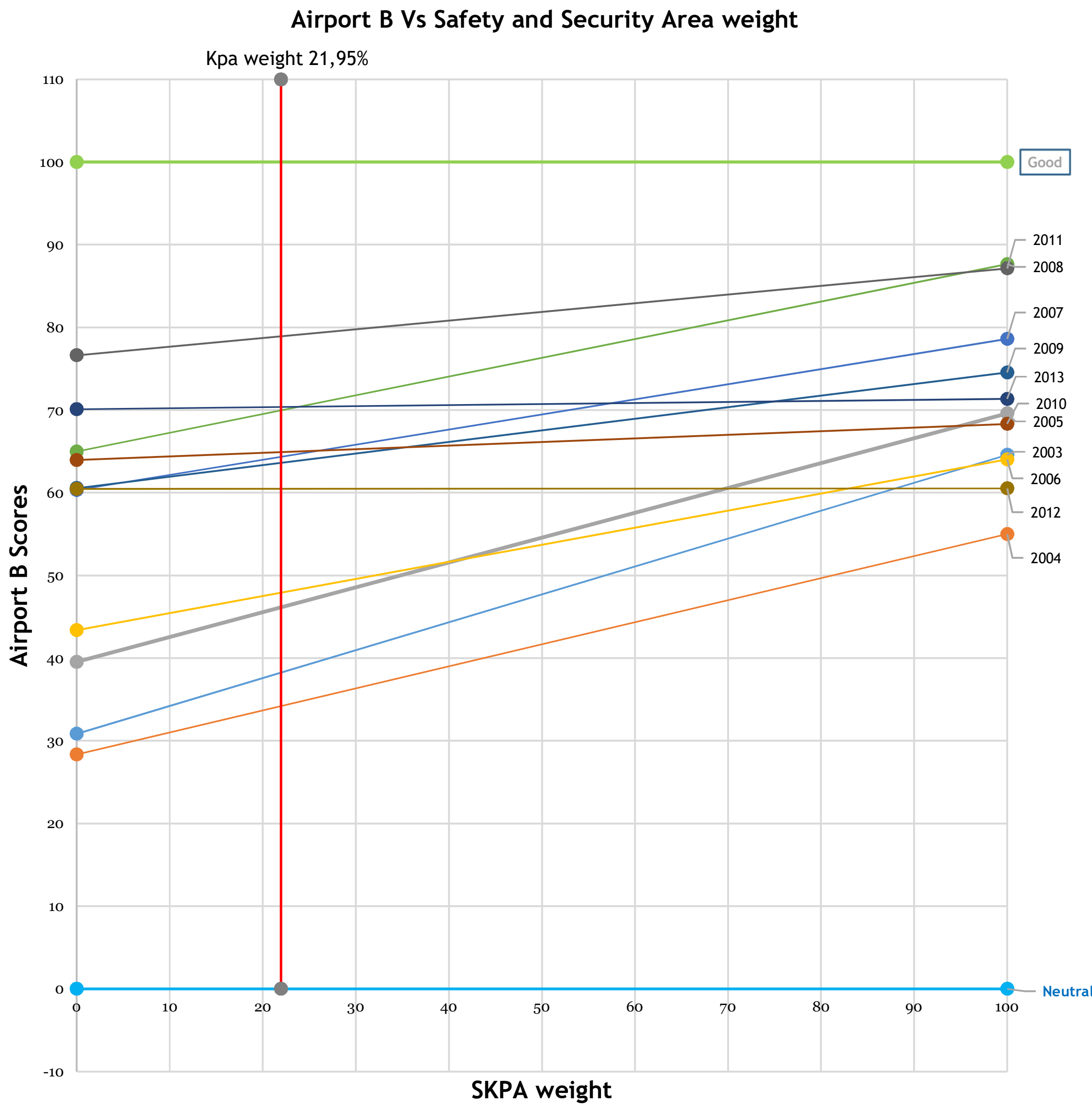

Figure 5.5 - Sensitivity analysis of SKPA weight for Airport B.

Source: Annex 3.

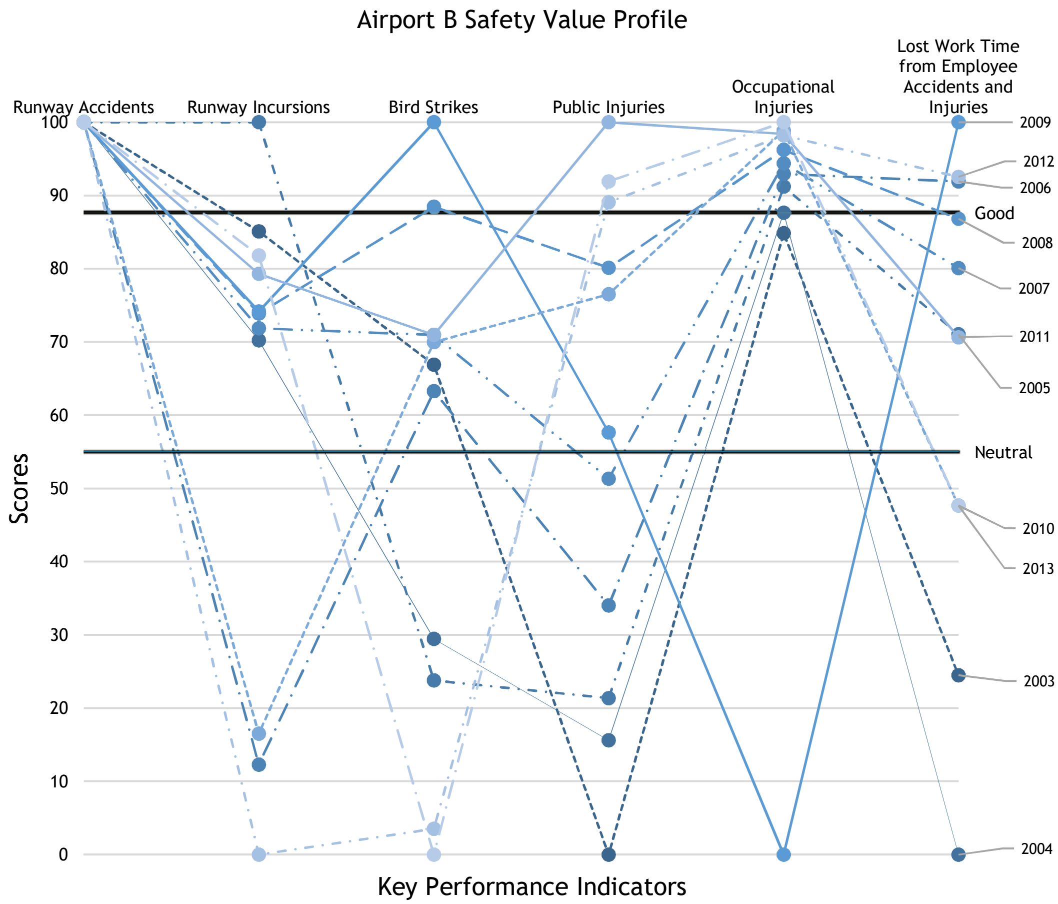

Figure 5.6 - Safety value profile for Airport B.

Source: Annex 3.

In the safety value profile for Airport B (Figure 5.6), again, we can define three major zones of achievement for the performance of an indicator: the exceed threshold (over the green line) that comprises 87 to 100 scores, the compliance zone (between the green and the horizontal blue lines) - 55 to 86 scores and the non-compliance zone (under the horizontal blue line) - 0 to 54 scores. Thus, for airport B Safety Value Profile, it is possible to observe that the options 2008 and 2011 have the best profile, with all the indicators are above the neutral level, in the compliance and in the exceed threshold zone; the option 2004 again has the worst profile, with indicators like Bird Strikes, Public Injuries and Occupational Injuries in the non-compliance zone. It is possible to realise from this profile that Airport B has a very good record in the Indicator for Occupational Injuries, except 2009.

Figure 5.7 - Linear regression between Airport B overall score and its safety KPA score. Source: Annex 3.

Figure 5.7 depicts another PESA-AGB output, that is, the impact of the SKPA scores in the Airport B overall scores. The determination coefficient value means that 49,71% of the results are explained by the model.

It is possible to group the options under evaluation in quadrants, as follows:

- Quadrant 1 (Q_1): years with a **high** SKPA scores and **high** airport overall scores - 2007, 2008, 2009, 2010, 2011, 2012 and 2013;
- Quadrant 2 (Q_2): years with a **low** SKPA scores and **high** airport overall scores - none;
- Quadrant 3 (Q_3): years with a **low** SKPA scores and **low** airport overall scores - none;
- Quadrant 4 (Q_4): years with a **high** SKPA scores and **low** airport overall scores - 2003, 2004, 2005 and 2006.

5.2.3 Airport C

The sensitivity analysis of Figure 5.8 related with Airport C, and as in airport A and B, the overall tendency remains the same; but in this case all the years analysed have a direct relation, meaning that a decrease or increase in the Safety area weight is directly associated with the year scoring. Thus, demonstrating that for airport C, there is an interaction of Safety area performance in the Airport C score, or a Safety area performance that impacts the overall score of the Airport.

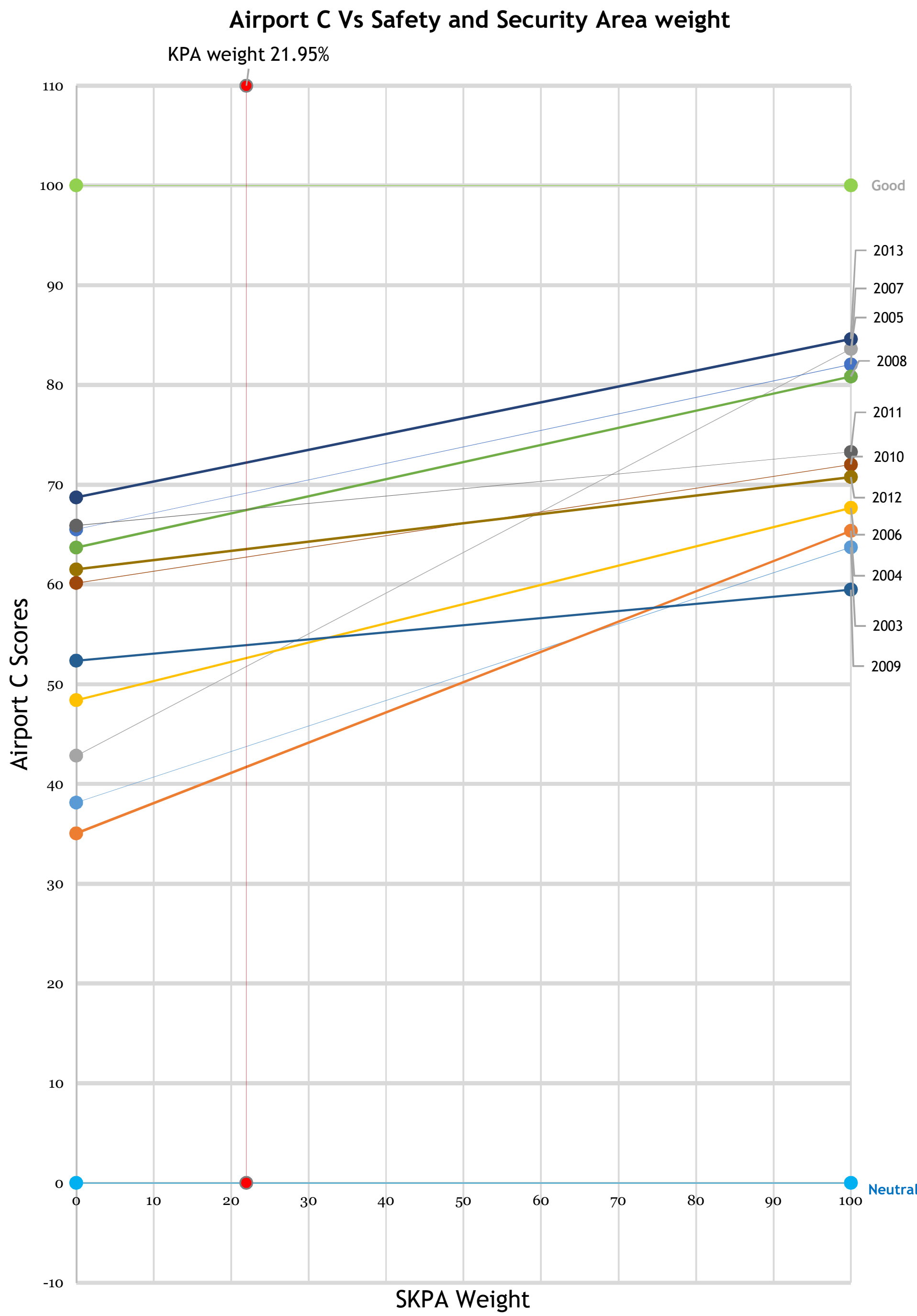

Figure 5.8 - Sensitivity analysis of SKPA weight for Airport C.

Source: Annex 3.

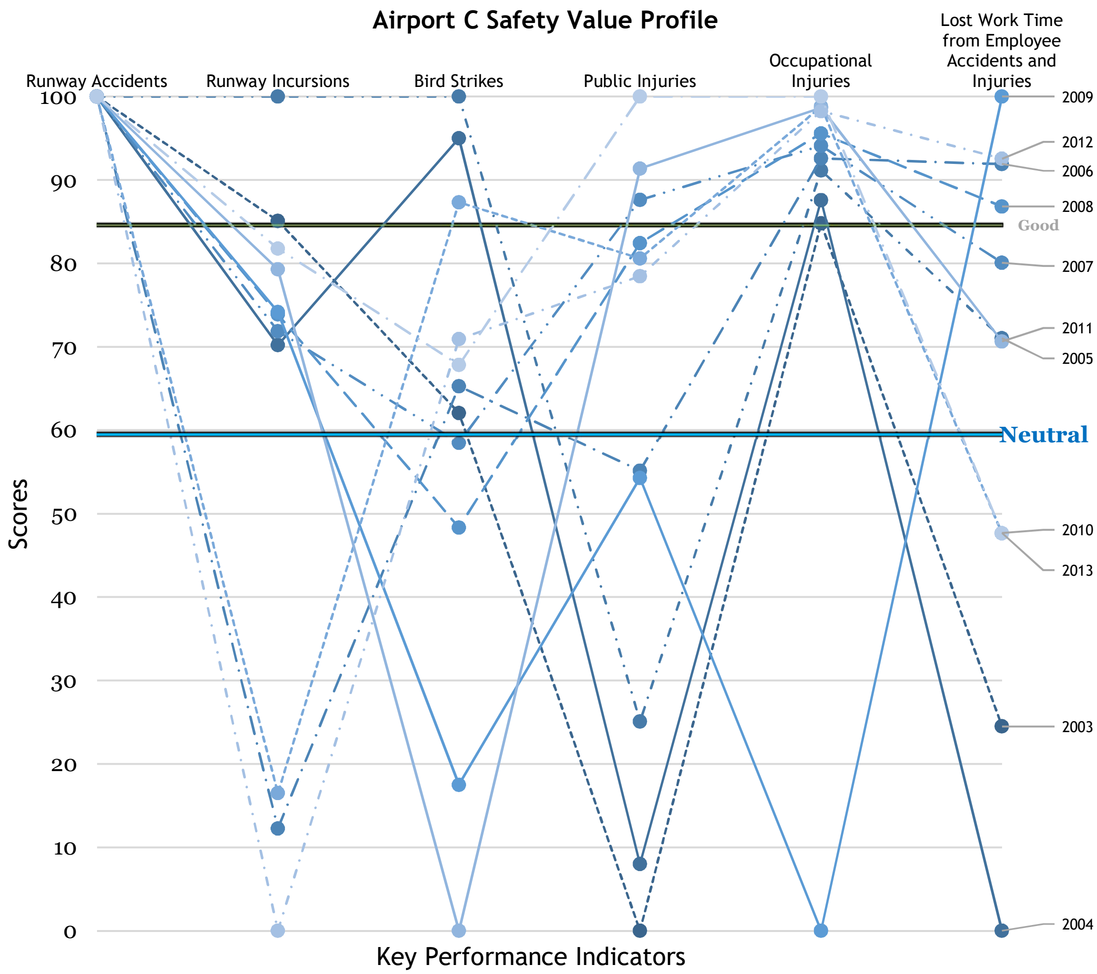

Figure 5.9 - Safety value profile for Airport C.

Source: Annex 3.

For the safety value profile for Airport C (Figure 5.9), we can define three major zones of achievement for the performance of an indicator: the exceed threshold (over the green line) that comprises 85 to 100 scores, the compliance zone (between the green and the horizontal blue lines) - 59 to 85 scores and the non-compliance zone (under the horizontal blue line) - 0 to 58 scores. Thus, for airport C Safety Value Profile, it is possible to observe that the option 2013 has the best profile, with all the indicators above the neutral level, in the compliance and in the exceed threshold zone; and the option 2009 has the worst profile, with indicators like Bird Strikes, Public Injuries and Occupational Injuries in the non-compliance zone.

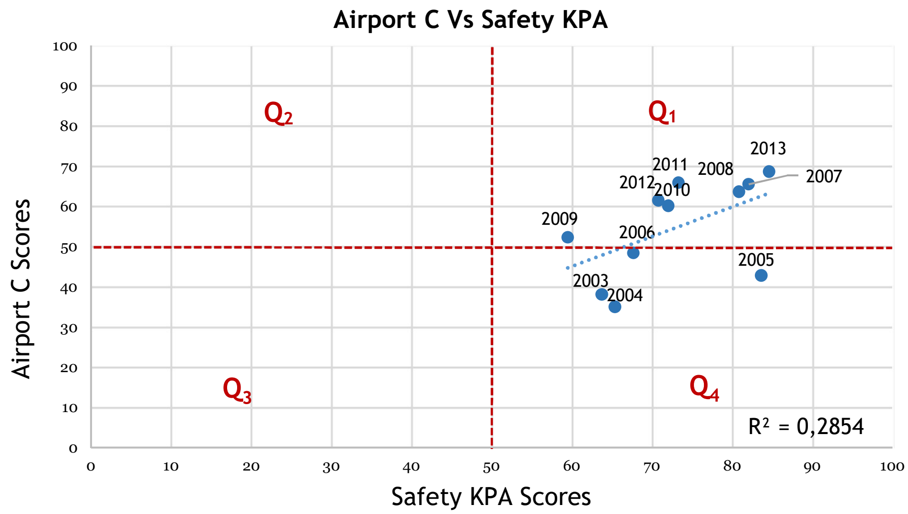

Figure 5.10 - Linear regression between Airport 3 overall score and its safety KPA score. Source: Annex 3.

Figure 5.10 evidences another PESA-AGB output, that is, the impact of the SKPA scores in the Airport C overall scores. The determination coefficient value means that the model explains 28.5% of the results; thus, grouping the options under evaluation in quadrants, as follows:

- Quadrant 1 (Q_1): years with a **high** SKPA scores and **high** airport overall scores - 2007, 2008, 2009, 2010, 2011, 2012 and 2013;
- Quadrant 2 (Q_2): years with a **low** SKPA scores and **high** airport overall scores - none;
- Quadrant 3 (Q_3): years with a **low** SKPA scores and **low** airport overall scores - none;
- Quadrant 4 (Q_4): years with a **high** SKPA scores and **low** airport overall scores - 2003, 2004 and 2005.

5.3. Peer-benchmarking

The last case study englobes the three airports in a peer-benchmarking analysis. As far as a more comprehensive analysis from airports A, B and C (Table 5.1, Table 5.2 and Table 5.3) as a group, it can be observed that Runway Accidents are the only Safety Performance Indicator with maximum score, reflecting the absence of any related occurrence reported in any airport over that time.

PESA-AGB model outputs will allow keeping track of performance and value over time. After the performance assessments, it is possible to calculate the value scores of the SKPA over the years in the three airports. For management purposes and to identify possible actions to be taken, as for the scores achieved by the airports as depicted in Table 5.4, we can compare the results for each year in the Safety Performance Area. Trough Figure 5.11 it is possible to observe that there is a similar trend over the options, evidencing the fact that the behaviour of SKPA scores follows systematic procedures, practices, and policies for the management of safety across the airport group strategy.

Table 5.4 - Summary of the scores obtained for Airport: scores for safety key performance area along 11 years.

	Safety Performance Area		
	Airport A	Airport B	Airport C
2003	69.37	64.59	63.73
2004	44.14	55.01	65.38
2005	58.67	69.60	83.63
2006	75.22	64.04	67.67
2007	87.06	78.61	82.06
2008	81.75	87.65	80.85
2009	58.15	74.57	59.48
2010	50.99	68.33	72.02
2011	72.51	87.14	73.29
2012	56.95	60.53	70.77
2013	73.47	71.35	84.60

Source: Annex 3.

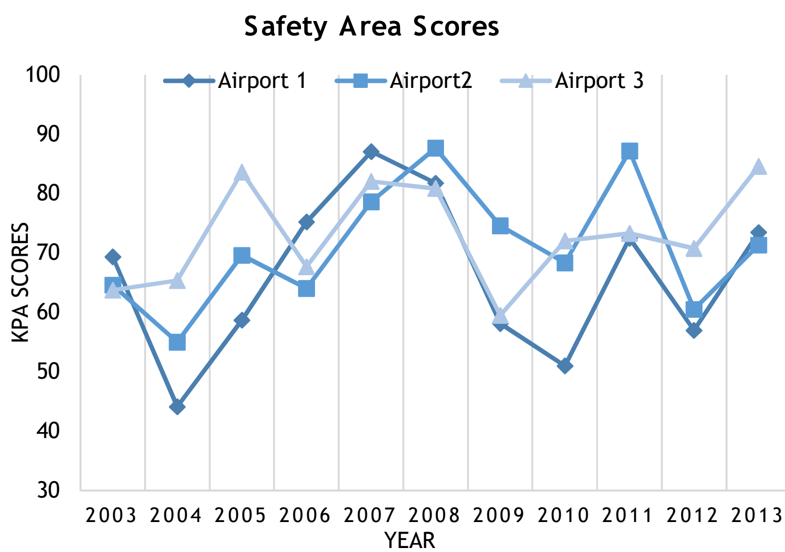

Figure 5.11 - Safety KPA scores evolution in time.

Source: Annex 3.

5.4. Conclusions

A Multi-Criteria Decision Analysis approach based on the key area of Safety was used to evaluate its impact on the overall performance of three airports and under two distinct processes, peer benchmarking and self-benchmarking (along several years in the recent past).

The case studies consider Airport A, the largest one in terms of number of passenger and movements in similitude to Lisbon airport; Airport B mainly a Low-Cost Carrier and Cargo one, resembles Oporto airport; and finally, Airport C, an LCC oriented one with seasonality peaks along the year resembles the Faro airport. Lastly considering these airports as an airport group, is presented a case study that performs a peer-benchmarking analysis in relation to the safety performance area.

The Safety Performance Area has the most weight and so is the most important area for managers, and relative to airport performance, according to the survey made with the expert's opinion, this was expectable for the Safety Area, as it reflects the primary concerns of stakeholders and major repercussions it can have if any kind of failure happens.

Also, Key Performance area of Safety is divided into 6 SKPI, Runway Accidents takes leading place with 21.57% weight, as experts consider that this indicator has a major impact in the safety area of any airport. The least concern for stakeholders is Lost Work Time from Employees Accidents and Injuries with the value of 11.76%. Runway Incursions, Bird Strikes, Public Injuries and Occupational Injuries stand in the intermediate weights of importance with 19.61%, 17.65%, 15.69% and 13.73% respectively.

For the first three case studies regarding the self- benchmarking of airports A, B and C, a sensitivity analysis relating to the weight of the Safety Key Performance Area of the Airport was performed, this allowed to visualize the ranking of the options (years) and the potential actions to be observed if the weight of the Safety Key Performance Area (SKPA) is changed.

Also for the Self- Benchmarking study, other outputs include the Safety Area performance profile for 2003-2013 options and also a quadrant analysis contrasting the SKPA scores with the Airports overall score.

In the first case study regarding Airport A, for Indicators, we can see the Runway Accidents have the highest score over these years, due to no reporting of an accident in commercial aviation relating to airport jurisdiction or ground operations. The best overall year for Safety Performance Area was 2007, and the worst 2004 with a score bellow 50. From the quadrant analysis, it can be shown that for both Airport Score and Safety Area Score the majority of the years in this study have good records, only 2004 has poor performance.

Regarding Airport B, similar to Porto Airport, Runway Accidents Indicator has again a clean sheet record with no accident reporting. The best overall year for Safety Performance Area was 2008 closely followed by 2011, and the worst 2004. From the quadrant analysis, it can be shown that for both Airport Score and Safety Area Score most of the years in this study have good records, with the years 2007-2013 having exceptional performance, and the years 2003-2006 an average performance.

For Airport C, resembling Faro Airport, and regarding indicators, as in the other airports, there's no Runway Accidents and so, achieves 100% score. The best year in overall Safety Area Performance is 2013, and the worst is 2009, however being the worst relatively, is has an average score of 59.48. The quadrant analysis reveals the years 2007-2013 with an exceptional performance, and the years 2003-2006 with an average performance.

In the Peer-Benchmarking, from the analysis of the SKPA scores and overall scores of the 3 airports we can make some assumptions. There is a relation over the Safety Performance Scores of the airports, years 2004 and 2010 for example have poorer evaluation scores in terms of Safety Performance in the Peer Group, this is an important conclusion as it can perhaps correlate economy crisis and its repercussions in the Safety Area of an Airport.

There is a clear evolution of the safety performance area and consequently, good overall airport score evidencing, from the managerial perspective, that measures and actions are well taken, including (quite sure) safety culture and SMS disseminations over the last years. There is clearly a relation between Safety Performance and the way it affects the overall performance of the airport, at least in the expert's opinion.

This method proves itself to be very flexible and user-friendly, and able an easy integration of the Safety area in particular with other different Key Performance Areas of an Airport.

The results evidence the importance of this type of evaluation to understand how airports deal with Safety issues and how this key performance area may impact in any benchmarking process and the overall evaluation of an airport. Using this methodology, we can provide an evaluation of an infrastructure comprising a multitude of complexities and particularities, and especially, in this case, the performance of a very sensitive subject like the Safety area, as a self-assessment tool or compare it with other airports, over the years.

Chapter 6

Conclusions

6.1. Dissertation Synthesis

This work was focused on the safety performance area providing the opportunity to evaluate and measure airports individually or groups of airports as in the best practices in the industry. As operators, airlines, regulators, consulting companies and financial analysts show an increased interest in this kind of assessment. It can also be a valuable tool for managers, helping to identify flaws and comparing them to standards. So, in that way, it helps to gain a better understanding of the problems in the transportation system in general and detecting variances in safety performance.

The second chapter, deals with airport safety, one of the most critical areas in commercial aviation, looking at main safety statistics connected to airport influence, namely accidents and incidents occurrence rates related to ground operations.

Additionally, addressing also, the key procedures that airports rely to ensure safety performance, namely Safety Management Systems and Safety Culture and Occupational health and safety, relating it to recent legislation and policies regarding these matters.

In the third chapter, a literature review is made on airport benchmarking, defining performance and efficiency, regarding key areas and related key indicators. An overview of the topic to better understand the common methodologies in use was made, mainly the corresponding weaknesses. The chapter ends with some insights about decision-making particularly in airport infrastructures.

The fourth chapter begins with an explanation of MCDA methodologies and in particular the MACBETH tool. Both are necessary to explain why we used PESA-AGB model to assess efficiency and performance evaluation of 3 airports (cases of study in the next chapter 5). Advantages, disadvantages and areas of application of several MCDA methodologies are evidenced; MACBETH mathematical foundation is detailed, and PESA-AGB model is explain in detail.

The fifth chapter finally applied the model to four case studies involving different airports. The airports (A, B and C) chosen for this case studies were based on the three most important Portuguese airports (Lisbon, Porto and Faro). Each case study followed the same structure, applying PESA-AGB model to the airport data to obtain the performance and efficiency scores for the Safety Performance Area for each airport, as well as its safety key performance indicators.

The Safety Performance Area has the greatest weight and so is the most important area for managers, and relative to airport performance, according to the survey made with the expert's opinion, this was expectable for the Safety Area with 21.95%.

The Key Performance area of Safety is divided into 6 SKPI, Runway Accidents with 21.57% weight, as experts consider that this indicator has a major impact in the safety area of any airport. The least concern for stakeholders is Lost Work Time from Employees Accidents and Injuries with the value of 11.76%. Runway Incursions, Bird Strikes, Public Injuries and Occupational Injuries stand in the intermediate weights of importance with 19.61%, 17.65%, 15.69% and 13.73% respectively.

For the first three case studies regarding the self- benchmarking of airports A, B and C, a sensitivity analysis relating to the weight of the Safety Key Performance Area of the Airport was performed, this allowed to visualize the ranking of the options (years) and the potential actions to be observed if the weight of the Safety Key Performance Area (SKPA) is changed. Other outputs included the Safety Area performance profile for 2003-2013 options and also a quadrant analysis contrasting the SKPA scores with the Airports overall score.

In the Self-Benchmark of Airport A, we can realise that Runway Accidents have the highest score over these years, due to no reporting of any accident in commercial aviation relating to airport jurisdiction or ground operations. The best overall year for Safety Performance Area was 2007, and the worst 2004 with a score bellow 50. From the quadrant analysis, it can be shown that for both Airport Score and Safety Area Score most of the years in this study have good records, only 2004 has a poor performance.

Regarding Airport B, similar to Porto Airport, Runway Accidents Indicator has no record for accident reporting. The best overall year for Safety Performance Area was 2008 closely followed by 2011, and the worst 2004. From the quadrant analysis, it can be shown that for both Airport Score and Safety Area Score most of the years in this study have good records, with the years 2007-2013 having exceptional performance, and the years 2003-2006 an average performance.

For Airport C, resembling Faro Airport, and regarding indicators, as in the other airports, there's no Runway Accidents and so, achieves 100% score. The best year in overall Safety Area Performance is 2013, and the worst is 2009, however being the worst relatively, is has an average score of 59.48. The quadrant analysis reveals the years 2007-2013 with an exceptional performance, and the years 2003-2006 with an average performance.

Regarding the Peer-Benchmark analysis of the SKPA scores and overall scores of the 3 airports we can make some assumptions. There is a relation over the Safety Performance Scores of the airports, years 2004 and 2010 for example have poorer evaluation scores in terms of Safety Performance in the Peer Group, this is an important conclusion as it can perhaps correlate economy crisis and its repercussions in the Safety Area of an Airport.

6.2. Concluding Remarks

The results evidence the importance of this type of decision support. It can help to understand how airports deal with performance and efficiency assessment and how the Key Performance Indicators of Safety impact in the overall airport evaluation and the Key Performance Area of Safety. This assessment methodology proves itself very powerful for stakeholders if the data is available.

The major difficulties in attaining the assessment arise especially from the difficulty of collecting safety data from safety records of airports, generally not available to the public; mathematical assumptions were made in this process precisely to fulfil data gaps.

For management purposes, PESA-AGB model outputs allow identifying if actions needed to be taken in the Safety area and to monitor SKPA scores achieved by the airports so stakeholders can keep track easily of performance and values over time.

Based on such information, it is possible to derive a panel data with SKPA value profile divided into three major zones of performance achievement, evidencing: an exceed threshold above the “good” line; the compliance zone between “good” and “neutral” lines, and the non-compliance zone below the “neutral” line. That is, from an airport Safety Value Profile, it is possible to observe what are the options with the best profile, and what are the ones that require intervention. Moreover, a quadrant analysis allows observing the actual impact of the SKPA in the airport overall scores.

However, all these powerful conclusions must be validated by airport stakeholders, if possible in real time; but we felt some difficulties to do so mainly because they are too absorbed to pay attention to these new challenges!

6.3. Areas for Future Work

In future work, and to further demonstrate and evidence the impact of the Safety KPA and related KPIs in the overall performance of the airport, other interesting approaches may be followed as, for example:

- Outline different scenarios that will test the model response and sensitivity;
- Expand the model to other airports of different operational characteristics;
- Apply the model to more indicators in this area, as well as to others that also contemplate security and illicit acts;
- Develop an TIC-based application that allows real-time assessment of the impact of safety indicators on the performance of both the area itself and the airport in general.

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Annexe 1

Measuring Attractiveness by a Categorical Based Evaluation Technique (MACBETH) Mathematical Foundation

Let $X\,(with\,\#X = n \geq 2)$ be a finite set of elements (alternatives, choice options, performance levels) that an individual or a group, J, wants to compare in terms of their relative attractiveness (desirability, value).

The judgements are represented by a v function and linear functions $s_k\!: x\,P^k y, s_k < v(x) - v(y) < s_{k+1}$ which allows numerical representation of semantic categories of difference of attractiveness through a real number interval. There are no restrictions for the number of semantic categories that can be used. However, an individual can only evaluate a limited number of judgement categories, around seven. Therefore, to ease the judgemental process, MACBETH offers six semantic categories of difference of attractiveness, “very weak” (C_1), “weak” (C_2), “moderate” (C_3), “strong” (C_4), “very strong” (C_5) or “extreme” (C_6) to J as possible answers.

To determine the real numbers $s_0, s_1, s_2, s_3, s_4, s_5$ and $v\!: A \rightarrow \Re$, $v(x)\ (x \in A)$ the following conditions must be guaranteed:

(i) $0 = s_0 < s_1 < s_2 < s_3 < s_4 < s_5$

(ii) $\forall k \in \{2, 3, 4, 5\}, s_k - s_{k-1} \geq s_1 - s_0$

(iii) $\forall x, y \in A$ with $x\,P^k y$:

$$\begin{cases} s_{k+1} < v(x) - v(y) \leq s_k & \text{if and only if } (x, y) \in C_k \text{ for } k \in \{1, 2, 3, 4, 5\} \\ s_5 < v(x) - v(y) & \text{if and only if } (x, y) \in C_6 \end{cases}$$

Where P^k represents the difference of attractiveness, which is stronger as k is bigger for a j criteria [110].

Ordinal Value Scale

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

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

$v(x) = v(y)$ if and only if J judges equal attractiveness between the elements x and y (1)

$v(x) > v(y)$ if and only if J judges x to be more attractive than y. (2)

A value difference scale (defined on X) is a quantitative representation of preferences that is used to reflect, not only the order of attractiveness of the elements of X for J, but also the differences of their relative attractiveness, or in other words, the strength of J 's preferences for one element over another. For this, J is asked to provide preferential information about two elements of X at a time, firstly by giving a judgement as to their relative attractiveness (ordinal judgement) and secondly, if the two elements are not deemed to be equally attractive, by expressing a qualitative judgement about the difference of attractiveness between the most attractive of the two elements and the other.

It is necessary to perform an analysis of cardinal (Value Scale) (transitivity) and semantics (relations between differences) coherence, suggesting, in the case of incoherence, how to solve it. By linear programming, a scale of ranks is suggested and the intervals at which they can vary without making the problem inconsistent (PPL not feasible). According to [111], only after this adjustment, with the introduction of expert inputs, is the cardinal scale of values characterised.

It is necessary to add them in a single rank by a weighted sum having the rank of each alternative for each criterion.

The problem is to weight our various criteria, respecting the opinions of decision-makers, for the attribution of weights and construction of the function that leads to the synthesis criterion. Unlike AHP method that compares the importance of the criteria directly, MACBETH makes the comparison indirectly, considering fictitious alternatives that represent each one of the criteria.

The fictitious alternative a_i represents the j criteria when it presents the best rank in j and the worst in all other criteria. Another alternative is introduced, corresponding to an artificial criterion, with the lowest score in all the criteria, to avoid that a real criterion has zero weight. The possible attribution of zero weight to a relevant criterion would violate the axiom of exhaustion [112].

In the MACBETH method [111], when the decision maker does his value judgments about the potential actions (alternatives) in each situation, he will do so regarding the attractiveness he feels for this alternative.

This task is defined [113] such as the construction of a criterion function v_j such that:

(i) for x, y ϵ *X*, $v(x) > v(y)$ if and only if for the evaluator x is more attractive (locally) than y (x P y);
(ii) any positive difference $v(x) > v(y)$ represents numerically the value difference between x and y, with P y always in terms of a fundamental point of view j, or criterion j.

Thus, for x, y, z, w ϵ *X* with x more attractive than y and z more attractive than w, we find that $v(x) - v(y) > v(z) - v(w)$ if and only if "the difference in attractiveness between x and y is greater than the difference in attractiveness between z and w".

The fundamental question in this method is [114] "Given the impacts $i_j(x)$ and $i_j(y)$ of two potential actions x and y of A from a fundamental point of view, being judged x more attractive than y, the difference of attractiveness between x and y is "weak", "strong", ...? "

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

If on the one hand, the MACBETH method introduces an interval of the real line associated with each of the categories, on the other hand, this range is not fixed a priori, being determined simultaneously with the numerical scale of value v that is being sought.

This method is linked to the theoretical problem of numerical representation of multiple semi-orders by constant thresholds of Doignon [115], represented by m binary relations ($P^{(1)}$, $P^{(2)}$, ..., $P^{(k)}$, ..., $P^{(m)}$), where $P^{(k)}$ represents the stronger and higher preference ratio k, given a criterion j.

The preferences are represented by a function v and by threshold functions s_k: $xP^{(k)}y,\ s_k < v(x) - v(y) \leq s_{k+1'}$, thus it is possible to represent numerically the difference of attractiveness semantics categories across a range of real numbers.

There is no restriction on the number of semantic categories to be used. However, a person can simultaneously evaluate a limited number of classes of an absolute judgment of the value expression, being this number around seven classes.

In MACBETH, the decision maker's judgment expression is made by a semantic scale formed by six categories, not necessarily equal in size:

- C_1 weak difference of attractiveness $\rightarrow$ $C_1 = [\ s_1, s_2]\ and\ s_1 = 0$;
- C_2 weak difference of attractiveness $\rightarrow$ $C_2 =]\ s_2, s_3]$;
- C_3 weak difference of attractiveness $\rightarrow$ $C_3 =]\ s_3, s_4]$;
- C_4 weak difference of attractiveness $\rightarrow$ $C_4 =]\ s_4, s_5]$;
- C_5 weak difference of attractiveness $\rightarrow$ $C_5 =]\ s_5, s_6]$;
- C_6 weak difference of attractiveness $\rightarrow$ $C_6 =]\ s_6, +\ ]$.

Constant thresholds delimit the categories s_1, …, s_6 determined simultaneously with the value scale v.

Matrix of value judgments

To facilitate the expression of the absolute judgments of the difference in attractiveness between the pairs of alternatives it is necessary to construct matrices of value judgments. Figure 1 shows the upper triangular matrix constructed for each criterion, in which it is assumed that $X = \{x_{\text{n}}, \dots, x_{\text{n}-1}, \dots, x_1\}$ the set of n alternatives to be evaluated, and that these are ordered in decreasing order of attractiveness a $x_{\text{n}}\ P^{\,(\text{k})}\ x_{\text{n}-1}$ not existing indifference in any case to this criterion.

	x_{n}	$x_{\text{n}-1}$	…	…	x_2	x_1
x_{n}		$X_{\text{n},\text{n}-1}$	…	…	$X_{\text{n},2}$	$X_{\text{n},2}$
$x_{\text{n}-1}$			…	…	$X_{\text{n}-1,2}$	$X_{\text{n}-1,1}$
…				…	…	…
…					…	…
x_2						$X_{2,1}$
x_1						

Figure 1 – Matrix of value judgments for local evaluation of actions. Source: Bana e Costa & Vansnick [110].

Each element $X_{\text{i,j}}$of the matrix takes the value k (k = 1, 2, 3, 4, 5, 6) if the decision maker judges that the difference the attractiveness of pair $(x_{\text{n}}, x_{\text{n}})$ belongs to category C_k. These numbers have no mathematical meaning only act as semantic indicators of which category of the difference of attractiveness has been assigned to the respective pair.

I. *Inconsistency in Judgments Value*

In cases where value matrices are big, the evaluation of all alternatives consistently becomes difficult. In these cases, it is common for inconsistencies to occur in the decision maker's value judgments. There are two types of inconsistencies: semantics (where the assignment of the difference of attractiveness category to a pair of alternatives is not logically acceptable) and cardinal (if the representation of judgments is not possible through a cardinal scale within the real numbers).

Semantics Inconsistency

Suppose that a decision maker assigned the pairs of alternatives (x, y) and (y, z) categories of attractiveness difference C_k and $C_{k'}$, respectively. Being k> k ', then x is more attractive than y in a more intense way than y is more attractive than z. Transitivity requires that the difference in attractiveness between x and z belong to a category $C_{k''}$, where k"≥ k, which means that the difference in attractiveness between the pair (x, z) is at least as large as that between the pair (x, y). The use of a consistency test in real cases causes the decision makers to redo their value judgments when involved in some situation of inconsistency.

Cardinal Inconsistency

Cardinal inconsistency occurs in situations where the decision maker generates a set of judgments that are semantically consistent but cannot be represented numerically. It is known from the theory[113], that the numerical representation of multiple semi-orders by constant thresholds is not always possible.

The judgment of the difference in attractiveness between alternatives x and z was indicated by the decision maker making impossible to construct the constant thresholds, because the theoretical condition cannot be respected, and the problem has no solution, although it is semantically consistent.

What is desired is that the difference in value between the alternatives is a number between absolute values s_k and $s_{k+1'}$ .Since the difference in attractiveness between two alternatives is, for example, strong, this does not mean that the range of category C_4 is large, but rather that the absolute values of the thresholds in this category are high.

II. Mathematical Foundations

Mathematically, the MACBETH method consists of four sequential linear programming problems (LPPs) that perform the cardinal consistency analysis, the construction of the cardinal value scale and reveal sources of inconsistency.

- 1^{st} LPP:

The 1^{st} PPL verifies the existence of cardinal inconsistencies, and mathematically is represented by (I):

$Mi\ c$

$subject\ to$

$r0)\ s_1, \dots, s_6 \geq 0; v(x) \geq 0\ \forall\ x \in X; c \geq 0$

$r1)\ s_1\ =\ 0$

$r2)\ v(x_1)\ =\ 0, where\ for\ \forall\ x \in X, is\ x\ Px_1$

LPP (I)

$r3)\ k\ =\ \{2, \dots, 6\}:\ \ s_k - \ s_{k-1}\ \geq 1000$

$r4)\ k\ =\ \{1, \dots, 6\}, (x, y) \in C_k : v(x) - \ v(y) \geq s_k + 1 - \mathrm{c}$

$r5)\ k\ =\ \{1, \dots, 5\}, (x, y) \in C_k : v(x) - \ v(y) \leq s_{k+1} - 1 + \mathrm{c}$

The objective function of (I) is the minimisation of the auxiliary variable c, whose utility is to verify if there is inconsistency in the decision maker's judgments (for c = 0, there are no inconsistencies). The r0 constraint guarantees the non-negative number of all variables of the problem. The restrictions r1 and r2 set a basis for the scale, ensuring that the lower threshold of the C_1 difference of attractiveness category and the value of the less attractive alternative is equal to zero.

The set of restrictions r3 establishes that the minimum size of each category is equal to 1000 units, arbitrary value chosen in such a way that the error introduced in the following two restrictions does not have a significant value.

The constraints r4 and r5 are the application of the Doignon formula to the problem of multiple semi-orders: s_k: $xP^{(\mathrm{k})}y,\ s_k < v(x) - \ v(y) \leq s_{k+1'}$, for each pair of alternatives in order to be possible to use linear programming, the equation above has been transformed into two, represented by the constraints r4 and r5, since in linear programming it is not possible to use strict inequalities, a constant with a value of 1 unit has been included, so that the theoretical condition is respected.

When there are cardinal inconsistencies, the problem of numerical representation of multiple semi-orders has no solution. With the introduction of variable c, PPL (I) always has a solution, that is, it will always produce a scale that represents the judgments of value of the decision maker. When the objective function value is nonzero ($c \neq 0$) there are inconsistencies, that is, the scale does not authentically represent the judgements of the decision maker.

- 2nd LPP

The 2nd PPL is responsible for the construction of the Cardinal value that represents the set of judgments of the decision maker. It is represented by the LPP (II):

$$Min\ \left\{\sum[\varepsilon(x,y)+\eta(x,y)]+\sum[\alpha(x,y)+\delta(x,y)]\right\}$$

$r0)\ s_1, \ldots, s_6 \geq 0; v(x) \geq 0\ \forall\ x \in X; c \geq 0$

$r1)\ s_1\ =\ 0$

$r2)\ v(x_1)\ =\ 0, where\ for\ \forall\ x \in X, is\ x\ Px_1$

$r3)\ k\ =\ \{2, \ldots, 6\}:\ \ s_k -\ s_{k-1}\ \geq 1000$

LPP (II)

$r4)\ k\ =\ \{1, \ldots, 6\}, (x,y) \in C_k : v(x) -\ v(y) \geq s_k + 1$

$r5)\ k\ =\ \{1, \ldots, 5\}, (x,y) \in C_k : v(x) -\ v(y) \leq s_{k+1} - 1$

$r6)\ k\ =\ \{1, \ldots, 5\}, (x,y) \in C_k : v(x) -\ v(y) = 0.5(s_k + s_{k+1}) + \varepsilon(x,y) - \eta(x,y)$

$r7)\ (x,y) \in C_6 : v(x) -\ v(y) = s_6 + 1 - \alpha(x,y) + \delta(x,y)$

The problem of the numerical representation of semi-orders by constant thresholds, when constructed per the MACBETH method, admits infinite solutions. The criterion adopted by [113], [114] that is the choice of solution is the minimisation of the absolute deviations between the value difference between two alternatives

$v(x) -\ v(y)$ and the midpoint of the category of attractiveness difference to which they belong (0, 5 * $0.5(s_k + s_{k+1})$, for $k \neq 6$. For category C_6 the criterion chosen was the minimization of the absolute deviations between the value difference of the alternatives and the $s_6 + 1$ point. The objective function of (II) is, therefore, the minimization of the sum of the absolute deviations.

The restrictions r0, r1, r2 and r3, are the same as those of the LPP (I). The constraints r4 and r5, in the same way, are like those already presented, and there is no need to include the auxiliary variable c since all the sources of inconsistency have already been analysed.

The restriction r6 makes the difference in value between the pair (x, y) equal to the central category value of the difference of attractiveness to which they belong, plus an absolute deviation. This constraint is applied to all the parallel pairs belonging to C_k with k = 1, … ,5. For pairs that have the extreme attractiveness difference, that is, k = 6, the restriction r7 makes the difference of value between the pair of alternatives equal to the infinity threshold of the category plus 1 unit plus the absolute deviation. That is, it seeks to make the difference in value between pairs of alternatives belonging to the C_6 category as close as possible to the lower threshold of this category.

- 3th and 4th LPPs

When in PPL (I) c is nonzero, there are inconsistencies in the value judgments of the decision maker. The most appropriate procedure is a review of the initial judgments, arguing with possible modifications to try to overcome problems of inconsistency. LPPs (lII) and (IV) show the possible causes of inconsistency. They present the same objective function, giving only the restrictions.

$$Min \left\{\sum[\alpha(x,y)+\beta(x,y)]\right\}$$

$r0)\ s_1,\dots,s_6 \geq 0; v(x) \geq 0\ \forall\ x \in X; c \geq 0$

$r1)\ s_1\ =\ 0$

$r2)\ v(x_1)\ =\ 0, where\ for\ \forall\ x \in X, is\ x\ Px_1$

$r3)\ k\ =\ \{2,\dots,6\}:\ \ s_k -\ s_{k-1}\ \geq 1000$

LPP (III)

$r4)\ k\ =\ \{1,\dots,6\}, (x,y) \in C_k : v(x) -\ v(y) \geq s_k + 1$

$r5)\ k\ =\ \{1,\dots,5\}, (x,y) \in C_k : v(x) -\ v(y) \leq s_{k+1} - 1$

$r6)\ k\ =\ \{1,\dots,6\}, (x,y) \in C_k : v(x) -\ v(y) = s_k + 1 - \alpha(x,y) + \delta(x,y)$

$r7)\ \ k\ =\ \{1,\dots,5\}, (x,y) \in C_k : v(x) -\ v(y) = s_{k+1} - 1 + \beta(x,y) - \gamma(x,y)$

$$Min \left\{\sum[\alpha(x,y)+\beta(x,y)]\right\}$$

$r0)\ s_1,\dots,s_6 \geq 0; v(x) \geq 0\ \forall\ x \in X; c \geq 0$

$r1)\ s_1\ =\ 0$

$r2)\ v(x_1)\ =\ 0, where\ for\ \forall\ x \in X, is\ x\ Px_1$

LPP (IV)

$r3)\ k\ =\ \{2,\dots,6\}:\ \ s_k - \ s_{k-1}\ \geq 1000$

$r6)\ k\ =\ \{1,\dots,6\}, (x,y) \in C_k : v(x) -\ v(y) = s_k + 1 - \alpha(x,y) + \delta(x,y)$

$r7)\ \ k\ =\ \{1,\dots,5\}, (x,y) \in C_k : v(x) -\ v(y) = s_{k+1} - 1 + \beta(x,y) - \gamma(x,y)$

The objective function minimises the sum of the variables $\alpha(x,y)$ and $\beta(x,y)$, highlighting in (III) and (IV) pairs of alternatives whose identification with the respective categories specified by the decision maker introduce problems of inconsistency. Thus, those for which the values of $\alpha(x,y)$ or $\beta(x,y)$ are nonzero in the optimal solution of (III) or (IV). Thus, an altered matrix that leads to consistency is suggested to the decision maker.

The difference between the optimal solutions of these two problems lies in the fact that they restrict (ll) or not (V) the possible solutions to values of the variables $\alpha(x,y)$ and $\beta(x,y)$ not exceeding the value of c, by the introduction r4 and r5 restrictions (III) or not (IV).

III. Determination of weights for the criteria

Given the absolute value judgments per each of the criteria, it is necessary to obtain information of an inter-criteria nature (represented by scale constants, substitution rates or weights), for an overall assessment of the alternatives. In the MACBETH method, each criterion is represented by a fictitious alternative that has the best possible evaluation in this criterion and the worst in the other criteria.

Unlike the AHP method that compares the importance of the criteria directly, MACBETH makes the comparison indirectly, by comparing the dummy alternatives that represent each one of the criteria. The fictitious alternative x_i represents the criterion j when it has the highest attractiveness in j and the worst in the other criteria. In order, not to lose information about the criterion considered less attractive, one should introduce into the matrix of value judgments an other fictional alternative, which must have the worst level of impact in all fundamental points of view. The inclusion of this alternative avoids zero weight being attributed to any criterion, which violates Roy's axiom of exhaustion.

With this set of judgments, the MACBETH method is executed first for the verification of any semantic and cardinal inconsistencies and, later, for the determination of a cardinal value scale that represents the value judgments of the decision maker. The LPPs are like the previous ones, except for the normalisation constraint added in this module.

Annexe 2

Step by Step example on how to obtain Safety/Security KPA scores using PESA - AGB model

Step1 – Structuring

a. KPI performance descriptor:

To define each KPI performance descriptor we analyse the KPI data from a time-span.

Table 1 – Runway Incursions KPI data.

	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012
Runway Incursions	0.059	0.063	0.056	0.077	0.062	0.062	0.062	0.076	0.061	0.080

Using

Table 1 we can identify that the best year as 2005 (0,056) and the worst year as 2012 (0,080). With this information, the performance descriptor is built as shown in

Table 2.

Table 2 – Runway Incursions KPI performance descriptor.

	Runway Incursions
L4 (Target)	0.042
L3	0.048
L2	0.054
L1 (Neutral)	0.060

2. **Step – Survey**

From the application of the survey, we obtain three outputs: criteria judgement matrix, key performance indicators status quo and key performance areas status quo.

a. Criteria Judgement Matrix

Table 3 – Runway Incursions KPI criteria judgement.

	Runway Incursions					
	AD	AD	AD	AD	AD	AD
No Difference	0	0	0	0	0	0
Very Weak	1	0	0	2	1	1
Weak	0	3	2	2	3	3
Moderate	2	2	3	7	8	9
Strong	3	7	9	7	5	4

	Runway Incursions					
	AD	AD	AD	AD	AD	AD
Very Strong	9	7	5	1	2	2
Extreme	4	0	0	0	0	0
Mode	Very Strong	Strong	Strong	Moderate	Moderate	Moderate
Weighted Arithmetic Mean	4.63	3.95	3.89	3.16	3.21	3.16
Difference of Attractiveness	Strong-Very Strong	Moderate-Strong	Moderate-Strong	Moderate	Moderate	Moderate

Table 3 depicts the expert's answers to question 8 of the survey. This result will be later used to obtain the value function. (Note: each KPI of the model follow this process).

b. Key Performance Indicators Status Quo

Table 4 –Judgements on each KPI of Safety and Security KPA.

	Runway Accidents	Runway Incursions	Bird Strikes	Public Injuries	Occupational Injuries	L.W. T. E. A. I.*
Very Weak	0	0	0	0	0	0
Weak	0	0	3	2	1	1
Moderate	0	1	1	4	7	9
Strong	2	3	6	5	5	6
Very Strong	6	10	4	4	3	2
Extreme	11	5	5	4	3	1
Mode	Extreme (6)	Very Strong (5)	Strong (4)	Strong (4)	Moderate (3)	Moderate (3)
Weighted Arithmetic Mean	5.47	5.00	4.37	4.21	4.00	3.63
All Worst	Very Strong	Very Strong	Strong	Strong	Strong	Moderate-Strong

***Lost Work Time from Employee Accidents and Injuries**

Table 5 –Status quo of each KPI of Safety and Security KPA.

Safety and Security	Status Quo
Runway Accidents	5,47
Runway Incursions	5,00
Bird Strikes	4,37
Public Injuries	4,21
Occupational Injuries	4,00
Lost Work Time from Employee Accidents and Injuries	3,63

Table 4 and Table 5 depict the expert's answers to question 7 of the survey. These results will be later used to build KPI judgement matrix and weight ponderation.

c. Key Performance Areas Status Quo

Table 6 –Judgements on each KPA.

	Core	Safety and Security	Service Quality	Productivity / Cost Effectiveness	Financial / Commercial	Environmental
Very Weak	0	1	0	0	1	2
Weak	2	2	1	1	2	26
Moderate	6	4	12	9	16	17
Strong	22	13	41	28	24	18
Very Strong	30	37	16	40	32	11
Extreme	21	24	11	3	6	7
Weighted Arithmetic Mean	4,77	4,91	4,30	4,43	4,26	3,38
Status Quo	Strong-Very Strong	Strong-Very Strong	Strong	Strong	Strong	Moderate

Table 7 –Status quo of each KPA.

Key Performance Areas	Status Quo
Safety and Security	4,91
Core	4,77
Productivity / Cost Effectiveness	4,43
Service Quality	4,30
Financial / Commercial	4,26
Environmental	3,38

Table 6 and

Table 7 depict the expert's answers to question 6 of the survey. This result will be later used to build KPI judgement matrix and weight ponderation.

4. Step - Evaluation

This step uses the outputs of step 1 and 2 to build the value functions, judgment matrices and to determine weights ponderations.

a. Value Function

This matrix is built for each one of the KPI using the expert's judgments collected in Table 3.

Table 8 –Runway Incursions judgment matrix.

Runway Incursions				
0.0556		0.0637	0.0717	0.0798
0.0637	0.0556	Moderate	Moderate-Strong	Strong-Very Strong
0.0717		0.0637	Moderate	Moderate-Strong
0.0798			0.0717	Moderate

Applying MACBETH mathematical foundations, from the matrix on

Table 8 we obtain the Value function for this KPI, as shown in Figure 1.

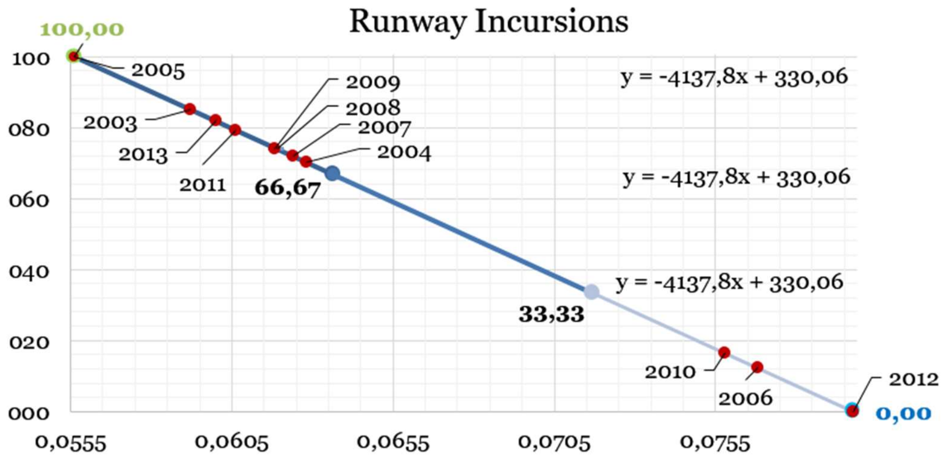

Figure 1 – Runway Incursions value function.

With the value function of Figure 1, we can obtain the score for each year (option) for this KPI. (Note: each KPI of the model follow this process).

b. <u>Key Performance Indicators Judgement Matrix and Weights Ponderation</u>

This matrix (

Table 9) is built for the Safety and Security KPA using the expert's judgments collected in Table 4 and Table 5.

Table 9 –Safety KPI's judgment matrix.

	Safety and Security					
	Runway Incursions	Bird Strikes	Public Injuries	Occupational Injuries	Lost Time Occupational Injuries	All Worst
Runway Accidents	Very Weak	Very Weak-Weak	Very Weak-Weak	Very Weak-Weak	Weak	Very Strong
Runway Incursions		Very Weak	Very Weak	Very Weak-Weak	Very Weak-Weak	Very Strong
Bird Strikes			Very Weak	Very Weak	Very Weak	Strong
Public Injuries				Very Weak	Very Weak	Strong
Occupational Injuries					Very Weak	Strong
Lost time Occupational injuries						Moderate-Strong

Applying MACBETH mathematical foundations, from the matrix on

Table 9, we obtain the weights ponderation for each KPI, as shown in

Table 10. (Note: each KPA of the model follow this process).

Table 10 –KPI weight ponderation of Safety KPA.

Safety and Security	**Key Performance Indicators**	**Weights**
Runway Accidents	11	**21.57%**
Runway Incursions	10	**19.61%**
Bird Strikes	9	**17.65%**
Public Injuries	8	**15.69%**
Occupational Injuries	7	**13.73%**
Lost Work Time from Employee Accidents and Injuries	6	**11.76%**

c. Key Performance Areas Judgement Matrix and Weights Ponderation

This matrix (
Table 11) is built using the expert's judgments collected in Table 6 and

Table 7.

Table 11 –Airport KPA's judgment matrix

	Core	Productivity / Cost Effectiveness	Service Quality	Financial / Commercial	Environmental	**Status Quo**
Safety and Security	Very Weak	Very Weak	Very Weak	Very Weak	Weak	Strong-Very Strong
	Core	Very Weak	Very Weak	Very Weak	Very Weak-Weak	Strong-Very Strong
		Productivity / Cost Effectiveness	Very Weak	Very Weak	Very Weak-Weak	Strong
			Service Quality	No	Very Weak	Strong
				Financial / Commercial	Very Weak	Strong
					Environmental	Moderate

Applying MACBETH mathematical foundations, from the matrix on

Table 11, we obtain the weights ponderation for each KPA, as shown in

Table 12.

Table 12 –KPA weight ponderation.

Key Performance Areas	*Current Scale*	*Weight*
Safety and Security	9	21,95%
Core	8	19,51%
Productivity / Cost Effectiveness	7	17,07%
Service Quality	6	14,63%

Financial / Commercial	6	14,63%
Environmental	5	12,20%

5. **Step – Classifications**

This step uses the outputs of step 4 to obtain the final scores for each KPI, each KPA and airport overall score.

a. Value Scores

With the value function shown in Figure 1, by direct correspondence we obtain the KPI scores as

Table 13 depicts. (Note: each KPI of the model follow this process).

Table 13 –Runway Incursions scores.

Runway Incursions scores											
Options	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013
Scores	85,10	70,21	100,0	12,28	71,86	73,88	74,18	16,50	79,29	0,0	81,79

b. KPA scores

Multiplying each KPI scores (

Table 13) with each KPI weights ponderation (
Table 10) and then summing all this results, we obtain the KPA score for each year (option), as
Table 14 depicts. (Note: each KPA of the model follow this process).

Table 14 –Safety and Security KPA scores.

	Runway Accidents	Runway Incursions	Bird Strikes	Public Injuries	Occupational Injuries	Lost Time from Employee Accidents and Injuries	Key Performance Area Score
2003	100.00	85.10	73.41	9.90	100.00	24.50	69.37
2004	100.00	70.21	9.65	1.55	49.99	0.00	44.14
2005	100.00	100.00	0.00	0.00	66.57	71.03	58.67
2006	100.00	12.28	67.21	95.67	98.80	91.91	75.22
2007	100.00	71.86	80.33	98.91	89.51	80.08	87.06
2008	100.00	73.88	100.00	28.55	97.27	86.83	81.75
2009	100.00	74.18	22.40	40.28	0.00	100.00	58.15
2010	100.00	16.50	45.90	65.41	16.17	47.67	50.99
2011	100.00	79.29	18.40	99.42	60.07	70.65	72.51
2012	100.00	0.00	28.42	56.59	77.22	92.55	56.95
2013	100.00	81.79	22.40	100.00	77.32	47.67	73.47

c. Airport scores

Multiplying each KPA scores (
Table 14) with each KPA weights ponderation (Table 12) and then summing all these results, we obtain the airport score for each year (option), as
Table 15 depicts.

Table 15 – Overall Airport 1 scores, with Safety and Security integrated in another Key Performance Areas

	Safety and Security	Core	Productivity / Cost Effectiveness	Service Quality	Financial / Commercial	Environmental	Airport 1 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
Weights	21,95%	19,51%	17,07%	14,63%	14,63%	12,20%	

Annexe 3

PESA-AGB: Scores Outputs

PESA-AGB

Score Outputs

Produced by:

Núcleo de Investigação em Transportes
Transportation Research Team
DEPARTAMENTO DE CIÊNCIAS AEROESPACIAIS
Aerospace Sciences Department

Suported by:

BANA CONSULTING

Key Performance Areas Scores

AIRPORT 1

Safety and Security

	Runway Accidents	Runway Incursions	Bird Strikes	Public Injuries	Occupational Injuries	Lost Work Time from Employee Accidents and Injuries	Key Performance Area Score
2003	100,00	85,10	73,41	9,90	100,00	24,50	69,37
2004	100,00	70,21	9,65	1,55	49,99	0,00	44,14
2005	100,00	100,00	0,00	0,00	66,57	71,03	58,67
2006	100,00	12,28	67,21	95,67	98,80	91,91	75,22
2007	100,00	71,86	80,33	98,91	89,51	80,08	87,06
2008	100,00	73,88	100,00	28,55	97,27	86,83	81,75
2009	100,00	74,18	22,40	40,28	0,00	100,00	58,15
2010	100,00	16,50	45,90	65,41	16,17	47,67	50,99
2011	100,00	79,29	18,40	99,42	60,07	70,65	72,51
2012	100,00	0,00	28,42	56,59	77,22	92,55	56,95
2013	100,00	81,79	22,40	100,00	77,32	47,67	73,47
Weigths	21,57%	19,61%	17,65%	15,69%	13,73%	11,76%	

AIRPORT 2

Safety and Security

	Runway Accidents	Runway Incursions	Bird Strikes	Public Injuries	Occupational Injuries	Lost Work Time from Employee Accidents and Injuries	Key Performance Area Score
2003	100,00	85,10	66,90	0,00	84,84	24,50	64,59
2004	100,00	70,21	29,45	15,61	87,65	0,00	55,01
2005	100,00	100,00	23,77	21,36	91,23	71,03	69,60
2006	100,00	12,28	63,26	34,02	92,92	91,91	64,04
2007	100,00	71,86	70,97	51,32	94,39	80,08	78,61
2008	100,00	73,88	88,45	80,10	96,25	86,83	87,65
2009	100,00	74,18	100,00	57,64	0,00	100,00	74,57
2010	100,00	16,50	69,98	76,51	98,85	47,67	68,33
2011	100,00	79,29	70,94	100,00	98,41	70,65	87,14
2012	100,00	0,00	3,53	89,06	98,21	92,55	60,53
2013	100,00	81,79	0,00	91,89	100,00	47,67	71,35
Weigths	21,57%	19,61%	17,65%	15,69%	13,73%	11,76%	

AIRPORT 3

Safety and Security

	Runway Accidents	Runway Incursions	Bird Strikes	Public Injuries	Occupational Injuries	Lost Work Time from Employee Accidents and Injuries	Key Performance Area Score
2003	100,00	85,10	62,08	0,00	84,79	24,50	63,73
2004	100,00	70,21	95,01	8,01	87,60	0,00	65,38
2005	100,00	100,00	100,00	25,10	91,15	71,03	83,63
2006	100,00	12,28	65,28	55,15	92,61	91,91	67,67
2007	100,00	71,86	58,50	87,60	94,09	80,08	82,06
2008	100,00	73,88	48,34	82,42	95,57	86,83	80,85
2009	100,00	74,18	17,50	54,27	0,00	100,00	59,48
2010	100,00	16,50	87,32	80,59	98,80	47,67	72,02
2011	100,00	79,29	0,00	91,35	98,64	70,65	73,29
2012	100,00	0,00	70,95	78,47	98,25	92,55	70,77
2013	100,00	81,79	67,84	100,00	100,00	47,67	84,60
Weigths	21,57%	19,61%	17,65%	15,69%	13,73%	11,76%	

Airport Scores

Airport 1

	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
Weigths	21,95%	19,51%	17,07%	14,63%	14,63%	12,20%	

Airport 2

	Safety and Security	Core	Productivity / Cost Effectiveness	Service Quality	Financial / Commercial	Environmental	Airport Score
2003	64,59	1,14	10,71	27,85	57,86	17,03	30,85
2004	55,01	6,71	7,40	29,45	43,89	24,32	28,35
2005	69,60	11,77	10,26	49,58	59,23	35,29	39,56
2006	64,04	34,34	21,00	38,90	59,73	37,85	43,39
2007	78,61	46,16	59,27	67,11	62,42	41,06	60,34
2008	87,65	61,18	83,71	36,19	44,76	62,98	65,00
2009	74,57	45,92	69,19	61,51	50,42	57,73	60,56
2010	68,33	67,21	78,78	62,54	38,31	62,54	63,95
2011	87,14	83,99	90,99	70,00	48,05	67,99	76,62
2012	60,53	82,95	61,29	45,29	29,32	78,74	60,46
2013	71,35	80,99	52,07	66,16	61,64	90,58	70,11
Weigths	21,95%	19,51%	17,07%	14,63%	14,63%	12,20%	

Airport 3

	Safety and Security	Core	Productivity / Cost Effectiveness	Service Quality	Financial / Commercial	Environmental	Airport Score
2003	63,73	19,11	28,21	28,82	47,93	35,87	38,14
2004	65,38	15,40	11,81	37,38	44,76	30,04	35,06
2005	83,63	21,52	17,95	34,87	53,34	35,28	42,83
2006	67,67	40,38	37,76	46,11	42,97	50,71	48,40
2007	82,06	64,47	84,63	68,29	38,70	39,60	65,53
2008	80,85	59,59	87,57	47,05	37,16	57,78	63,70
2009	59,48	37,79	64,58	44,14	56,25	50,89	52,35
2010	72,02	57,78	73,26	53,85	44,63	50,32	60,14
2011	73,29	67,63	78,00	53,12	53,87	62,66	65,90
2012	70,77	66,27	37,96	74,72	48,35	70,24	61,52
2013	84,60	81,44	39,13	63,07	48,46	92,39	68,73
Weigths	21,95%	19,51%	17,07%	14,63%	14,63%	12,20%	

Annexe 4

Publication Abstracts

21ST ATRS WORLD CONFERENCE

AIRPORT BENCHMARKING ISSUES. THE KEY PERFORMANCE AREA OF SAFETY

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Abstract

The utility of an airport benchmarking process is widely recognised in a world where competition between airports is becoming a reality. Therefore, there is a need for a wide consensus to establish and construct reliable databases for measuring airport performance and consequently the development and the implementation of even more accurate performance management systems. A wide number of studies that focus on airport benchmarking - but mainly based on economic and productivity performance indicators, are done and can be found in the literature. However, there is a lack of studies that focus on the airport performance in a holistic form, set in different areas for a truly global analysis. A Multi-Criteria Decision Analysis (MCDA) approach applied to Safety key performance area from PESA–AGB (Performance Efficiency Support Analysis – Airport Global Benchmarking) model, based on MACBETH (Measuring Attractiveness by a Categorical Based Evaluation Technique) methodology, is used to evaluate its impact on the overall performance of three airports and under two distinct processes, peer and self-benchmarking - along eleven years. The Safety area performance analysis is done comparing scores among different airports (peer benchmarking) and assessing scores of each airport along several years (self-benchmarking). This proves to be a useful and flexible tool for stakeholders. The results evidence the importance of this type of evaluation to understand how airports deal with Safety issues and how this key performance area may impact in any benchmarking process, and on the overall evaluation of such complex transport infrastructure too.

Keywords: *Airport benchmarking, Safety, Multi-Criteria Decision Analysis*

1. Introduction

In spite of accidents in aviation make headlines all over the world, aviation is arguably the safest mode of mass transportation [3], and the technological development over the years have provided very good safety records for commercial aviation (Boeing, 2011). Accidents and non-predicted events will invariably happen, and the probable cause for that will be a Safety failure of some kind [5].

A more realistic objective of Safety would be to bring under control, in aviation operational contexts, all variables that can precipitate bad or damaging outcomes, and so, a definition of Safety would be, as according to ICAO, "The state in which the possibility

GLOBAL DECISION ANALYSIS MODEL FOR AIRPORT PERFORMANCE MANAGEMENT

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Key words: Airports, Performance, Efficiency, MCDA , Benchmarking

Abstract. *Airport benchmarking depends on airport performance and efficiency indicators, which are important issues for business, operational management, regulatory agencies, airlines and passengers. There are several sets of indicators to evaluate airports efficiency as well as several techniques to benchmark such infrastructures. Airport performance measures provides a useful set of measures across a number of categories that will be helpful for airports around the world for the efforts of the performance management of these infrastructures. It is suggested that these measures are divided into six categories KPAs – Key Performance Areas, which have associated to a list of PIs – Performance Indicators. After defining witch set of PIs of the KPAs that are to be benchmarked for the efficiency evolution, either of a set of airports or the same airport along several years under several constraints, a model based on multidimensional tool, Multicriteria Decision Analysis (MCDA, by Measuring Attractiveness by a Categorical Based Evaluation Technique, MACBETH) is created, it provides the knowledge for establishing priorities and witch option will be selected, this action can be taken by an individual or a group of individuals. This model is essential, firstly to evaluate the performance of any airport in a global perspective [air side, land side, and related catchment area], facing the challenges of the next future, and secondly to benchmark all the direct competitors or self-benchmark during a period of time.*

INTRODUTION

Airports of all sizes have a need for performance measures, but the types and quantity of those measures varies, from general aviation (GA) to large hub airports. The need and relevance of monitoring performance and efficiency with financial and operational data is, largely, to understand, manage, and maximize airport revenue. The pursuit of new ways of maximizing the revenue made airport management more aggressive and performance measurement programs were introduce to improve the airport efficiency and increase the revenue. In addition, airports have become interested in assessing their performance against others and encouraged airport management to use best practices from other airports as well as from private organization with non-aviation industries [1].

The Airport as a Catalytic Element of the Regional Development in the Hinterland

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Abstract

The catalytic influence of airports on the regional economic development is well known and increasingly relevant. Concepts, such as: airport region, airport corridor, airport city, airea or aerotropolis have been developed to conceptualize those influences. In this sense, determining the limits of influence of an airport – hinterland – is thus a key aspect to both support the implementation of public policies as well as support airport business development. Notwithstanding, the literature on the topic is relatively scarce and few methods have been developed. Typically, the Hinterland is measured in terms of travel time isochronous normally measured along the transport network or distance isochronous. However, the validity of such method, and practice, raises some doubts. For example, the actual distribution of economic activities and population is ignored as well as the mutual influence of other airports.

The objective of this paper was to assess the validity of the hinterland defined by the Portuguese airport manager – ANA Aeroportos de Portugal. We developed a case study involving the most important mainland portuguese national airports – Lisbon (LIS), Oporto (OPO) and Faro (FAO). ANA defines the hinterland of each airport in terms of a travel time, in a total of 120 minutes, 90 minutes and 60 minutes, respectively. We developed a comprehensive survey to the companies located in the within the hinterland of every airport aiming to understand the existence of any relationship between them and the closest airport. We followed a stratified sample method to determine the size of the survey. We only considered import and export companies with the highest business volumes. Data analysis was performed by SPSS (a statistical analysis tool). We collected a total of 243 surveys.

The results suggest that distance and travel time are indeed relevant factors in the choice of the airport. Yet, others, such as, the airport's destinations or type of airlines (i.e. low cost companies) also play a relevant role. The main conclusion of the study was that the calculation of an airport's hinterland based solely on the travel time or distance is potentially misleading. Further research is now needed to calculate their actual influence even including other indicators.

Keywords: Airport, Hinterland, Regional Development.

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18TH ATRS WORLD CONFERENCE

DETERMINATION AND EVALUATION OF THE AIRPORT CATCHMENT AREA

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The definition of the Hinterland or the Catchment Area of an airport is very broad and current literature suggests doing it in combination with certain pre-defined criteria: the assessment of the impact or effectiveness of a certain airport, or from the perspective of competition between airports. Traditionally the Catchment Area is measured by radial geographic distances around the airport or by the travel time on the transportation network from any given point to the airport.

This work determines and evaluates the size of an airport Catchment Area using conventional GIS approach and studies the main Portuguese airports. Considering the travel time suggested by the airport authorities, two temporal scenarios (2001-2011) were elaborated based on available data in national census and using a wider set of indicators. An inquiry to the most important business stakeholders close the frontier of the Catchment Area was performed to understand the existence of a relationship with the closest airport.

This work is a part of a broader study that aims to determine the existence (and thus the importance) of any impact of the Catchment Area on the overall efficiency of an airport and in the regional development.

Keywords: Catchment Area, Airport Efficiency, Regional Development, Hinterland Impact, GIS Network Analysis

Related Topic Areas: Airport and Airline Performance; Airport Economics; Aviation and Economics Development

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The definition of the Hinterland or the Catchment Area of an airport is very broad and current literature suggests doing it in combination with certain pre-defined criteria: the assessment of the impact or effectiveness of a certain airport, or from the perspective of competition between airports.

Some authors prefer to make a definition of the Catchment Area before any analysis and without favor any indicator; others prefer to do it with by the discrimination of sets of indicators that are potentially usable. Traditionally the Catchment Area is measured by radial geographic distances around the airport or by the travel time from one point to the airport.

The general aim of this work is to determine and evaluate the size of an airport Catchment Area using conventional GIS approach. It is possible to consider the travel time on the transportation network from any given point to the airport. We elaborate two temporal scenarios (2001-2011) based on available data in national census and using a set of indicators such as: Population Density, Education Level, Household Income, Economically Active Population, Employment Level, Business Density, Sectorial Structure of Employment, Business Volume, Health, Tourist Attractions, Hotel Establishments, Accommodation Capacity and Occupation Rate.

At this stage of the research the transportation network is already built as well as the embedded census data, so that the Catchment Areas of our three case studies (Lisbon, Oporto and Faro airports) were determined. It was considered different travel time suggested by the airport authorities: for Oporto airport was considered 90 minutes, for Lisbon airport 120 minutes, and for Faro airport 60 minutes. The next step is to inquiry the more important business stakeholders close the frontier of the Catchment Area (last 30 minutes of each one) to understand the relationship with the closest airport.

This work is a part of a broader study that aims to determine the existence (and thus the importance) of any impact of the Catchment Area on the overall efficiency of an airport.

KEYWORDS: Catchment Area, Airport Efficiency, Regional Development, Hinterland Impact, GIS Network Analysis