



UNIVERSIDADE DA BEIRA INTERIOR  
Engenharia

**Airports' Performance and Efficiency  
Concerning Low-Cost Carriers Operation.  
An MCDA and SPSS analysis**

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Dissertação para obtenção do Grau de Mestre em  
**Engenharia Aeronáutica**  
(Ciclo de estudos integrado)

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Covilhã, Abril de 2017







## Dedicatory

To my family and friends, especially to my parents, sister and brother-in-law for their unconditional love and support throughout this entire degree. I couldn't finish this without them.

*“To most people, the sky is the limit.  
To those who love aviation, the sky is home”  
Anonymous*



## Acknowledgements

First and foremost, I need to thank my supervisor Prof. Jorge Miguel Reis Silva for all his guidance, knowledge and motivation. I'm not only grateful for his support in each step of this work but also for his friendship and kindness.

I would like to give my gratitude to Maria Emilia Balthazar, my unofficial co-supervisor, for the opportunity to work and contribute to her PhD research. For her friendship and motivation to always improve my work and me as a person. For all the after hours spent cracking our heads to make our objectives come true.

My written appreciation to Prof. Rosário Macário and PhD Vasco Reis for their trust and for allowing me the possibility to participate in different research projects.

My greatest acknowledgement to NIT - Núcleo de Investigacao em Transportes and all its past, present and future researchers for the help making this research group more than one team, a family. A place that some call "arrumos" but I call a second home.

I want to thank all my friends for their support and encouragement throughout my life. Special thanks to my big friends Miguel Miranda and Laura Martins with whom I shared my last 6 years very closely. To my parents, Helena e José Rosa, for their love and unconditional support even through difficult times. I'm grateful to my sister Carina, to my brother-in-law Daniel e to the rest of my family for their support and love.

Last but not least, to the people who I did not mention above but contributed for this work and for making me grow professionally and personally. Big thanks for the ones that always supported me and made my life better and happier. Also for the ones that always tried to throw me down for making me a stronger person.

To all: Obrigado.



## List of Publications

### Articles produced as a result of this dissertation research (annexe 5):

1. **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).
2. **MCDA Modelling of Airport Impacts due to LCC's Operation**  
Tiago Rosa, Maria E. Baltazar, Jorge Silva (2015). Proceedings of ICEUBI 2015 - International Conference on Engineering, 2-4 December, Covilhã (Portugal), ISBN: 978-989-654-260-3, pp.50-62.
3. **Low-Cost Carriers Impacts on Airport Performance. An MCDA Model**  
Tiago Rosa, Maria E. Baltazar, Jorge Silva (2016). Working paper published in ResearchGate, DOI: 10.13140/RG.2.2.31658.41927/1.
4. **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).
5. **Impact in Tourism Sector of Portuguese Airports Hinterland due to Low-Cost Carriers Operation**  
Tiago Rosa, Maria E. Baltazar, Jorge Silva (2017). Invtur 2017 - International conference - Co-creating the future of tourism, 17-19 May, (Manuscript accepted for presentation).
6. **Impact in Tourism Sector of Portuguese Airports Hinterland due to Low-Cost Carriers Operation**  
Tiago Rosa, Maria E. Baltazar, Jorge Silva (2017). Journal of Tourism and Development - Special issue, (Manuscript accepted for publication).
7. **Low-Cost Carriers Socio-Economic Impact in Tourism Development: The Case of Faro's Airport Hinterland**  
Tiago Rosa, Maria E. Baltazar, Jorge Silva (2017). Tourism Spectrum - Special issue: Low Cost Carriers and Tourism Destinations, March, vol. 3, No. 1, Fifth Issue, pp.29-40.
8. **Performance and Efficiency Support Analysis for Airports and Airlines Benchmarking**  
Maria E. Baltazar, Tiago Rosa, Jorge Silva (2017). Journal of Air Transport Management - Special issue: Multiple Criteria Decision Making in Air Transport Management, (Manuscript submitted for publication).



## Resumo

Na última década, o crescimento das companhias aéreas de baixo custo criou uma nova relação mais complexa entre a companhia aérea, o aeroporto e o passageiro. Os aeroportos dependem da decisão das companhias aéreas de operar nas suas infraestruturas. No entanto, as companhias aéreas de baixo custo têm exigências operacionais diferentes das companhias de aéreas de bandeira/tradicionais. O estudo do crescimento das companhias aéreas de baixo custo permite que aos gestores dos aeroportos identificar os seus impactos positivos e negativos nas áreas e indicadores de desempenho e conseqüentemente os impactos no desempenho e eficiência globais do aeroporto. Com essa informação, os gestores aeroportuários podem estruturar seus planos de ações de curto e longo prazo e iniciativas considerando os impactos da operação de companhias de aéreas de baixo custo.

Esta pesquisa concentra-se na avaliação do desempenho e eficiência do aeroporto devido à operação de companhias aéreas de baixo custo através de um “*benchmarking*”<sup>1</sup> interno. Para isso, a metodologia de análise multicritério de apoio à decisão (MCDA) escolhida foi MACBETH (*Measuring Attractiveness by a Categorized Based Evaluation Technique*) usando o modelo PESA-AGB (*Performance Efficiency Support Analysis - Airport Global Benchmarking*). É ainda, realizada uma análise estatística, utilizando o tráfego das companhias aéreas de baixo-custo e os resultados do modelo PESA-AGB para identificar e quantificar as áreas de desempenho dos aeroportos e as pontuações globais dos aeroportos que têm maior correlação com a evolução da operação das companhias aéreas de baixo custo, por um período de onze anos (2003-2013), usando Microsoft Excel e SPSS (*Statistical Package for the Social Sciences*).

Os resultados obtidos permitem identificar um conjunto de áreas de desempenho que apresentam níveis significativos de correlação com o número de passageiros e movimentos das companhias aéreas de baixo custo. Foram determinados elevados coeficientes de correlação de Pearson quando estudadas as correlações entre a pontuação global de desempenho e eficiência dos aeroportos com o tráfego das companhias aéreas de baixo custo.

## Palavras-chave

Desempenho Aeroportuário; Eficiência Aeroportuária; Companhias de Baixo; MCDA; MACBETH; SPSS

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<sup>1</sup> “*benchmarking*” é um padrão econômico para medir o desempenho do negócio, comparando a produtividade e eficiência, avaliando processos específicos, políticas e estratégias, e para determinar o desempenho geral do negócio.



## Resumo Alargado

### Introdução

Esta secção resume, em língua portuguesa, o trabalho de investigação desta dissertação. Inicialmente é descrito o enquadramento da dissertação, de seguida aborda os seus objetos e os objetivos, terminando com a apresentação das principais conclusões e indicação das perspetivas de investigação futura.

### Enquadramento da Dissertação

Nas últimas décadas, a aviação mostrou um crescimento contínuo não só no número de movimentos de aeronaves, mas mais importante no número de passageiros transportados. Embora tenha havido algumas interrupções temporárias devido a eventos extremos, como terrorismo, crises e guerras, o crescimento global tem sido positivo e exponencial [1].

Uma das principais causas do rápido crescimento do tráfego aéreo foi a desregulamentação do transporte aéreo nos anos setenta, nos Estados Unidos da América. Isso levou à liberação progressiva do mercado aéreo, criando a oportunidade para um novo e revolucionário modelo de negócios aparecer, com o objetivo de minimizar os custos operacionais da companhia aérea. Como consequência do menor custo operacional, as companhias aéreas com este modelo de negócios começaram a diminuir o preço dos seus bilhetes, criando um novo mercado de clientes que anteriormente não podiam pagar os preços elevados dos bilhetes das companhias aéreas tradicionais. Devido a esta característica e a um conjunto de outras características operacionais, estas transportadoras são chamadas de companhias aéreas de baixo custo [2].

Nos anos 90, o processo de liberalização do sector do transporte aéreo na Europa começou por remover a regulamentação sobre tarifas e entrada de rotas, causando a revolução das companhias aéreas de baixo custo na Europa [2], liderada na Irlanda, pela Ryanair e no Reino Unido com a EasyJet.

Para alcançar baixos custos de operação, os aeroportos foram e continuam a ser pressionados a fazer várias mudanças operacionais e de custo para poder acomodar as exigências criadas por parte do modelo de negócios das companhias aéreas de baixo custo [1]. Essas alterações passam, por exemplo, pela aplicação de menores taxas de operação para as companhias aéreas de baixo custo, reduzindo o uso de *jetways* [4], ou por usar terminais de baixo custo. Outra mudança operativa comum nos aeroportos é aumentar a eficiência das operações em placa, permitindo que as companhias aéreas tenham a aeronave o menor tempo possível no chão, reduzindo assim as taxas de ocupação das portas de embarque/"stands" que as companhias

aéreas têm de pagar ao aeroporto [5]. Para enfrentar este problema operacional, os aeroportos necessitam de expandir sua capacidade e de melhorar a eficiência das suas infraestruturas e sistemas. Todos estes fatores criaram a necessidade de os aeroportos efetuarem “*benchmarking*” internos e de se comparar com os outros aeroportos, em “*benchmarkings*” externos [1].

## **Objetos e Objetivos**

Os objetos desta dissertação são o desempenho e eficiência aeroportuária e o tráfego das companhias aéreas de baixo custo.

O primeiro objetivo é compreender as relações aeroportos-companhias aéreas e como estas evoluíram ao longo dos anos. Para isto é também necessário conhecer os diferentes modelos de negócios utilizados pelas companhias aéreas e quais as suas implicações esperadas nesta relação.

O segundo objetivo é compreender a necessidade do “*benchmarking*” aeroportuário e identificar quais as diferentes metodologias de “*benchmarking*” aeroportuário, estudando as suas vantagens e desvantagens. De seguida é necessário caracterizar as infraestruturas aeroportuárias, determinado o melhor método para avaliar o desempenho e eficiência aeroportuária englobando todas as suas áreas. Adicionalmente, é preciso estudar as metodologias utilizadas para determinar correlações entre variáveis.

O próximo objetivo é caracterizar a evolução e identificar as tendências do transporte aéreo, focando a análise nos três principais aeroportos de Portugal continental. Seguidamente, é necessário obter as pontuações de desempenho aeroportuário de modo a poder comparar a sua evolução com a evolução do tráfego das companhias de baixo custo.

Concluída a análise de evolução das pontuações de desempenho e do tráfego, é necessário analisar e verificar a existência de possíveis correlações entre estas variáveis, e se existem quantificá-las.

Por fim, o último objetivo é verificar se as correlações acontecem de igual forma em todos os aeroportos ou se cada aeroporto apresenta diferentes tipos e níveis de correlações com o tráfego de companhias de baixo custo.

## **Principais Conclusões**

A liberalização do transporte aéreo provocou grandes mudanças no sector, fazendo surgir um modelo de negócios mais agressivo e focado em baixos custos e em elevada produtividade. Nas últimas décadas, as companhias de baixo custo mostraram um rápido crescimento a um ritmo constante, excetuando na maioria dos casos o período de 2008-2009. Adicionalmente, as

características operacionais destas companhias aéreas centradas na redução de custos e na elevada produtividade alteraram a relação tradicional entre companhias aéreas e aeroportos, transformando-a numa relação entre as companhias aéreas, aeroportos e passageiros. Nesta nova relação, os aeroportos viram-se obrigado a alterar o seu processo operacional e económico, tendo criado novos focos para a criação de receitas, de modo a combater as reduções nos preços de taxas aeroportuárias. Mais ainda, as novas necessidades operacionais dos aeroportos, bem como o início das suas privatizações, levaram a que estes procurem cada vez mais determinar e avaliar o seu desempenho aeroportuário.

Apesar do conceito de “*benchmarking*” não ser novo, a sua aplicação nos aeroportos ainda é relativamente escassa em termos de variedade de metodologias utilizadas. A maioria dos estudos estão focados a determinação do desempenho e eficiência aeroportuária utilizando apenas certas áreas de desempenho chave. O MCDA permite que esta análise incorpore um número indeterminado de áreas e indicadores de desempenho, criando assim uma avaliação do desempenho global das infraestruturas e sistemas aeroportuários.

O modelo utilizado nesta dissertação não é isento de desvantagens. Apesar do modelo PESA-AGB possuir um grande número de áreas de desempenho, ainda é necessário incorporar algumas áreas na avaliação. Outra desvantagem do modelo está relacionada com a metodologia que este usa, o MACBETH. As bases matemáticas do MACBETH utilizam como um dos “*inputs*” as opiniões de um grupo de especialistas, que estão sujeitas às subjetividades de cada um deles. O questionário efetuado para a recolha destas opiniões foi enviado para 500 especialistas tendo sido recebidas 81 respostas. Contudo, este facto não afeta a qualidade das respostas, porem quanto maior o numero de respostas mais reduzida será a subjetividade do modelo.

Outra dificuldade encontrada nesta investigação foi a recolha de dados para os 42 indicadores de desempenho dos três aeroportos. Os relatórios públicos dos aeroportos apenas disponibilizam parte da informação necessária, tendo sido necessário recorrer, para alguns anos da análise, a aeroportos de semelhante dimensão e tipo de operação.

Em relação à análise do número de passageiros e movimentos das companhias aéreas de baixo custo a informação encontra-se mais acessível, facilitando a rápida caracterização das variáveis. Contudo os relatórios de informação de tráfego para o aeroporto do Porto e Lisboa consideram o número de tráfego das companhias aéreas de baixo custo como irrelevante para o ano 2003 e para os anos anteriores. Ao utilizar zero como representação destas companhias no ano de 2003, pode-se incorrer em erros estatísticos aquando da análise de correlações.

A fraqueza da análise de correlações nos três casos de estudos foi o facto de a amostra ser pequena. Apesar de não existir literatura que defina um número mínimo para efetuar este tipo de análise, uma amostra com o valor 11 pode não ser suficiente para a representação das companhias aéreas de baixo custo no desempenho aeroportuário.

Todavia este estudo permitiu identificar um grupo de áreas chave do desempenho aeroportuários que possuem altos coeficientes de correlação. A tabela abaixo demonstra as correlações obtidas para cada uma das áreas de cada aeroporto.

Tabela 1 - Coeficientes de correlação de Pearson entre o tráfego das companhias de baixo custo e as áreas de desempenho do aeroporto 1, 2 e 3.

	Coeficientes de correlação de Pearson					
	Aeroporto 1		Aeroporto 2		Aeroporto 3	
	Passageiros LCCs	Movimentos LCCs	Passageiros LCCs	Movimentos LCCs	Passageiros LCCs	Movimentos LCCs
Segurança	0,39	0,43	0,37	0,40	0,37	0,41
Core	0,93	0,90	0,97	0,98	0,91	0,86
Produtividade / Eficiência de Custos	0,64	0,71	0,79	0,82	0,65	0,65
Qualidade de Serviço	0,89	0,85	0,67	0,68	0,78	0,74
Financeiro / Comercial	-0,67	-0,64	-0,39	-0,41	0,02	-0,02
Ambiental	0,87	0,82	0,97	0,96	0,78	0,70
Pontuação do Aeroporto	0,934	0,943	0,90	0,92	0,92	0,89

Fonte: baseada no anexo 4.

Os resultados obtidos mostram uma clara correlação entre as companhias de baixo custo e a pontuação de desempenho aeroportuário dos três aeroportos analisados, sendo que a área de “Core” é a que apresenta um resultado mais elevado e consistente em todos os aeroportos.

O modelo PESA-AGB mostrou-se como uma ferramenta bastante útil para a análise de desempenho, com grande versatilidade, capaz de processar grandes quantidades de informação e de se adaptar a qualquer tipo de aeroporto, quer em tamanho quem em tipo de operação.

### Perspetivas de Investigação Futuras

Como consequência do trabalho desenvolvido e do conhecimento adquirido, as perspetivas de investigação futuras são as seguintes:

- I. Versões futuras do modelo PESA-AGB deveriam incluir novas áreas de desempenho aeroportuário, como o caso da área de influência do aeroporto;
- II. O estudo de outras metodologias estatísticas no que diz respeito à determinação de correlações;
- III. Analisar a influência das variações operacionais das companhias áreas de baixo custo no desempenho aeroportuários, mais propriamente no que diz respeito ao fenómeno de responsabilidade associados a estas companhias aéreas;

- IV. Efetuar os casos de estudo analisando não só as áreas chave de desempenho, mas também todos os indicadores de desempenho;
- V. Introduzir ao estudo de correlações variáveis socioeconómicas e de turismo, referentes à área de influência do aeroporto;
- VI. Compreender como identificar e determinar os impactos diretos (positivos e negativos) da operação de companhias aéreas de baixo custo no desempenho aeroportuário;
- VII. Conhecendo os impactos diretos, construir modelos preditivos de modo a poder determine os impactos esperados do aumento ou diminuição da operação de companhias aéreas de baixo custo.

## Referencias

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## Abstract

In the last decade, LCCs (Low-cost Carriers) growth has created a more complex airline-airport-passenger relationship. Airports depend on airlines decision to operate in their infrastructures. However, LCCs have different service demands than legacy carriers. The study of LCCs' growth enables airport's decision makers to identify their positive and negative impacts on KPAs and on KPIs and therefore the impacts on airport's global performance and efficiency. With this information, airports' decision makers can structure their short and long-term actions plans and initiatives considering LCCs' operation impacts.

This research focuses on assessing airport's performance and efficiency due to LCCs' operations through an internal benchmarking. For this purpose, MACBETH (Measuring Attractiveness by a Categorical Based Evaluation Technique) was the Multi-Criteria Decision Analyses (MCDA) methodology chosen using the PESA-AGB (Performance Efficiency Support Analysis - Airport Global Benchmarking) model. Moreover, a statistical analysis is carried out, using LCCs' traffic and PESA-AGB model outputs, to identify and quantify the airports' KPAs (key performance areas) and airports' overall scores that have a greater correlation with LCCs' operations evolution, during an eleven years' period (2003-2013), using Microsoft Excel and SPSS (Statistical Package for the Social Sciences).

The final results depict a set of KPAs with a high level of correlation with the number of LCCs' passengers and movements. Moreover, high Pearson correlation coefficients were determined when the correlation between the three airports' overall performance and efficiency scores and LCCs' traffic was studied.

## Keywords

Airport Performance; Airport Efficiency; Low-Cost Carriers; MCDA; MACBETH; SPSS



# Table of Contents

Dedicatory.....	v
Acknowledgements.....	vii
List of Publications.....	ix
Resumo.....	xi
Resumo Alargado.....	xiii
Abstract.....	xix
Table of Contents.....	xxi
List of Figures.....	xxv
List of Tables.....	xxix
List of Acronyms.....	xxxii
Chapter 1.....	1
Introduction.....	1
1.1 Theme Description.....	3
1.2 Objects and Objectives.....	4
1.3 Dissertation Structure.....	6
Chapter 2.....	7
Air Transport Sector.....	7
2.1 Introduction.....	9
2.2 Air Transport Structure.....	9
2.2.1 Airline Industry liberalisation.....	12
2.3 Low-Cost Carriers Growth.....	15
2.4 Low-Cost Carriers Business Model.....	16
2.5 Conclusion.....	19
Chapter 3.....	21
Benchmarking and Airports Performance Analysis.....	21
3.1 Introduction.....	24
3.2 Airport Infrastructure.....	24
3.3 Airport Benchmarking.....	25
3.4 Airport Performance Analysis.....	26
3.4.1 Methodologies for Airport Benchmarking.....	27
3.4.2 Decision-Making in Airport Infrastructures.....	30
3.5 Conclusion.....	32
Chapter 4.....	33
Airports Multi-Criteria Decision Analysis.....	33
4.1 Introduction.....	35
4.2 MCDA Methodologies.....	35

4.2.1	Measuring Attractiveness by a Categorical Based Evaluation Technique (MACBETH) .....	36
4.3	Performance and Efficiency Support Analysis for Airport Global Benchmarking (PESA - AGB).....	45
4.3.1	Structuring .....	45
4.3.2	Survey and Meetings .....	49
4.3.3	Evaluation .....	52
4.3.4	Classification and Outputs .....	53
4.4	Linear Regression and Correlation Coefficient.....	55
4.5	Conclusion.....	56
Chapter 5	.....	57
Case Studies	.....	57
5.1	Introduction .....	59
5.2	Airport 1 (Case 1) .....	60
5.2.1	LCCs' Traffic Evolution .....	61
5.2.2	PESA-AGB Model Outputs.....	62
5.2.3	Airport's 1 Performance Correlation with LCCs' Traffic .....	63
5.3	Airport 2 (Case 2) .....	71
5.3.1	LCCs' Traffic Evolution .....	72
5.3.2	PESA-AGB Model Outputs.....	73
5.3.3	Airport's 2 Performance Correlation with LCCs' Traffic .....	75
5.4	Airport 3 (Case 3) .....	82
5.4.1	LCCs' Traffic Evolution .....	83
5.4.2	PESA-AGB Model Outputs.....	84
5.4.3	Airport's 3 Performance Correlation with LCCs' Traffic .....	86
5.5	Analysis of Airport 1, 2 and 3 Case Studies .....	93
5.6	Conclusion.....	99
Chapter 6	.....	101
Conclusions	.....	101
6.2	Dissertation Summary.....	103
6.3	Concluding Remarks.....	104
6.4	Prospects for Future Work .....	106
References	.....	107
Annexe 1	.....	115
PESA-AGB Model Flowchart.....		115
Annexe 2	.....	117
PESA-AGB: Scores Outputs.....		117
Annexe 3	.....	135
PESA-AGB: Step by step example on how to obtain airport final score .....		135
Annexe 4	.....	143

SPSS Analysis .....	143
Annexe 5 .....	165
Publication Abstracts .....	165



## List of Figures

Figure 1.1 - IFR movements evolution from 2001 to 2013 and 2014 to 2021 forecast growth...	3
Figure 2.1 - Traditional airline-airport relationship. ....	11
Figure 2.2 - New commercial model of airline-airport-passenger relationship. ....	12
Figure 2.3 - European liberalisation process.....	14
Figure 2.4 - Worldwide low-cost carrier capacity share of total seats: 2006-2016. ....	15
Figure 3.1 - Generic framework for operational performance analysis.....	27
Figure 3.2 - Quantitative methodologies to assess productivity and efficiency. ....	28
Figure 3.3 - Collaborative Decision Making Process. ....	31
Figure 4.1 - Matrix of value judgments for local evaluation of actions.....	40
Figure 4.2 - PESA-AGB Model building tasks. ....	45
Figure 4.3 - Structuring step of PESA-AGB model. ....	45
Figure 4.4 - Survey and meeting steps from PESA-AGB model. ....	50
Figure 4.5 - Example of criteria judgement matrix. ....	51
Figure 4.6 - Building process of a decision conference. ....	52
Figure 4.7 - Evaluation step from PESA-AGB model. ....	52
Figure 4.8 - Example of a criteria value function from PESA-AGB model. ....	53
Figure 4.9 - Example of a judgement matrix and respective weight ponderation. ....	53
Figure 4.10 - Classification step from PESA-AGB model. ....	54
Figure 5.1 - Case studies process.....	59
Figure 5.2 - Bottom-up process used to conduct steps (iii) and (iv) analysis. ....	60
Figure 5.3 - Airport 1 passengers and movements evolution distributed by type of airline. ...	61
Figure 5.4 - Airport 1 KPAs scores and overall ranking by year. ....	62
Figure 5.5 - Airport 1 overall scores evolution. ....	63
Figure 5.6 - Airport's 1 safety and security KPA scores vs number of LCCs' passengers. ....	64
Figure 5.7 - Airport's 1 safety and security KPA scores vs number of LCCs' movements. ....	64
Figure 5.8 - Airport's 1 core KPA scores vs number of LCCs' passengers.....	65
Figure 5.9 - Airport's 1 core KPA scores vs number of LCCs' movements. ....	65
Figure 5.10 - Airport's 1 productivity/cost effectiveness KPA scores vs number of LCCs' passengers.....	66
Figure 5.11 - Airport's 1 productivity/cost effectiveness KPA scores vs number of LCCs' movements. ....	66
Figure 5.12 - Airport's 1 service quality KPA scores vs number of LCCs' passengers. ....	67
Figure 5.13 - Airport's 1 service quality KPA scores vs number of LCCs' movements. ....	67
Figure 5.14 - Airport's 1 financial/commercial KPA scores vs number of LCCs' passengers. ...	68
Figure 5.15 - Airport's 1 financial/commercial KPA scores vs number of LCCs' movements. ..	68
Figure 5.16 - Airport's 1 environmental KPA scores vs number of LCCs' passengers. ....	69

Figure 5.17 - Airport's 1 environmental KPA scores vs number of LCCs' movements. ....	69
Figure 5.18 - Airport's 1 overall scores vs number of LCCs' passengers.....	70
Figure 5.19 - Airport's 1 overall scores vs number of LCCs' movements. ....	70
Figure 5.20 - Airport 2 passengers and movements evolution distributed by type of airline. ..	73
Figure 5.21 - Airport 2 KPAs scores and overall ranking by year. ....	74
Figure 5.22 - Airport 2 overall scores evolution. ....	74
Figure 5.23 - Airport's 2 safety and security KPA scores vs number of LCCs' passengers. ....	75
Figure 5.24 - Airport's 2 safety and security KPA scores vs number of LCCs' movements.....	75
Figure 5.25 - Airport's 2 core KPA scores vs number of LCCs' passengers. ....	76
Figure 5.26 - Airport's 2 core KPA scores vs number of LCCs' movements. ....	76
Figure 5.27 - Airport's 2 productivity/cost effectiveness KPA scores vs number of LCCs' passengers. ....	77
Figure 5.28 - Airport's 2 productivity/cost effectiveness KPA scores vs number of LCCs' movements.....	77
Figure 5.29 - Airport's 2 service quality KPA scores vs number of LCCs' passengers.....	78
Figure 5.30 - Airport's 2 service quality KPA scores vs number of LCCs' movements. ....	78
Figure 5.31 - Airport's 2 financial/commercial KPA scores vs number of LCCs' passengers. ..	79
Figure 5.32 - Airport's 2 financial/commercial KPA scores vs number of LCCs' movements...	79
Figure 5.33 - Airport's 2 environmental KPA scores vs number of LCCs' passengers. ....	80
Figure 5.34 - Airport's 2 environmental KPA scores vs number of LCCs' movements. ....	80
Figure 5.35 - Airport's 2 overall scores vs number of LCCs' passengers.....	81
Figure 5.36 - Airport's 2 overall scores vs number of LCCs' Movements. ....	81
Figure 5.37 - Airport's 3 passengers and movements evolution distributed by type of airline.	84
Figure 5.38 - Airport 3 KPAs scores and overall ranking by year. ....	85
Figure 5.39 - Airport 3 overall scores evolution. ....	85
Figure 5.40 - Airport's 3 safety and security KPA scores vs number of LCCs' passengers. ....	86
Figure 5.41 - Airport's 3 safety and security KPA scores vs number of LCCs' movements.....	86
Figure 5.42 - Airport's 3 core KPA scores vs number of LCCs' passengers. ....	87
Figure 5.43 - Airport's 3 core KPA scores vs number of LCCs' movements. ....	87
Figure 5.44 - Airport's 3 productivity/cost effectiveness KPA scores vs number of LCCs' passengers. ....	88
Figure 5.45 - Airport's 3 productivity/cost effectiveness KPA scores vs number of LCCs' movements.....	88
Figure 5.46 - Airport's 3 service quality KPA scores vs number of LCCs' passengers.....	89
Figure 5.47 - Airport's 3 service quality KPA scores vs number of LCCs' movements. ....	89
Figure 5.48 - Airport's 3 financial/commercial KPA scores vs number of LCCs' passengers. ..	90
Figure 5.49 - Airport's 3 financial/commercial KPA scores vs number of LCCs' movements...	90
Figure 5.50 - Airport's 3 environmental KPA scores vs number of LCCs' passengers. ....	91
Figure 5.51 - Airport's 3 environmental KPA scores vs number of LCCs' movements. ....	91
Figure 5.52 - Airport's 3 overall scores vs number of LCCs' passengers.....	92

Figure 5.53 - Airport's 3 overall scores vs number of LCCs' movements. ....	92
Figure 5.54 - Airport 1, 2 and 3 LCCs' traffic evolution.....	93
Figure 5.55 - Airport 1, 2 and 3 overall scores. ....	94



## List of Tables

Table 2.1 - Control and cooperation between subsectors in the air transport Industry.....	9
Table 2.2 - Air transportation trends. ....	13
Table 2.3 - Summary of LCCs and legacy carriers common characteristics. ....	19
Table 3.1 - Classification of airport activities.....	25
Table 3.2 - Main methodologies used in airport performance assessment. ....	28
Table 4.1 - Scope of each key performance area (KPA) and key performance indicator (KPI) of PESA-AGB. ....	47
Table 4.2 - KPIs' performance descriptor structure. ....	49
Table 4.3 - Example of KPA scores table. ....	54
Table 5.1 -Airport 1 number of passengers and movements from 2003 to 2013.....	61
Table 5.2 - Airport 1 scores table. ....	62
Table 5.3 - Linear correlation between LCCs' traffic and airport's 1 KPAs and overall scores.	71
Table 5.4 - Airport 2 number of passengers and movements from 2003 to 2013. ....	72
Table 5.5 - Airport 2 scores table. ....	73
Table 5.6 -Linear correlation between LCCs' traffic and airport's 2 KPAs and overall scores.	82
Table 5.7 -Airport 3 number of passengers and movements from 2003 to 2013.....	83
Table 5.8 - Airport 3 scores table. ....	84
Table 5.9 -Linear correlation between LCCs' traffic and airport's 3 KPAs and overall scores.	93
Table 5.10 - Coefficient of determination for linear regressions between LCCs' traffic and airport 1, 2 and 3 KPAs and overall scores. ....	95
Table 5.11 - Adjusted coefficient of determination for linear regressions between LCCs' traffic and airport 1, 2 and 3 KPAs and overall scores. ....	96
Table 5.12 - Standard error of the estimate for the linear regressions between LCCs' traffic and airport 1, 2 and 3 KPAs and overall scores. ....	97
Table 5.13 - Pearson correlation coefficient for linear regressions between LCCs' traffic and airport 1, 2 and 3 KPAs and overall scores. ....	98



## List of Acronyms

- A-CDM: Airport Collaborative Decision Making  
ACI: Airports Council International  
AHP: Analytic Hierarchy Process  
ATC: Air Traffic Control  
CDM: Collaborative Decision Making  
DEA: Data Envelopment Analysis  
EU: European Union  
FAA: Federal Aviation Administration  
GDS: Global Distribution Systems  
ICAO: International Civil Aviation Organization  
IFR: Instrument Flight Rules  
KPIs: Key Performance Indicators  
LCCs: Low-Cost Carriers  
LPPs: Linear Programming Problems  
MACBETH: Measuring Attractiveness by a Categorical Based Evaluation Technique, Measuring Attractiveness by a Categorical Based Evaluation Technique  
MCDA: Multi-Criteria Decision Analysis, Multi-Criteria Decision Analysis  
PESA - AGB: Performance and Efficiency Support Analysis for Airport Global Benchmarking, Performance and Efficiency Support Analysis for Airport Global Benchmarking  
PESA-GB: Performance and Efficiency Support Analysis for Global Benchmarking  
 $R_a^2$ : Adjusted Coefficient of Determination  
 $R^2$ : Coefficient of Determination  
SFA: Stochastic Frontier Analysis  
SPSS: Statistical Package for the Social Sciences, Statistical Package for the Social Sciences  
TFP: Total Factor Productivity  
USA: United States of America  
WLU: Work Load Unit  
WSM: Weighted Sum Methods



# **Chapter 1**

## **Introduction**

### **1.1 Theme Description**

### **1.2 Object and Objectives**

### **1.3 Dissertation Structure**



## 1.1 Theme Description

In the last decades, the aviation has shown and continuous growth in the number of aircraft movements, but more important in the number of passengers transported. Although there have been some temporary interruptions due to extreme events, like terrorism, crisis and war, the overall growth has been positive and exponential [1]. Figure 1.1 shows the Instrument Flight Rules (IFR) movements evolution from 2001 to 2013 and the forecast growth from 2014 to 2021 [2].

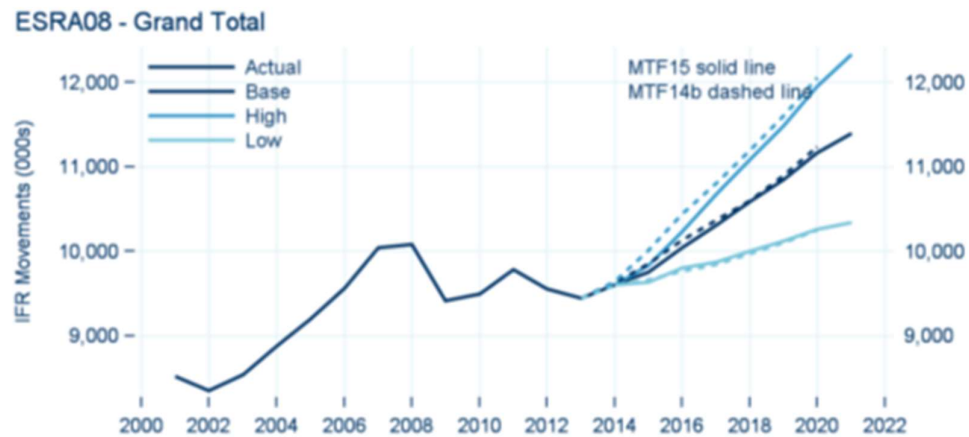


Figure 1.1 - IFR movements evolution from 2001 to 2013 and 2014 to 2021 forecast growth.

Source: [2].

One of the major causes of the rapid growth in air traffic was the air transport deregulation in the seventies. This led to the progressive liberation of the market, which opened the door to new revolutionary business models aiming to minimise the airline operational costs. As a consequence of the lower operational cost, airlines adopting this type of business models began decreasing their ticket prices, creating a new market of customers who previously could not afford the high rates of legacy carriers. Due to the characteristics of such operation, these carriers are called Low-Cost Carriers (LCCs) [3].

The European Union liberalisation package began removing regulation over fares and route entry in the nineties, causing the revolution of LCCs in Europe [4], which was led by Ireland, with Ryanair, and by the United Kingdom, with EasyJet.

To achieve low operation costs, airports started and still continue to be pressured to make several costs and operational changes to meet the objectives of LCCs' business model [1]. These changes can be, for example, lower operating taxes for airlines by reducing the use of jetways [5], or by using low-cost terminals. Another common operational change in the airport is to

increase the turnaround efficiency allowing the airlines to have the aircraft less time on the ground, and therefore having lower stand/gate occupation taxes [6].

Consequently, all of this changes in the airport financial and operational activities created the need to assess airports efficiency and performance, and to compare it with other airports. Moreover, is necessary to identify these airport's changes impacts due to the operation of different airline business models types.

## 1.2 Objects and Objectives

The objects of this work are airport's performance and efficiency and LCCs' traffic with the main objective of determining correlations between LCCs' operation and airport's efficiency.

Therefore, specific objectives were defined based on seven scientific questions:

### Question 1

***What is an airport-airline relationship? How did it evolve throughout the years?  
And why?***

The objective is foremost to comprehend airports-airlines relationship and how it evolved through the years. Due to the existence of airlines with different business models, it's also necessary to assess how each business model approach this relation and its expected implications.

### Question 2

***Why it's necessary to benchmark airports? Which methodologies are currently used and  
what's their contribution?***

The objective is to understand the need for airport benchmark and to identify the different benchmark techniques. This question also has the objective of characterising the methodologies currently used for airport benchmark, identifying their advantages and disadvantages and understanding how they can help a decision-making process.

### Question 3

***How to assess airports' overall performance and efficiency using MCDA? What statistical  
analysis is used to determine correlations between variables?***

The objective is to understand how to characterise an airport infrastructure and to determine the best way to obtain the airports' overall performance and efficiency using MCDA. Thus, this questions goal is choosing the case studies methodologies. Firstly, is necessary to define a

model structure to assess airports' performance and efficiency. Moreover, finding the methodology commonly used to check the existence of correlations needs to be addressed.

#### Question 4

***How airlines traffic evolved? In what way the LCCs' market share changed?***

The objective is to identify the evolution and trends of air transport market in the world, focusing on the European aviation, more precisely in Portugal continental airports. Understanding and studying air transport evolution in these three airports can help understand how the number of movements and passengers changes airports' performance and efficiency.

#### Question 5

***How airports' performance and efficiency progressed over the years? Does it follow the same trend of LCCs' traffic evolution?***

After analysing the air transport evolution, the objective of this question is to obtain the airports' performance and efficiency scores in order to compare them with LCCs' traffic. There is a need to check for possible similar trends to support a more extensive analysis, using another tool to complement this study.

#### Question 6

***Is LCCs' traffic evolution correlated with each airport performance and efficiency scores? In what degree?***

The objective is to analyse the correlation between LCCs' operation and airports' overall performance and efficiency scores and to identify in which Key Performance Areas (KPA) these possible correlations are valid. If valid, determine the degree of the variables correlation.

#### Question 7

***Do the three case studies produced the same correlation results among the airports?***

Finally, the last objective is to determine if the existing correlations between LCCs' operation and airports' KPAs and overall performance and efficiency scores are replicated in other airports and if the results vary and how. The goal of this question is to comprehend if every airport experiences the same type of correlation with LCCs' traffic or if each case is different.

### 1.3 Dissertation Structure

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

Chapter 1 consists of an introduction to the work through a theme description and presentation of the dissertation objects and objectives. This chapter also describes the dissertation structure.

Chapter 2 presents a state of the art review in air transportation relationships, describing the most common airline business model from LCCs and legacy carriers. A comparison showing the biggest differences between LCCs' and legacy carriers' business models is also provided in this chapter to help understand their influence in airport benchmarking.

Chapter 3 depicts a literature review on airport benchmarking and the most common tools to analyse airports performance and efficiency. This chapter also describes the usual decision-making processes in complex infrastructures like airports.

Chapter 4 introduces a brief description of MCDA to the methodology used in the study, Measuring Attractiveness by a Categorical Based Evaluation Technique (MACBETH). This chapter continues by explains the tool used to analyse the case studies, which is called Performance and Efficiency Support Analysis for Airport Global Benchmarking (PESA - AGB). To describe the tool, all the steps to conclude the evaluation process are presented. A brief review of linear regression and correlation coefficients is done to allow the identification of the correlations between airports' performance and efficiency scores and LCCs' traffic evolution.

Chapter 5 contains the case studies. This chapter comprises three case studies, each one analysing different airports. In each case study is done an airport traffic analysis, differentiating the airline type, and assessing the airport performance and efficiency scores using PESA-AGB model presented in chapter 4. Moreover, a correlation analysis of these two parameters is performed to identify possible correlations.

Chapter 6 presents the work conclusions, with a brief dissertation summary and concluding remarks. Some areas of future research work are also presented at the end of this chapter.

# **Chapter 2**

## **Air Transport Sector**

### **2.1 Introduction**

### **2.2 Air Transport Structure**

#### **2.2.1 Airline Industry liberalisation**

### **2.3 Low-Cost Carriers Growth**

### **2.4 Low-Cost Carriers Business Models**

### **2.5 Conclusion**



## 2.1 Introduction

Contrary to commonly considered, the air transport business is a highly heterogeneous sector with a considerable group of actors. What makes this a heterogeneous group of actors is the fact that while some remain subject to state control, other are fully privatised or even under a mixed regime. The privatised actors focus their business in profit maximisation, while the state-controlled ones have the objectives such as maximisation of employment and/or value added, in general, the maximisation of socioeconomic surplus [7].

Economic prosperity can increase the demand for mobility and sequentially increase the use of air transport. Many studies conclude that wealthier person tends to travel further and more often, paying for more goods and services from third parties. This tendency is amplified in air transport, due to technological advances, low energy costs, improved operational cost efficiencies and strengthened competition within the industry [8].

## 2.2 Air Transport Structure

Nowadays, air transport has an increasing impact in world's economy. The growth of air travelling, whether for tourism or business purposes, caused a development in airport capacities, supporting millions of jobs. The increasing affordability of air travelling created a new destination and market opportunities. LCCs are a good example of the mass customization of the air travel services, opening air transportation to customer segments that couldn't fly regularly before [8].

In order to understand the evolution of the air transport sector, it is necessary to understand the relationships between all actors. Table 2.1 identifies the common cooperation between the different actors in the air transport industry.

Table 2.1 - Control and cooperation between subsectors in the air transport Industry.

Market Actors	Airlines	Handling Companies	Airport Operators	Authorities
Airlines	<ul style="list-style-type: none"> <li>- Mergers and acquisitions (e.g. Air France and KLM; Air Berlin and Condor);</li> <li>- Alliances (e.g. STAR);</li> <li>- Code-share agreements;</li> <li>- Joint ventures (e.g. Lufthansa Cargo and DHL Express);</li> </ul>	-	-	-

Market Actors	Airlines	Handling Companies	Airport Operators	Authorities
	- Participations (e.g. Thomas Cook in Air Berlin).			
<b>Handling Companies</b>	- Previously sometimes integrated into airline (cfr. monopoly risk by dominant national carrier), nowadays often outsourced. - Specific contracts (e.g. in 2007 Martinair with Aviapartner, for 9 German airports, for 3 years).	- Concentration by take-overs (e.g. Aviapartner, Menzies,...).	-	-
<b>Airport Operators</b>	- Participations (e.g. Lufthansa in Munich); - Co-operation between airports and airlines (e.g. Charleroi and Ryanair).	- Assignment, concessions; - Integration (e.g. Aeropuertos Argentina 2000).	- Mergers / acquisitions (e.g. Brussels Airport by Macquarie).	-
<b>Authorities</b>	- Participation government in Flag Carriers (e.g. Olympic, TAP,...).	- Monopoly by airport authority or its sole concessionaire; - Concession assignment control.	- Participation government in airports, including (partial) privatisation.	- Participation governments in airlines (e.g. French and Italian State in Alitalia).

Source: Adapted from [7].

There are various links between the different air transport actors, both within a particular subsector, like the airline industry, and beyond, between airlines and ground-handling companies. Different types of agreements are made between each company operating in the air transport business with different actors [7].

Each merger or acquisition can have an impact on the relations with other actors. After a thorough analysis of the strategic behaviour of several carriers, Voorde and Macário [8] (pp.11) concluded that although “(...) *each airline tends to position its own product in a specific way,*

*the available tools are invariably the same*". Therefore, the approach used by the airlines mostly combines control over the unit cost and optimisation of the seat occupancy or loading factor with the attempt to maximise the yield (passengers and freight) [8].

For the goal of this thesis, the focused key link between actors is the airline-airport relationship, in order to understand how this relationship started and how it has evolved.

Airports depend on the decision of airlines wanting to operate in their infrastructures, and so without airlines, airports have no market. For this reason, airports normally viewed airlines as their primary customers [9]. Figure 2.1 represent how airline-airport relationship was traditionally viewed.

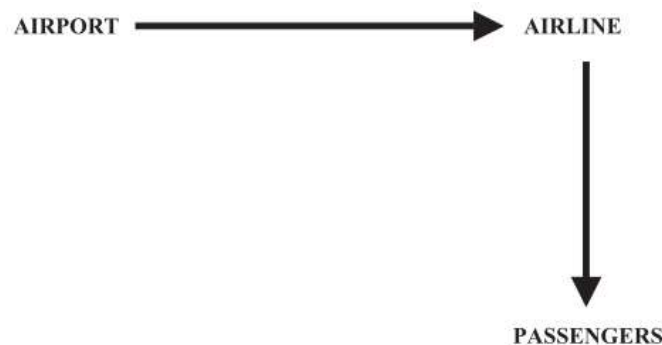


Figure 2.1 - Traditional airline-airport relationship.

Source: [9].

When operating in an airport, airlines pay several fees, such as landing fees, passenger or tonne of freight handled fees, aircraft parking fees and other aeronautical charges like air traffic control and air-bridges. These fees represent what is normally designated as airport aeronautical revenues. Aeronautical revenues used to be the biggest source of income for European airports. However, the perception of passengers as airlines business change since the 90's, when the traditional public utility model of airport management change to a more commercial business model. With this new business model, airports around the world started viewing passengers as important customers for airports, shifting their focus from the aeronautical revenues to the non-aeronautical revenues [9]. To raise the non-aeronautical revenues, the airports started developing new business areas, such as rents, concessions, car parking, consultancy and property development. The increased focus of airports management on passenger spending in the terminals and car parks has led to the creation of a more complex airline-airport-passenger relationship as represented in Figure 2.2.

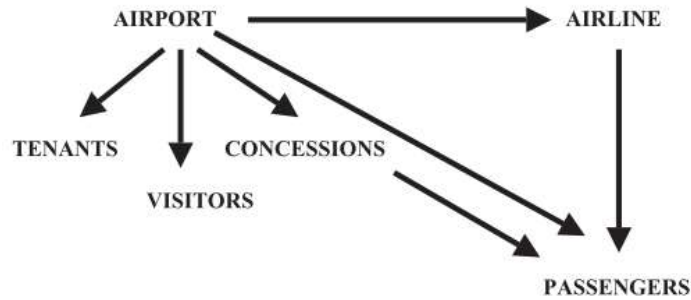


Figure 2.2 - New commercial model of airline-airport-passenger relationship.

Source: [9].

In the last decades, airlines promote a rigid cost control due to their competitive and deregulated market. The increase of oil prices and limited capacity for an increasing demand require airlines to seek cost reductions at their primary supplier. This forced airport to increase their efficiency [10].

Airlines have a strong influence in airport managers' decisions because they can choose to move their operations to other airports unless the airport offers a reduction of fees or commercial incentives [9]. This adds to pressure on airport management to sell off marginal capacity cheaply forcing airports to reconsider their strategy with respect to their relationship with airlines [11].

Airport managers, attempting to improve their financial performance, have seen LCCs as a way to increase passenger numbers. However, LCCs have different service demands as legacy carriers. For example, they don't require business lounges, high-level check-in services, or the use of air-bridges, and baggage transfer services. All of these are space consuming facilities. LCCs objective is to be an efficient user of the airport's facilities, with rapid turnaround times and not demanding high levels of service within the terminal [9]. Nonetheless, LCCs also look for the reduction in airport charges because, although airport costs represent on average 4% of legacy carriers' operating costs, it goes up to 17% of LCCs' operating costs, representing the third most important cost for LCCs after fuel and aircraft leasing costs [11].

Therefore, LCCs have to change the airline-airport relationship. Airports have positively responded to LCCs' growth and its opportunities. This new airline-airport-passenger relationship has led airports to significantly reduce their aeronautical revenues while seeking to increase their non-aeronautical revenues through increased passenger numbers [10].

### 2.2.1 Airline Industry liberalisation

The evolution of air transportation has shown several trends, identified in Table 2.2, mainly caused by social, technological, economic and political drivers [8].

Table 2.2 - Air transportation trends.

Contextual Drivers	Internal	
	Trends and Drivers	Trends
<b>Social</b>	- Networks and growing impacts of networking.	<ul style="list-style-type: none"> <li>- Changes in air transportation market structure;</li> <li>- Changes in airlines, airline- airport and airports relationships;</li> <li>- Declining Yields.</li> </ul>
<b>Technological</b>	- Technological evolution.	
<b>Economic</b>	<ul style="list-style-type: none"> <li>- Evolution towards a mass-market sector;</li> <li>- Increasing safety concerns;</li> <li>- Emerging new forms of modal competition;</li> <li>- Irregular space and time distribution of the sector.</li> </ul>	
<b>Political</b>	- Liberalisation and deregulation of the market.	

Source: adapted from [8].

The political driver has been the most significant driver marking the pace of the competitive market waving in the air transport sector [8].

Due to the increasing number of flight between different countries, in 1994 was sign the Convention on International Civil Aviation, also known as Chicago Convention. This convention set a number of measures regulation aviation, allowing the development and evolution of air transport “*in a safe and orderly manner and that international air transport services may be established on the basis of equality of opportunity and operated soundly and economically*” [12] (pp.1). However, the United States of America (USA) were in favour of an “open sky” regulation, so in the late seventies, they started the deregulation of their air transport sector. The “open sky” politic, allowed the introduction of new concepts like code-sharing, free fares and a greater freedom in establishing routes and frequencies [13].

Liberalisation of the air transport market in Europe started only in 1987, and would only be complete in 1997, almost two decades after USA deregulation process. One of the reasons for this prolonged process, was the fact of Europe being a group of different countries each one with its own legacy carrier supported by the state. Before the liberalisation, Europe air transport market was heavily regulated, with low completion between legacy carriers since the states had bilateral agreements imposing fares, frequencies of flight and operations in certain routes and airports. This meant that market entry for different carriers was practically impossible [13].

The liberalisation process was divided into three measure packages, approved in three different dates. Figure 2.3 outlines the European air transport liberalisation process, referring the main measures adopted in each package.

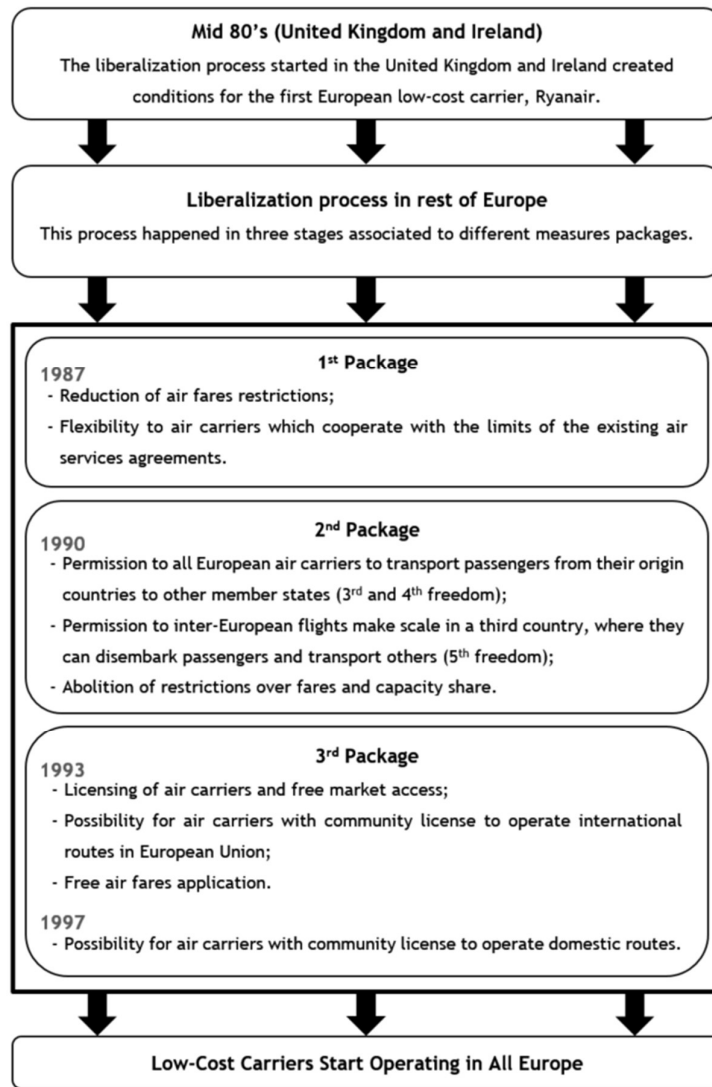


Figure 2.3 - European liberalisation process.

Source: Adapted from [13].

The three liberalisation packages main regulation outcomes can be summarised as [14]:

- **Licensing of air carriers:** This states that members shall permit any European Union (EU) carrier holding an operating license granted pursuant to the regulation to exercise traffic rights within the EU;
- **Market access:** This states that there aren't access restrictions to routes between member states. In other words, any carrier holding a valid air operators' certificate in the EU cannot be stopped from operating any other route within the EU, including unrestricted access to cabotage<sup>2</sup> routes;

<sup>2</sup> Cabotage is the transport of goods or passengers between two places in the same country by a transport operator from another country.

- **Fares and rates for all air services:** The basic effect of this regulation is freedom for EU carriers to set fares for scheduled, chartered and cargo services.

The approval of the third and last liberalisation package led to the end of bilateral agreements between states and created a free European air transport market. Since 1997, air carriers have a greater freedom to establish their fares, capacity and to operate in new routes, which allowed bigger market competition and diversity of fares, resulting in the arising of new air carriers, including the low-cost carriers [13].

## 2.3 Low-Cost Carriers Growth

North America experienced a first wave of LCCs start-ups following US airline deregulation. Following European air transport liberalisation, Europe experienced a “second-wave” of LCCs resulting in a key growth area for air traffic [15].

LCCs have created a new competitive environment within liberalised markets and have been experiencing substantial growth. Currently, LCCs can be found in almost every market in the world and it is expected that they continue to increase their market share especially in the Asia-Pacific region with as much as a 60 percent market share expected by 2030. As shown in Figure 2.4 these carriers have been successful at acquiring market share and it is expected that LCCs will increase their global market from 25.5 percent to 34 percent by 2030 [15], [16].

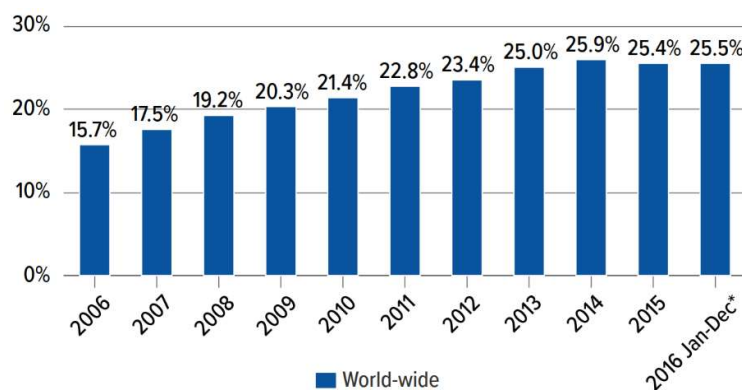


Figure 2.4 - Worldwide low-cost carrier capacity share of total seats: 2006-2016.

Source: CAPA - Centre For Aviation With Data Provided by OAG [16].

Numerous authors have concluded that deregulation has been the underlying reason for Europe’s LCCs growth and expansion [17]-[22].

By 2000, LCCs had still a low market share in Europe, where the top six out of fourteen legacy carriers represented 64% of air traffic [23]. Nevertheless, LCCs in Europe were gathering strength and beginning to expand rapidly. A study conducted by the UK Civil Aviation Authority emphasised that this led to a major shift in the industry, creating not only travel opportunities to new types of customers, but also threatening the high cost operating structures of legacy

carriers. The European market produced a greater opportunity for LCCs than that in North America [14]:

- Larger number of short/medium routes in Europe;
- Very expensive flight and train fares within Europe;
- Closer High-density cities in Europe than they are in North America;
- Successful replicability of Southwest model in Europe.

United Kingdom, Spain, Germany and Italy represent the biggest LCC market in Europe representing more than two-thirds of the total number of transport passengers and exceeding half of the destinations offered by LCCs in Europe [24].

However, while there are many successful cases of LCCs, the list of failed ones is long calling into question why this business model didn't work for so many carriers. O'Connell (2007) explain this problem as many major carriers attempted to reproduce LCCs' business model but never absolutely adopting it. In other words, some carriers try to adopt an LCCs' commercial image without changing their cost structure, which ultimately led to their failure [14].

O'Connell [14] (pp.77) adds that *"There has been a paradigm shift in the airline business since the start of the new millennium, as low cost carriers have won the favour of investors and have altered the strategic thinking of airline directors worldwide"* .

Although every carrier is unique, there are common characteristics in all LCCs' business models enabling them to succeed where others have failed. Next section 2.4, depicts the general characteristics that allowed the successful of LCC's model structure.

## **2.4 Low-Cost Carriers Business Model**

LCCs' business model is not a new one. In 1971, a new American airline, Southwest, was founded with a revolutionary business model in the sector, which combined high productivity with low cost. In Europe, Ryanair was founded in 1985 with the goal of offering low-cost flights between Ireland and the United Kingdom. Despite Ryanair initial growth, as many new LCCs, it faced big financial losses. However, in 1995, Ryanair adopts a new business model similar to Southwest Airlines, become one of the oldest and most successful LCC [15].

Although all LCCs operate in different environments, they present similar basic characteristics which differentiate them from legacy carriers. These characteristics include a simple fare structure, one aircraft type, direct ticket sales, flying to cheaper and less congested airports, no frequent flier programs, no free food and beverages, and fast aircraft turnaround times [15].

**(i) Lower labour costs and higher labour productivity**

One of the airline's biggest costs is labour costs, so LCCs' business model tries to increase productivity while keeping the cost under control. This can be done by paying lower wages than the industry average, like many LCCs do, or by maintaining competitive wages, but having a higher employee productivity resulting in low labour costs per hour of productivity [15].

**(ii) Lower ticket distribution costs**

Another airline industry cost comes from ticket distribution. The first step LCCs' business model took to reduce these costs was to remove travel agent commissions. Later, with the internet growth, started selling electronic tickets through their online websites [15]. The majority of legacy airlines rely on Global Distribution Systems (GDS) to distribute their tickets worldwide, such as Amadeus, Galileo, Sabre, Apollo and Worldspan. Using a GDS imply an average 13 dollars booking fee as opposed to a minor few dollars through internet electronic ticketing [25].

One successful approach used by LCCs is to initially use multiple GDS and, as their brand becomes stronger, slowly end their GDS agreements which enable a wide distribution network initially, and then lower its costs by pushing ticket sales toward the carrier website [15].

**(iii) No-frills service**

No-frills service is one of the most pinpointed characteristics by the consumers to differentiate LCCs and legacy airline. In legacy carriers, passengers received a complimentary hot meal with an extensive beverage service whereas in Europe LCCs everything is on a buy-on-board basis, including beverages. No-frills service is not only related to in-flight services. Many LCCs, in another attempt to reduce costs, don't offer the amenities of frequent flier programs or expensive business lounges. Normally, LCCs have luggage allowances restriction, particularly in Europe, where there are strict rules concerning luggage allowance weights per passenger. This generates extra marginal revenue by conserving fuel [15].

As Vasigh et al. [15] (pp.380) said *"The underlying premise behind the LCCs' no-frills service strategy is ultimately a "pay as you go" approach, where the ticket price entitles you to just a seat on the aircraft"*.

**(iv) Common fleet type**

It is usual for successful LCCs to use a common fleet type. This offers several benefits for the carrier like spare parts inventories reductions, lower flight crew training expenses, and improved operational flexibility. Economies of scale is the most important element in this cost reduction strategy. By bulk purchasing, LCCs can benefit with discounts from suppliers. For

example, all the specialised equipment that might be needed for a specific aircraft type only needs to be purchased once [15].

Regardless of aircraft type, LCCs' aircraft are arranged in a high-density all-economy configuration, as every flight has a fixed cost, the more passengers on board, the more revenue the airline can obtain [15].

**(v) Point-to-point service**

Since market liberalisation, the legacy carriers have adopted a new route structure concept of *Hub & Spoke*, being *Hub* a major airport in a country or region and *Spoke* airports of smaller size. Operating in a *Hub & Spoke* system, means that the carrier offers flights between *Hub* airports and between them and *Spoke* airports [13]. This means that all *Spoke* flights come into one *Hub* airport and from there passengers have a connecting feed for the *Spoke* flights that depart shortly thereafter [15].

In spite of *Hub & Spoke* offering a large number of city connections, a *Hub* is also an extremely expensive operation. Besides having a revenue advantage of many city pair choices, the peak flight scheduling necessary for passenger convenience also means that economies of scale are not always achieved. Moreover, once the numbers of flights reach a critical level, any additional flight will increase costs resulting in diseconomies of scale. This is one of the major reasons why LCCs usually operate in a point-to-point or origin and destination (O&D) route structure. Under this route structure, airlines will still operate bases where economies of scale are realised, but will not have any peak level of flights [15].

In Europe, LCCs usually operate in a *Base & Spoke* system. The carrier bases aircraft at one airport (*Base*) and then flies to various destinations from there, enabling the carrier to create some economies of scale benefits. This increased utilisation of airport assets allows to operate more flights with fewer facilities and personnel, and this ultimately reduces costs [15].

**(vi) Use of secondary airports**

LCCs want to avoid congested primary airports, usually because it implies bigger turnaround times and higher airport fees. As an alternative, secondary airports are usually underutilised and although they are further from a city centre they offer lower landing fees, less congestion, and quicker turnarounds, resulting in a more cost-efficient operation [15].

**(vii) Higher aircraft utilisation**

Higher aircraft utilisation is another successful characteristic from LCCs' business models. In LCCs point of view, while the aircraft is sitting on the ground it is not earning money. Therefore, having a higher daily aircraft utilisation is beneficial for the carrier. One way to increase the

aircraft utilisation is by having a quicker turnaround time<sup>3</sup>. Offering free seating, passengers tend to enplane and deplane faster, and operating in a *Base & Spoke* system, handling operations are less complex. These efficiencies enable LCCs to operate more flights, therefore generating more revenue [15].

All of the characteristics differentiating LCCs and legacy carriers have been summarised in Table 2.3.

Table 2.3 - Summary of LCCs and legacy carriers common characteristics.

Product Features	Low-Cost Carrier	Legacy Carrier
<b>Brand</b>	One Brand: low fare	Brand Extensions: Fare + service
<b>Fares</b>	Simplified	Complex
<b>Distribution</b>	Online and Direct Booking	Online, Direct and Travel Agent
<b>Check-in</b>	Ticketless	Ticketless, IATA Ticket Contract
<b>Airports</b>	Secondary Mostly	Primary
<b>Connections</b>	Point to Point	Code Share, Global Alliances
<b>Class segmentation</b>	One Class	Two Classes
<b>Inflight</b>	Pay for Amenities	Complimentary Extras
<b>Aircraft utilisation</b>	Very High	Medium to High
<b>Turnaround Time</b>	25 minutes	Low Turnaround
<b>Product</b>	One Product: Low Fare	Multiple Integrated Products
<b>Ancillary Revenue</b>	Advertising, Onboard Sales	Focus on the Primary Product
<b>Aircraft</b>	Single Type	Multiple Types
<b>Seating</b>	Small Pitch	Generous Pitch
<b>Customer Service</b>	Generally, Under Performs	Full Service
<b>Operational Activities</b>	Focus on Core	Extensions

Source: Adapted from [26].

## 2.5 Conclusion

Air transport business is a highly heterogeneous sector with a considerable group of actors. The growth of air travelling has an increasing impact in the sector.

The easing of civil aviation constraints has been gradually introduced since the late 1980s involving both domestic and international markets. This resulted in a fundamental shift in airline economics and have subsequently provided the necessary environment for the growth of low-cost carriers from the mid-1990s to current times.

LCCs have developed various strategies in their business models to gain competitive advantages over legacy carriers. The characteristics of LCCs' business models are centred in cost reductions and higher productivity enabling them to increase their market margins and therefore offer

<sup>3</sup> Turnaround Time - can be defined as the time took between arriving and departing from the gate. It represents the time require to unload an airplane and finish preparing it for the next departure.

lower fares. Therefore, LCCs had to change the airline-airport relationship. This new airline-airport-passenger relationship has led airports to significantly reduce their aeronautical revenues while seeking to increase their non-aeronautical revenues through increased passenger numbers.

# **Chapter 3**

## **Benchmarking and Airports Performance Analysis**

### **3.1 Introduction**

### **3.2 Airport Infrastructure**

### **3.3 Airport Benchmarking**

#### **3.3.1 Airport Performance Analysis**

#### **3.3.2 Methodologies for Airport Benchmarking**

#### **3.3.3 Decision Making in Airport Infrastructures**

### **3.4 Conclusion**





### 3.1 Introduction

As describe in chapter two, the liberation of the air transport industry led to the growth of air traffic and consequently increased airports congestion.

To face this problem, airports need to expand their capacity and to improve runway and terminal systems efficiency. However, until the beginning of airport privatisation, slot demand was rather an inefficiency and needed improvements to face all air transport restructuring processes. All of this created the need for airports to start benchmarking themselves and to compare them with other airports [1].

### 3.2 Airport Infrastructure

International Civil Aviation Organization (ICAO) defines aerodromes as a defined area of land or water that uses all or a part of its Infrastructures (buildings, installations and equipment) for the arrival, departure and ground movements of aircraft [27].

Airports are aerodromes dedicated to serving regular air transportation and they can be characterised as a system of infrastructures that complement each other to allow the movement of aircraft, people and goods [28]; and they can be divided into three types according to airports activity [29]:

- General aviation;
- Regional (with public interest);
- International.

The basic Infrastructures of an airport consist of one or more runways, taxiways, apron area, gates, freight and passenger terminals, and ground transport interchanges. To complement this infrastructures airports offer a wide range of services, such as handling services, safety and security services, air traffic control, and even a large variety of commercial services [11]. All of this services can be divided into aeronautical services and non-aeronautical services as summarised in Table 3.1.

Table 3.1 - Classification of airport activities.

Aeronautical and Airside Services		Non-Aeronautical and Landside Services
Operational	Handling	Commercial
<ul style="list-style-type: none"> <li>- Air Traffic Control;</li> <li>- Meteorological Services;</li> <li>- Telecommunications;</li> <li>- Police and Security;</li> <li>- Fire, Ambulance and First Aid Services;</li> <li>- Runway, Apron and Taxiway Maintenance.</li> </ul>	<ul style="list-style-type: none"> <li>- Aircraft Cleaning;</li> <li>- Provision of Power and Fuel;</li> <li>- Luggage and Freight Loading and Unloading;</li> <li>- Processing of Passengers, Baggage and Freight.</li> </ul>	<ul style="list-style-type: none"> <li>- Duty-Free Shops;</li> <li>- Other Retailing Shopping;</li> <li>- Restaurants and Bars;</li> <li>- Leisure Services;</li> <li>- Hotel Accommodations;</li> <li>- Banks;</li> <li>- Car Rental and Parking;</li> <li>- Conference and Communications Facilities.</li> </ul>

Source: Adapted from [30].

Initially, airports were publicly owned and controlled based on public service obligations. Though in the last decades, airports managing and business model have suffered some transformations, mainly due to social, political, legal, technological and environmental changes [28] which led to the necessity of new management practices more focus on the “commercialisation” of the airport [11], [31].

The privatisation of airports increased airport competitiveness and the need to create performance indicators in order to gain insight into their performance so they can maximise their efficiency [32].

### 3.3 Airport Benchmarking

Airports Council International (ACI) defines benchmarking as an economic standard to measure business performance by comparing productivity and efficiency, evaluating specific processes, policies and strategies, and to determine the overall business performance. This makes airport benchmarking a component for airports strategic planning process and a tool to monitor and compare airport, economic, operational and service performance. Assessing the implementation of airport’s strategic planning, benchmarking measure the performance of discrete airport functions and by identifying and adopting the best practices, the airport can increase its efficiency, quality and customer satisfaction. In other words, airport benchmarking connects day-to-day operations and management strategies with the airports short and long-term actions plans and initiatives [33].

There are two main categories of benchmarking [34]:

- Partial - Assesses and compares individual processes, functions and services;

- Holistic - Creates a systematic approach to define and assess a critical group of processes, functions and services, which altogether indicate the relative performance of the organisation as a whole.

Within partial and holistic categories, there are two predominant types of benchmarking: Internal benchmarking, also known as Self-benchmarking, within the organization which compares internal performance of processes, functions and services over a time series; and external benchmarking, which compares the organization performance with peers or other organization in the same sector activity at a precise point in time or through a time series [33].

There are five stages of benchmarking process of an organisation [33], [35]:

- Decision stage, where is decided what to benchmark and chose the indicator for the benchmarking process, considering that they should be quantifiable;
- Identification stage, where the organisations will take part in the comparative analysis will be identified;
- Data stage, where the data is collected, analysed and identified key performance differentials;
- Analysis stage, where the rankings and new performance goals are produced;
- Action stage, where the best practices are applied to increase performance and efficiency of the organisation, by always monitoring the progress and communicating the results to the decision makers.

### **3.4 Airport Performance Analysis**

Analysis of airport performance has become one of the biggest topics for civil aviation authorities, even more in the economically fast-growing regions that faced the major increase in passengers and cargo transport. With the intensification of market competition and privatisation airport management, it is essential to have a well-structured system to assess airport performance on efficiency and competitiveness [36].

The structure of a performance analysis is based on the inputs, such as the resources deployed, the outputs, like quantity delivered, and the outcomes that consist of the quality achieved, taking into account the price and environmental impact. However, it is necessary to take into consideration the relations with and between third parties, such as airlines, external outputs, regulatory environment, geography and others. Figure 3.1 outlines a generic structure for performance analysis [37].

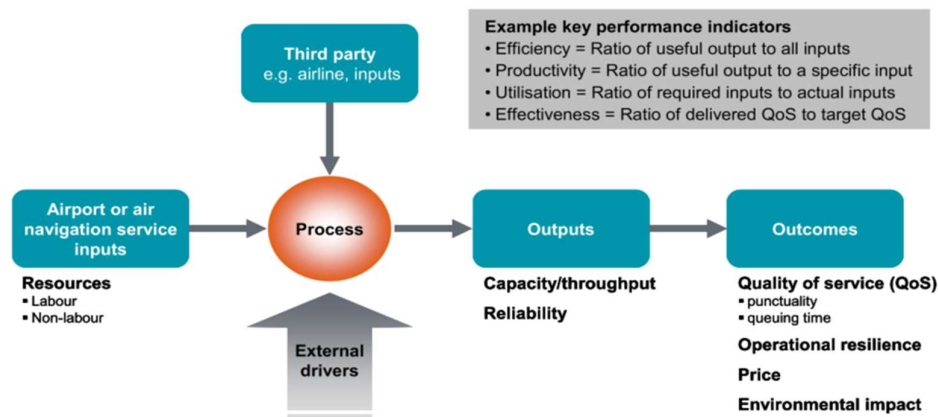


Figure 3.1 - Generic framework for operational performance analysis.

Source: [37].

Measuring airport performance enables airport managers and government to measure efficiency from an operational and financial perspective to alternative strategies for investments and to supervise airport safety and environmental impacts. By analysing the airport performance, the management is capable of identifying the areas that are performance good and the ones that need corrective actions. Airport customers, such as airlines, which act as the intermediary between the airport and passengers or freight shippers will also be interested in its performance.

Summing up, airport performance analysis is very important for the several different interested parties [38]:

- Government - for economic and environmental regulation;
- Airlines - to assess airports performance and prices;
- Airports managers - to assess and improve their airport;
- Airport owners and stakeholders - to determine the business performance and to return their investment.

### 3.4.1 Methodologies for Airport Benchmarking

There are a large variety of methods to benchmark, which allows the work to choose the most appropriate methodology to achieve its objectives.

Due to the fact of airports consisting of a multi processes system, a group of quantitative methodologies have been developed to assess productivity and efficiency of airports performance [1]. The difference between this two approaches of airports performance consists in the notion of maximum achievable outputs since efficiency considers the maximum potential outputs that can be created by the available inputs, while productivity considers the real outputs created [36].

Throughout the years a variety of methodologies appeared to assess productivity and efficiency. Von Hirschhausen and Cullmann organised these methodologies by type of approach as represented in Figure 3.2.

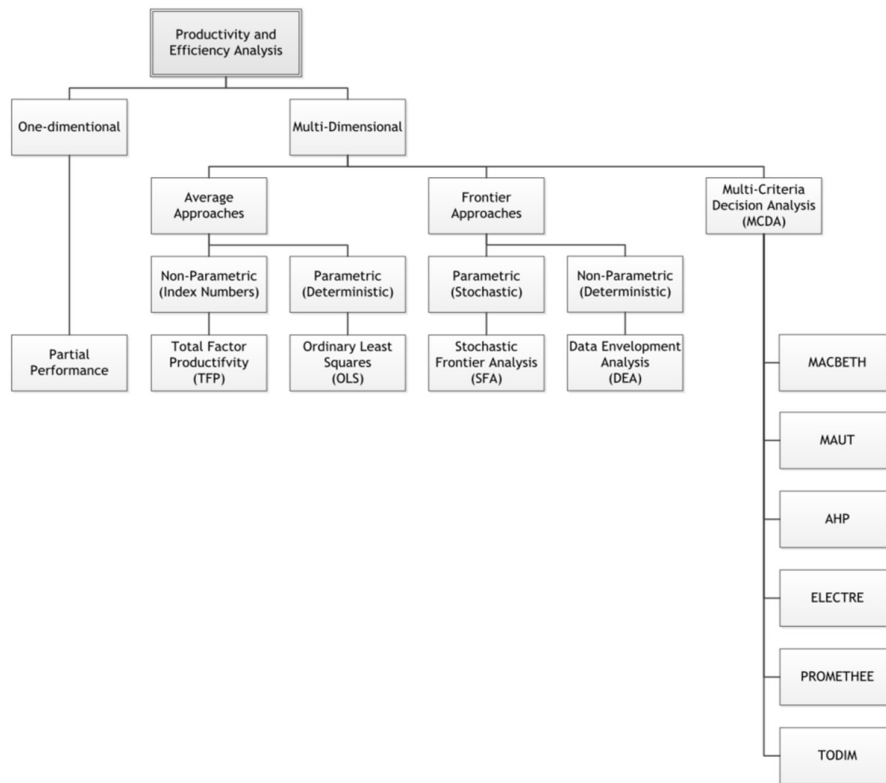


Figure 3.2 - Quantitative methodologies to assess productivity and efficiency.

Source: Adapted from [39] and [40].

The one-directional approach, particularly partial measures, consist in dividing one output by one input which makes this approach the simplest for to assess productivity. However, its results have to be taken with causation, because they fail to capture effects between different inputs. For this reason, to access airports performance it's recommended using multi-dimensional approaches. In Table 3.2 is describe the different types of major methodologies used in airport performance assessment with the main weakness of each one [36].

Table 3.2 - Main methodologies used in airport performance assessment.

	Methodology	Weakness
<b>Partial Measure</b>	This method 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.	This method only focuses on certain fields of airport performance. The evaluation result of this method would not be able to provide a more comprehensive evaluation of an airport's performance.

	<b>Methodology</b>	<b>Weakness</b>
<b>Multi-Criteria Decision Analysis (MCDA)</b>	<p>One of the widely-adopted methods. Traditionally, employing this method can be divided into two main steps: the first step is to acquire relative weights, and the second step is to rank the options.</p> <p>This method first selects evaluation indicators through expert survey or interview, and then chooses optimal solution bases on those selected indicators.</p>	<p>Because the selection of indicators is based on expert's experience and their own judgment, the result may be affected by subjective factors.</p>
<b>Total Factor Productivity (TFP)</b>	<p>In economies, TFP is a variable which account 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.</p>	<p>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.</p>
<b>Stochastic Frontier Analysis (SFA)</b>	<p>SFA, sometimes referred to as econometric frontier approach, is one of the main parametric approaches used by researchers to evaluate efficiency.</p>	<p>Although the parametric approaches consider the effect error, which is not considered in non-parametric approach, the parametric methods still face challenges on separating random error from efficiency.</p>
<b>Data Envelopment Analysis (DEA)</b>	<p>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.</p>	<p>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.</p>

Source: [36].

After a careful analysis of this group of methods to assess performance and efficiency, and every of its advantages and disadvantages, MCDA was chosen as the best one to apply in this study, complementing previous studies done by José Braz [40] and João Jardim [41] that study the MCDA as a tool for airport benchmarking.

### 3.4.2 Decision-Making in Airport Infrastructures

A decision is a response in a situation where is more than one possible course of action under consideration. The decision maker can form expectations concerning the outcomes following each course of action, expectations that can be described in terms of degrees of belief or probabilities [42].

There are many different definitions of decision making but they all revolve around the same principles [43]:

- "Decision making is the study of identifying and choosing alternatives based on the values and preferences of the decision maker";
- "Decision making is the process of sufficiently reducing uncertainty and doubt about alternatives to allow a reasonable choice to be made from among them".

Therefore, there is something to be decided and there are always alternatives that must be considered. The final result is usually a decision based on what needs to be solved and it's never a given fact that the decision is the absolutely correct one. Although there isn't a sole definition for decision making, its process can be defined in five steps [44]:

- (i) Gather the facts and define the problem - The identification of the real problem is the first step in the decision-making process. The correct characterisation of the main problem affects all following steps and its inaccurate definition means that every step in the decision-making process will be based on an incorrect starting point. Identify whether this decision is part of a bigger one or, on the contrary, it can be divided into smaller ones;
- (ii) Identify the alternatives - Brainstorm as many alternatives as possible without excluding any alternative, consider all of the alternatives and make a shortlist of the most viable ones. Although brainstorming is the most common technique to develop alternative solutions, decision makers can use several other ways to elaborate solutions;
- (iii) Assess the alternatives - Evaluate each alternative's positive and negative aspects and the risk each one may have, determine the impact of each alternative and identify a preferable one. Regardless of the method used for this, a manager needs to evaluate each alternative in terms of its feasibility, effectiveness and consequences;
- (iv) Implement the decision - The best alternative is the one that produces the most advantages and the fewest serious disadvantages. Sometimes, the selection process can

be fairly straightforward, such as the alternative with the most pros and fewest cons. Other times, the optimal solution is a combination of several alternatives;

- (v) Evaluate the outcomes - Ongoing actions need to be monitored. An evaluation system should provide feedback on how well the decision is being implemented, what the results are, and what adjustments are necessary to get the results that were intended when the solution was chosen. In order for a manager to evaluate his decision, he needs to gather information to determine its effectiveness. Was the original problem resolved? If not, is he closer to the desired situation than he was at the beginning of the decision-making process?

In more complex and bigger infrastructures, the decision-making process needs to involve every stakeholder. This means that normally they will try to reach a general consensus even though not all of them agree with the decision they can adapt and accept the chosen one. Decision making in airport infrastructures is facing a new approach called Collaborative Decision Making (CDM). This concept has been defined as a "cooperative effort between the various components of aviation transportation, both government and industry, to exchange information for better decision making" by the Federal Aviation Administration (FAA) [45].

In Europe, there already are a set of 20 airports with a fully implemented Airport Collaborative Decision Making (A-CDM) process. Figure 3.3 depicts the A-CDM process diagram.



Figure 3.3 - Collaborative Decision Making Process.

Source: [46].

A-CDM has a series of objectives like reducing delays, improve the existing system's predictability and optimising resources and reduce environmental impacts while doing so [47].

According to EUROCONTROL A-CDM carry several objectives [46]:

- For the Airport Operator, improved use of stands/gates leads to fewer late stand changes. More stable traffic flows and reduced taxi times make for fewer queues on runways and less congestion on the apron or taxiways;

- As an Aircraft Operator, you will have enhanced awareness of the status and location of your aircraft, as you will receive more accurate aircraft arrival times as well as improved departure sequence information. Fuel burn due to queues at the runway threshold will be reduced; this naturally has both economic and environmental benefits;
- Aircraft operators could further optimise their flight operations;
- Air Traffic Control will benefit from improved runway and capacity planning. More accurate take-off time predictions will help the Network Manager make more precise calculations of network demand;
- The Ground Handler will benefit from having more accurate in-block times for arrivals, as well as from knowing the exact time departing aircraft have been given start-up clearance. This makes for more accurate planning and a more efficient use of resources. Passengers will benefit from a reduction in delays and fewer missed connections.

Along with this increased predictability, A-CDM brings myriad other benefits for airports, such as environmental impact reduction and enhanced planning of the turn-around, to name only two.

### **3.5 Conclusion**

The characterisation of the airport as complex infrastructure with a large variety of stakeholders and the growth of sector privatisation led to a bigger airport competitiveness. This creates the need to benchmark this infrastructure in order to maximise their efficiency, making airport benchmarking a component for airports strategic planning process and a tool to monitor and compare airport's economic, operational and service performance.

Based on the literature and on the pros and cons of each method normally used in airport benchmark, MCDA was the one that better fitted the needs for this work. MCDA helps to integrate a large set of key performance areas with experts' experience and their own judgment, although the result may be affected by subjective factors.

When it comes to decision-making regarding airports and air transportation, the CDM approach poses very interesting solutions to long-time existing problems. With this concept involving ground handling, air and ground operations, ATC, basically every operational area of the airport, the decision making can not only be simplified but also enhanced.

# **Chapter 4**

## **Airports Multi-Criteria Decision Analysis**

### **4.1 Introduction**

### **4.2 MCDA Methodologies**

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

### **4.3 Performance and Efficiency Support Analysis for Airport Global Benchmarking (PESA - AGB)**

#### **4.3.1 Structuring**

#### **4.3.2 Survey and Meetings**

#### **4.3.3 Evaluation**

#### **4.3.4 Classifications and Outputs**

### **4.4 Linear Regression and Correlation Coefficient**

### **4.5 Conclusion**



## 4.1 Introduction

This chapter introduces a brief description of MCDA to the methodology used in the study, Measuring Attractiveness by a Categorical Based Evaluation Technique (MACBETH). This chapter continues by explains the tool used to analyse the case studies, which is called Performance and Efficiency Support Analysis for Airport Global Benchmarking (PESA - AGB). To describe the tool, all the steps to conclude the evaluation process are presented. A brief review of linear regression and correlation coefficients is done to allow the identification of the correlations between airports' performance and efficiency scores and LCCs' traffic evolution.

## 4.2 MCDA Methodologies

MCDA methods have been developed to improve decision quality involving multiple criteria by making choices more explicit, rational and efficient [48].

Lai, Potter and Beynon [49] states that the main method in MCDA is the analytical hierarchy process-AHP, that uses procedures for deriving the weights and the scores archived by alternatives that are based on pairwise comparisons between criteria and between options, respectively. There are other outranking methods like ELimination Et Choix Traduisant la Réalité, that is, Elimination and Choice Expressing Reality-ELECTRE designed for choosing a single action ELECTRE I or for choosing with rankings by eliminating a lot of alternatives, the remaining subset is the most satisfying alternative ELECTRE II, III and IV; Preference Ranking Organization Method for Enrichment of Evaluations-PROMETHEE defines preference functions based on differences between attributes among different schemes and Technique for Order Preference by Similarity to Ideal Solution-TOPSIS, this method uses ideal and non-ideal solutions to find the best alternative, but assumes that each indicator takes monotonic function utility.

The Weighted Sum Methods (WSM) are the most commonly used. The greatest problem of these methods is the determination of the weights vector that best illustrates the decision maker opinion on the influence of each criterion in the construction of the synthesis criterion. The trade-off methods [50], Analytic Hierarchy Process (AHP) [51] and MACBETH [52], [53] are some of the methods used to solve this problem. The choice of the MACBETH method is due to two main factors, namely:

- It allows the transformation of qualitative into quantitative evaluations, which is also done by the AHP method;
- It does not allow any degree of inconsistency in the decision maker judgments, establishing an interactive process judgement revision, also suggesting which ones should be reviewed. AHP method does not present this possibility, assigning a value of 10% for the maximum inconsistency in the judgments.

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

MACBETH is a decision-making method that allows options evaluation in a multiple criteria scenario and its main difference among other MCDA methods is that it only needs qualitative judgements about attractiveness difference between two elements at a time, in order to generate criteria's weight and in each criteria options numerical scores [54].

When 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 evaluation model, a value scale is calculated for each criterion and its weights. Value scores are subsequently aggregated additively, taking all the criteria into consideration to calculate the overall value scores, reflecting their attractiveness [55].

In this MCDA problem, for each criterion, it is necessary to determine a scale of values, that is, assign ranks to each alternative. In some cases, there is a common way of doing this assignment, and the cost of a commodity is the classic example. In other cases, the evaluation is qualitative, being necessary to make it quantitative.

MACBETH allows assigning ranks to each alternative either directly or through pairwise comparisons of the elements to determine their relative attractiveness. Given two alternatives, the decision maker should say which one is the most attractive (and has the highest rank) [56]:

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  $v: A \rightarrow \mathfrak{R}$ ,  $v(x)$  ( $x \in A$ ) 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 [57].

#### 4.2.1.1. Ordinal Value Scale

Ordinal value scales (defined on  $X$ ) are quantitative representations of preferences that reflect, numerically, the order of attractiveness of the elements of  $X$  for  $J$ . The construction of an ordinal value scale is a straightforward process, if  $J$  is able to rank the elements of  $X$  by order of attractiveness. Once the ranking is defined, one needs only to assign a real number  $v(x)$  to each element  $x$  of  $X$ , in such a way that:

$$v(x) = v(y) \text{ if and only if } J \text{ judges the elements } x \text{ and } y \text{ to be equally attractive.} \quad (1)$$

$$v(x) > v(y) \text{ if and only if } J \text{ judges } x \text{ to be more attractive than } y. \quad (2)$$

#### 4.2.1.2. Value difference Scale

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) coherences, 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 [58], only after this adjustment, with the introduction of expert inputs, is the cardinal scale of values characterised.

Having the rank of each alternative for each criterion, it is necessary to add them in a single rank by a weighted sum.

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 in an indirect way, 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 [59].

#### 4.2.1.3. Performance Descriptors and Value Profiles

Let  $h = 1, \dots, m$  designate the KPA,  $j_h = 1, \dots, n_h$  the KPI of KPA  $h$ ,  $X_{j_h}$  the performance descriptor of the KPI  $j_h$  and  $v_{j_h}: X_{j_h} \rightarrow \mathfrak{R}$  the respective value scale. For a given performance assessment and for a given KPA  $h$ , let  $x_{j_h}$  be the performance on KPI  $j_h$  of  $h$  and  $v_{j_h}(x_{j_h})$  the respective value score;  $x_{1_h}, \dots, x_{j_h}, \dots, x_{n_h}$  and  $v_{1_h}(x_{1_h}), \dots, v_{j_h}(x_{j_h}), \dots, v_{n_h}(x_{n_h})$ , are the performance and value profiles respectively. The partial value scores of the airport performance and the overall value are given by the simple additive model (3) and the hierarchical additive model (4)

$$v_h(x_{1_h}, \dots, x_{j_h}, \dots, x_{n_h}) = \sum_{j_h} k_{j_h} v_{j_h}(x_{j_h}) \quad \text{with} \quad \begin{cases} v_{j_h}(\text{target}_{j_h}) = 100, \\ v_{j_h}(\text{neutral}_{j_h}) = 0, \end{cases} \quad (3)$$

$$v(\text{overall}) = \sum_h (k_h \sum_{j_h} k_{j_h} v_{j_h}(x_{j_h})), \quad (4)$$

were  $\text{target}_{j_h}$  and  $\text{neutral}_{j_h}$  are the "target" and "neutral" reference levels of the KPI  $j_h$ ; and  $k_{j_h}$  and  $k_h$  are weights assign to the KPI and KPA respectively, such that  $\sum_{j_h} k_{j_h} = 1$  and  $k_{j_h} > 0$  and  $\sum_h k_h = 1$  and  $k_h > 0$ , for all  $j$  and all  $h$ .

By comparing the attractiveness of the alternatives, weights are assigned to the criteria in a way analogous to the cardinal scale of values (scores) adapted from [60].

The main difference between cardinal scale of values and weight assignment is that, while in the "scores" there is the restriction of the ranks occupy the whole defined range, in the "weights" the smaller weight occupies the lower value of the scale, but instead of setting the value of the highest weight, it requires that the sum of all weights is equal to unity.

#### 4.2.1.4. Theoretical aspects

##### 1. Difference of Attractiveness

In the MACBETH method [58], when the decision maker does his value judgments about the potential actions (alternatives) in each situation, he will do so in terms of the attractiveness he feels for this alternative.

This task is defined [61] such as the construction of a criterion function  $v_j$  such that:

- (i) for  $x, y \in X$ ,  $v(x) > v(y)$  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  $x, y, z, w \in X$  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 [62] "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", ...?"

A semantic scale formed by categories of attractiveness difference is introduced, to facilitate the interaction between the decision maker and the analyst. The decision maker should choose one, and only one, among the categories, presented.

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

Thus, this method is linked to the theoretical problem of numerical representation of multiple semi-orders by constant thresholds of Doignon [63], represented by  $m$  binary relations ( $P^{(1)}, P^{(2)}, \dots, P^{(k)}, \dots, P^{(m)}$ ), 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  $s_k: x P^{(k)} y, s_k < v(x) - v(y) \leq s_{k+1}$ , 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  $\rightarrow C_6 = ] s_6, + ]$ .

The categories are delimited by constant thresholds  $s_1, \dots, s_6$  determined simultaneously with the value scale  $v$ .

### II. Matrix of value judgments

To facilitate the expression of the absolute judgments of the difference of attractiveness between the pairs of alternatives it is necessary to construct matrices of value judgments. Figure 4.1 shows the upper triangular matrix constructed for each criterion, in which it is assumed that  $X = \{x_n, \dots, x_{n-1}, \dots, x_1\}$  the set of  $n$  alternatives to be evaluated, and that these are ordered in decreasing order of attractiveness a  $x_n P^{(k)} x_{n-1}$  not existing indifference in any case to this criterion.

	$x_n$	$x_{n-1}$	...	...	$x_2$	$x_1$
$x_n$		$X_{n,n-1}$	...	...	$X_{n,2}$	$X_{n,1}$
$x_{n-1}$			...	...	$X_{n-1,2}$	$X_{n-1,1}$
...				...	...	...
...					...	...
$x_2$						$X_{2,1}$
$x_1$						

Figure 4.1 - Matrix of value judgments for local evaluation of actions.

Source: Adapted from [57].

Each element  $X_{i,j}$  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  $(x_n, x_n)$  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.

### III. 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  $z$  belongs to a category  $C_{k'}$ , where  $k' \geq k$ , 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 [52], [63], 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.

#### **IV. Mathematical Formulation**

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<sup>st</sup> LPP:

The 1<sup>st</sup> LPP verifies the existence of cardinal inconsistencies, and mathematically is represented by (I):

*Min*  $c$

*subject to*

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

$$r1) s_1 = 0$$

$$r2) v(x_1) = 0, \text{ where for } \forall x \in X, \text{ is } x P x_1$$

LPP (I)

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

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

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

The objective function of (I) is the minimization 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  $r_0$  constraint guarantees the non-negative number for all variables of the problem. The restrictions  $r_1$  and  $r_2$  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 are equal to zero.

The set of restrictions  $r_3$  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  $r_4$  and  $r_5$  are the application of the Doignon formula to the problem of multiple semi-orders:  $s_k: x P^{(k)} y, s_k < v(x) - v(y) \leq s_{k+1}$ , 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  $r_4$  and  $r_5$ , 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.

- 2<sup>nd</sup> LPP

The 2<sup>nd</sup> 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):

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

$$r_0) s_1, \dots, s_6 \geq 0; v(x) \geq 0 \forall x \in X; c \geq 0$$

$$r_1) s_1 = 0$$

$$r_2) v(x_1) = 0, \text{ where for } \forall x \in X, \text{ is } x P x_1$$

$$r_3) k = \{2, \dots, 6\}: s_k - s_{k-1} \geq 1000$$

LPP (II)

$$r_4) k = \{1, \dots, 6\}, (x, y) \in C_k : v(x) - v(y) \geq s_k + 1$$

$$r_5) k = \{1, \dots, 5\}, (x, y) \in C_k : v(x) - v(y) \leq s_{k+1} - 1$$

$$r_6) k = \{1, \dots, 5\}, (x, y) \in C_k : v(x) - v(y) = 0.5(s_k + s_{k+1}) + \varepsilon(x, y) - \eta(x, y)$$

$$r_7) (x, y) \in C_6 : v(x) - v(y) = s_6 + 1 - \alpha(x, y) + \delta(x, y)$$

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 [61],

[62] that is the choice of solution is the minimization of the absolute deviations between the value difference of 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  $r_0, r_1, r_2$  and  $r_3$  are the same as those of the LPP (I). The constraints  $r_4$  and  $r_5$ , 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  $r_6$  makes the difference in value between the pair  $(x, y)$  equal to the category central 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  $k = 1, \dots, 5$ . For pairs that have the extreme attractiveness difference, that is,  $k = 6$ , the restriction  $r_7$  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.

- 3<sup>th</sup> and 4<sup>th</sup> 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 (III) and (IV) show the possible causes of inconsistency. They present the same objective function, giving only the restrictions.

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

$$r_0) s_1, \dots, s_6 \geq 0; v(x) \geq 0 \forall x \in X; c \geq 0$$

$$r_1) s_1 = 0$$

$$r_2) v(x_1) = 0, \text{ where for } \forall x \in X, \text{ is } x P x_1$$

$$r_3) k = \{2, \dots, 6\}: s_k - s_{k-1} \geq 1000$$

LPP (III)

$$r_4) k = \{1, \dots, 6\}, (x, y) \in C_k : v(x) - v(y) \geq s_k + 1$$

$$r_5) k = \{1, \dots, 5\}, (x, y) \in C_k : v(x) - v(y) \leq s_{k+1} - 1$$

$$r_6) k = \{1, \dots, 6\}, (x, y) \in C_k : v(x) - v(y) = s_k + 1 - \alpha(x, y) + \delta(x, y)$$

$$r_7) k = \{1, \dots, 5\}, (x, y) \in C_k : v(x) - v(y) = s_{k+1} - 1 + \beta(x, y) - \gamma(x, y)$$

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

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

$$r1) s_1 = 0$$

$$r2) v(x_1) = 0, \text{ where for } \forall x \in X, \text{ is } x P x_1$$

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 (II) 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).

#### V. *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 in an indirect way, 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 extra 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.

### 4.3 Performance and Efficiency Support Analysis for Airport Global Benchmarking (PESA - AGB)

PESA-AGB model is conceived based on PESA-GB (Performance and Efficiency Support Analysis for Global Benchmarking) model [64]. PESA-AGB was built, to assess airport performance and efficiency using pre-defined KPAs and KPIs.

This model is based on the MACBETH mathematical foundations described in the previous section and supported on the work of Bana e Costa et al [58]. It is structured in a 6 steps arrangement (Figure 4.2): Structuring (Step 1); Survey (Step 2); Meeting (Step 3); Evaluation (Step 4); Classification (Step 5); and Outputs (Step 6). Although the sequence of the task is as shown, it is possible to redefine or adjust any task at any time. A full visualisation of the PESA-AGB model is shown in Annexe 1.

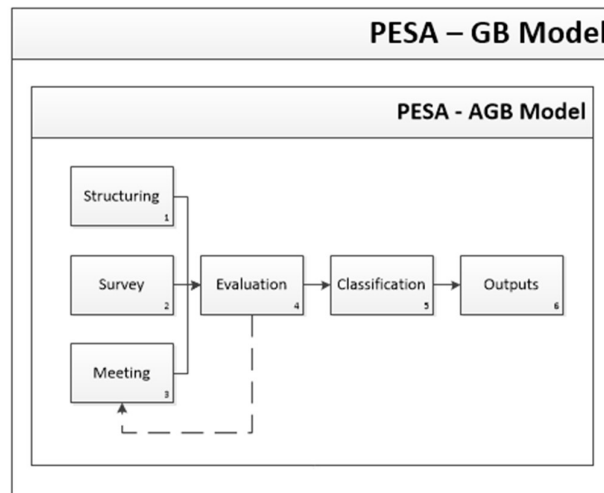


Figure 4.2 - PESA-AGB Model building tasks.

Source: Own elaboration.

#### 4.3.1 Structuring

Structuring (Step 1) consists in defining a decision tree and collecting Airport data for each KPI to build a performance descriptor consisting of a four-level scale (L1, L2, L3 and L4) for each KPI, as shown in Figure 4.3.

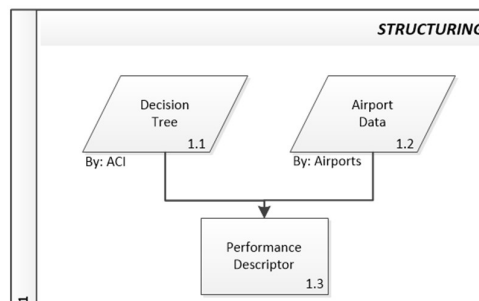


Figure 4.3 - Structuring step of PESA-AGB model.

Source: Own elaboration.

There are many different circumstances related to airport operations (aviation activities, commercial activities, location constraints, etc.) and it's important to find different key performance areas and indicators in order to be the most accurate for the analysis [41]. To structure the decision tree (1.1) a crucial step is the choice of KPIs, thus to do an external benchmarking evaluation the criteria must be in a complex form (output/input structure type), also the two-level structure must translate an exhaustive and non-redundant set of no more than 10 criteria within each KPA. For PESA-AGB it was used a set pre-defined KPAs and KPIs recommended by [65], who elaborated a guide to measure airport performance leading to a six KPAs decision tree: Core, Safety and Security, Service Quality, Productivity/Cost Efficiency, Financial/Commercial, and Environmental. Each KPA is associated with several KPIs - a total of forty-two items as referred by [66]:

- (i) **Core** - Used to characterise and categorise airports such as the number of passengers and operations. Although airports may have little control over these core indicators, especially in the short term, those are important indicators of overall airport activity and important drivers and components of other indicators [65]. This KPA is described by five KPIs;
- (ii) **Safety and Security** - These are critical airport functions which sometimes overlap. Safety indicators are used to track airfield safety issues as well as safety issues involving other airport portions, including roadways and general employee safety. Security indicators may be used to track security violations, thefts and crimes, and responsiveness [65]. This KPA is described by six KPIs;
- (iii) **Service Quality** - Focused both on how passengers perceive service level provided by the airport, and on service delivery objective measures [65]. This KPA is described by eight KPIs;
- (iv) **Productivity / Cost Efficiency** - Airports often combine productivity and cost effectiveness in a single KPA. As used by ICAO productivity refers to output to input relationship while cost effectiveness refers to the financial input or cost required to produce a non-financial output [65]. This KPA is described by nine KPIs;
- (v) **Financial / Commercial** - Covers a wide range of measures that analyses airport's financial performance including airport charges, airport financial strength and sustainability, and individual commercial functions performance [65]. This KPA is described by eight KPIs;
- (vi) **Environmental** - Many airports have developed or are developing environmental performance indicators. These indicators are used to track an airport's progress in minimising its operations environmental impacts [65]. This KPA is described by six KPIs.

Table 4.1 presents the six KPAs and their respective KPIs of PESA-AGB decision tree.

Table 4.1 - Scope of each key performance area (KPA) and key performance indicator (KPI) of PESA-AGB.

Level 1: Areas (KPA)	Level 2: Criteria (KPI)	Description
Core	Passengers;	Passengers, including enplaning and deplaning.
	Origin and Destination Passengers;	Passengers whose air travel begins or ends at the airport.
	Aircraft Movements;	Aircraft take-offs or landings at an airport. One arrival and one departure are counted as one movement.
	Freight or Mail Loaded/Unloaded;	Freight or mail loaded or unloaded at the airport.
	Destinations–Nonstop.	The number of airports with nonstop service, including destinations with only seasonal service.
Safety and Security	Runway Accidents;	Aircraft accidents involving a runway per thousand aircraft movements (take-offs and landings are counted separately).
	Runway Incursions;	The 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.
	Bird Strikes;	The number of incidents per thousand movements, involving bird strikes, which are collisions of airborne animals (usually birds, but also including bats) with aircraft.
	Public Injuries;	The number of public injuries per thousand passengers.
	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.
Service Quality	Practical Hourly Capacity;	Maximum aircraft movements per hour assuming an average delay of no more than four minutes, or such other number of delay minutes as the airport may set.
	Gate Departure Delay;	Average gate departure delay per flight in minutes - measured from scheduled departure time at average and peak times.
	Taxi Departure Delay;	Average taxi delay for departing aircraft per flight in minutes - measured by comparing actual taxi time versus unimpeded taxi time at average and peak times.
	Customer Satisfaction;	The overall level of passenger satisfaction as measured by survey responses.
	Baggage Delivery Time;	The average time for delivery of first bag and last bag.
	Security Clearing Time;	Average security clearing time from entering the queue to completion of processing - measured at average and peak times.
	Border Control Clearing Time;	Average border control clearing time from entering the queue to completion of processing - measured at average and peak times.
	Check-in to Gate Time.	Average time from entering the check-in queue, to arrival at the boarding gate - measured at average and peak times.
Productivity / Cost Effectiveness	Passengers per Employee;	Total passengers per employee, expressed as full time equivalents (FTEs).
	Aircraft Movements per Employee;	Aircraft movements per employee, expressed as full time equivalents (FTEs).
	Aircraft Movements per Gate;	Aircraft movements per gate.

Level 1: Areas (KPA)	Level 2: Criteria (KPI)	Description
	Total Cost per Passenger;	Airport total costs per passenger, i.e., operating costs plus non-operating costs, divided by passengers.
	Total Cost per Movement;	Airport total costs per movement, i.e., operating cost plus non-operating cost divided by movements.
	Total Cost per Work Load Unit <sup>4</sup> (WLU);	Airport total costs per WLU, i.e., operating costs plus non-operating costs divided by WLU.
	Operating Cost per Passenger;	Airport operating costs per passenger.
	Operating Cost per movement;	Airport operating cost per movement.
	Operating Cost per WLU.	Airport operating costs per WLU.
Financial / Commercial	Aeronautical Revenue per Passenger;	Aeronautical charges per passenger. Average of aeronautical revenues collected per passenger for use of airfield (landing fees, ramp/apron fees), gate charges, terminal space, passenger-related charges, and ground-handling user fees.
	Aeronautical Revenue per Movement;	Aeronautical charges per movement.
	Non-Aeronautical Operating Revenue as Percent of Total Operating Revenue;	Total non-aeronautical operating revenue as a percentage of total operating revenue.
	Non-Aeronautical Operating Revenue per Passenger;	Total non-aeronautical operating revenue per passenger.
	Debt Service as Percentage of Operating Revenue;	Debt service (principal plus interest) as a percent of operating revenue.
	Long-Term Debt per Passenger,	Long-term debt plus accrued interest payable less the balance in both the debt service reserve fund and debt service or sinking fund, per passenger.
	Debt to EBITDA Ratio;	Debt-to-EBITDA (earnings before interest, taxes, depreciation, and amortisation).
	EBITDA per Passenger.	EBITDA per Passenger.
Environmental	Carbon Footprint per Passenger;	The carbon footprint is the total set of greenhouse gas (GHG) emissions caused by activities at the airport within the airport's control, expressed in terms of the amount of carbon dioxide or its equivalent in other GHG emitted. Excludes emissions caused by airline/tenant operations and the public.
	Waste Recycling;	Percentage of solid waste that is recycled/reused/composted, including pre-consumer organics and post-consumer compostable, as well as airfield trash. Does not include construction waste.
	Waste Reduction percentage;	Percentage reduction over the previous year in tonnes of solid waste, including pre-consumer organics, and post-consumer compostable, as well as airfield trash. Does not include construction waste.
	Renewable Energy Purchased by the Airport;	The amount of renewable energy purchased by the airport, as a percentage of total energy consumed by the airport. Excludes energy purchases by tenants.
	Utilities/Energy usage Per Square Meter of Terminal;	Utilities and energy used per square meter of the terminal building (conditioned space).

<sup>4</sup> Work Load Unit (WLU) - Defined as one passenger or 100 kilograms of cargo [67].

Level 1: Areas (KPA)	Level 2: Criteria (KPI)	Description
	Water Consumption Per Passenger.	Water consumption in the terminal complex divided by the number of passengers.

Source: Own elaboration based on [65].

The airport collected data (1.2) needed to fill the performance table of each indicator is a vital phase, thus the unavailability of criteria data can hinder the use of certain KPIs.

Performance descriptors (1.3) were associated with the criteria to make them operational for the airport evaluation.

Descriptors are performance scales, illustrated in Table 4.2, formed by four reference levels of accomplishment that permit the assessment of performance on each KPI included in the PESA-AGB model and to trace the performance profile of each area. For all descriptors, are established two reference levels - “target” and “neutral” levels (which have very important meaning for managers), “target” being the best level of performance of airport data collected in the defined time span indicating that no improvement is required in the respective criterion, and “neutral” being the worst level of performance of airport data collected in the defined time span that is neutral in terms of need for improvement (because it ensures regular working conditions), but below this level action is recommended to improve the airport performance in that, at least until the “neutral” level is achieved.

Table 4.2 - KPIs' performance descriptor structure.

Level	Description
L4 (Target)	The best value of airport data collected, in the defined time span.
L3	The 1/3 of the difference between the best and the worst value of airport data collected, in the defined time span.
L2	The 2/3 of the difference between the best and the worst value of airport data collected, in the defined time span.
L1 (Neutral)	The worst value of airport data collected, in the defined time span.

Source: Own elaboration.

### 4.3.2 Survey and Meetings

Survey (Step 2) and meetings (Step 3) represent collected expert's judgments, through survey and/or meetings (Figure 4.4). Using expert's answers statistical averaging, a status quo scale (ordinal value scale) is created.

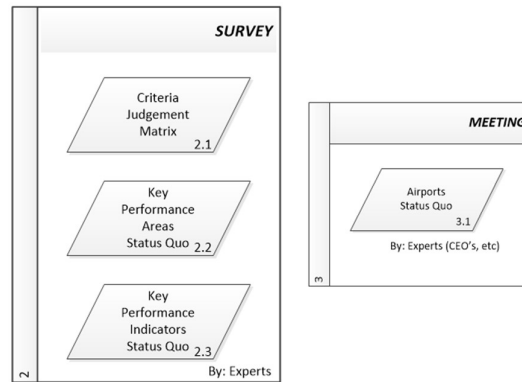


Figure 4.4 - Survey and meeting steps from PESA-AGB model.

Source: Own elaboration.

The survey consisted of the following six steps [68]:

- (i) Welcome message;
- (ii) Experts personal information: name, email and professional expertise;
- (iii) To rank KPAs by relevance order, from 1 (least relevant) to 6 (most relevant).  
Different KPAs can be assigned with the same rank;
- (iv) To choose KPA field of expertise;
- (v) To rank each KPIs from the KPA selected by relevance order, from 1 (least relevant) to 6 (most relevant). Different KPIs can be assigned with the same rank;
- (vi) To fill all KPIs judgement matrix. For each judgement matrix six questions are asked, so that: A refers to KPI best option, D refers to KPI worst option, B and C are intermediate values equally distributed between A and D. To answer these questions six semantic attractiveness difference categories are offered: “very weak”, “weak”, “moderate”, “strong”, “very strong” or “extreme”:
  - 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...?

Thus, with experts' answers statistical averaging, it is possible to build three outputs that reflect each KPA and associated KPIs experts' opinions. KPAs' and KPIs' status quo (2.2 and 2.3 of step 2), which follows section 4.2.1.1 mathematical foundations using experts' answers from survey steps (iii) and (v). Criteria judgement matrix (2.1), which follows section 4.2.1.2 - 4.2.1.4 mathematical foundations using experts' answers from survey step (vi). Figure 4.5 depicts an example of a criteria judgment matrix, which combines the performance descriptor (1.3) with the expert's judgements.

Criteria (KPI)					
<b>Level</b>	<b>Criteria Value</b>				<b>Current Scale</b>
L4	112	99	87	74	100
L3	99	Moderate	Moderate-Strong	Strong	57
L2	87	99	Weak-Moderate	Moderate-Strong	29
L1	74		87	Weak-Moderate	0
				74	

Figure 4.5 - Example of criteria judgement matrix.

Source: Own elaboration.

The meeting (Step 3), or decision conference, is a gathering of the key player who wish to benchmark their airport performance and efficiency, 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 of participants with a balanced perspective on meeting's subject (experts, stakeholders, decision makers, ...) in thinking more clearly about the issue. Figure 4.6 shows the building process of a decision conference [66].

Airports status quo (3.1), follows section 4.2.1.1 mathematical foundations using experts' shared opinions, where airports status quo allows to perform a global peer benchmarking between different airports.

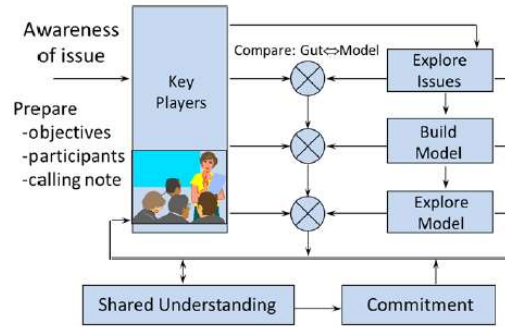


Figure 4.6 - Building process of a decision conference.

Source: [69].

### 4.3.3 Evaluation

Evaluation (Step 4) consists of the criteria functions and the KPIs, KPAs and airport's judgment matrices construction using the performance descriptors and the ordinal value scales obtain in section 4.3.1 and section 4.3.2, respectively (Figure 4.7).

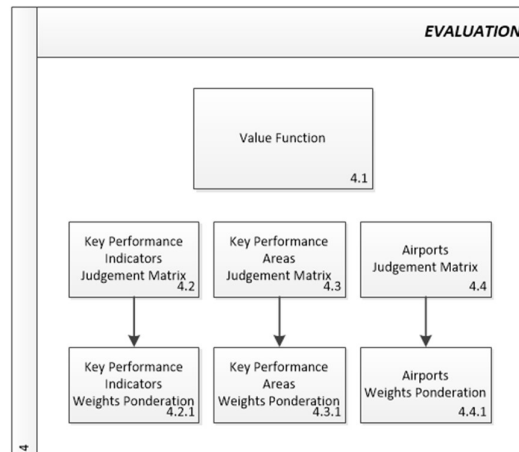


Figure 4.7 - Evaluation step from PESA-AGB model.

Source: Own elaboration.

Value function (4.1) consist in the characterization of the criteria (option) values in a set of 3 linear equations ( $y = mx + b$ ), each with its own (m) and (b) constants. Value functions are built using the current scale determine by the criteria judgment matrix in section 4.3.2. With these functions PESA-AGB model can assign scores to each criteria value, following the experts' judgments.

Figure 4.8 depicts an example of a criteria value function, obtained with the criteria judgment matrix of Figure 4.5.

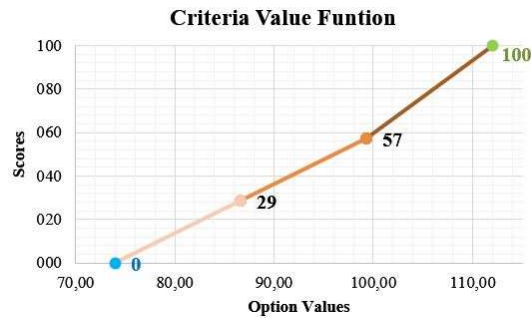


Figure 4.8 - Example of a criteria value function from PESA-AGB model.

Source: Own elaboration.

Judgement matrices (4.2, 4.3 and 4.4) and respective Weight ponderations (4.2.1, 4.3.1 and 4.4.1) are determined using the ordinal value scales (status quo scales) obtained from experts' judgements in section 4.3.2. Firstly, status quo scale is used to reorganised, in a matrix form, the criteria (KPIs), areas (KPAs) and airports from the most relevant to the least relevant ones. Thence, the judgment matrix is filled in a pair-wised comparison using the difference between the ordinal values given by the experts.

Figure 4.9 represent an example of a judgement matrix and respective weight ponderation using the status quo scale.

KPA						KPI's Weights
	KPI 2	KPI 3	KPI 4	KPI 5	Status Quo	
KPI 1	Very Weak	Very Weak	Very Weak-Weak	Weak	Very Strong	0,26
KPI 2		Very Weak	Very Weak	Very Weak-Weak	Strong-Very Strong	0,23
KPI 3			Very Weak	Very Weak	Strong-Very Strong	0,20
KPI 4				Very Weak	Strong	0,17
KPI 5					Moderate-Strong	0,14

Figure 4.9 - Example of a judgement matrix and respective weight ponderation.

Source: Own elaboration.

### 4.3.4 Classification and Outputs

Classification (Step 5) uses the value functions and weight ponderations from step 4 to obtain each KPI, KPA and airport scores for each option (Figure 4.10).

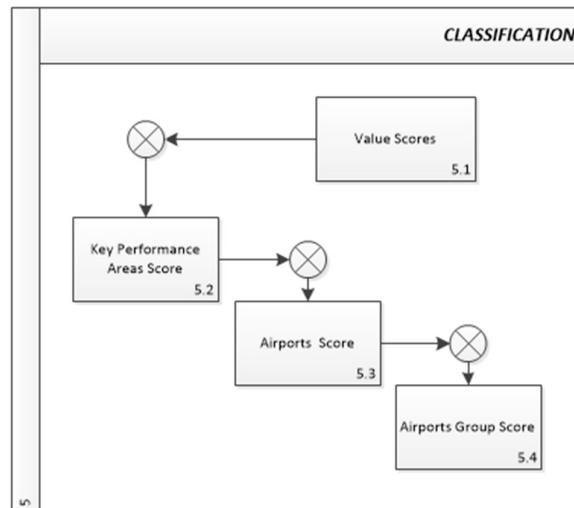


Figure 4.10 - Classification step from PESA-AGB model.

Source: Own elaboration.

Value Scores (5.1) is a simple step which assigns scores to each criteria value. The scores ( $y$ ) are determined using the linear equations ( $y = mx + b$ ) from value functions defined in section 4.3.3.

The next scores determination follow a bottom-up arrangement. KPAs scores (5.2) are determined by multiplying each value score of each criterion from that KPA with its weight ponderation determine in step 4.2.1. Airports scores (5.3) are obtained by multiplying each KPA score (5.2) with its weight ponderation determined in step 4.3.1. Airports group scores (5.4) are calculated multiplying each airport score (5.3) with its weight ponderation determined in step 4.4.1. Table 4.3 depicts an example of a KPA scores table.

Table 4.3 - Example of KPA scores table.

	KPA					KPA Score
	KPI 1	KPI 2	KPI 3	KPI 4	KPI 5	
2003	0,00	0,00	0,00	31,29	0,00	5,36
2007	56,40	72,68	55,10	24,15	45,11	52,72
2013	100,00	100,00	100,00	39,36	83,08	87,19
<b>Weights</b>	<b>0,26</b>	<b>0,23</b>	<b>0,20</b>	<b>0,17</b>	<b>0,14</b>	

Source: Own elaboration.

Outputs (Step 6) produces a wide outputs variety which allows monitoring performance over time. These outputs consist of performance profiles, sensibility analysis, options and difference profiles, and value by KPI, KPA and Airport.

Profiles of (quantitative or/and qualitative) performance can be traced both within and across areas. This allows understanding which year (option) presented the best and the worst profile, as well if the profile exceeded target or neutral values in any criteria or area.

Sensitivity Analysis of the KPI weights in the KPA scores or in the airport score allows the decision maker to observe the cost of increasing or decreasing these weights. This analysis is made in a pairwise form between years (options).

Using the options profile and respective difference profile it is possible to assess the pairwise profile of the options allowing to compare each KPI, KPA or airport between two years.

PESA-GBA model also produces graphics which depicts the ranking of each KPI, KPA, airport and airport group value scores.

Moreover, to better understand PESA-AGB model process a step by step example on how to obtain airport final score depicted in annexe 3.

#### 4.4 Linear Regression and Correlation Coefficient

Linear regression is the study of the relation between a depended variable (y) and one or more independent variables (x). It determines the best-fitting straight to the variables data, which is called linear regression straight. This straight is represented by an equation which relates the depended variable with the independent ones [70]:

$$Y = \beta_0 + \beta_1 X$$

- X - Independent variable;
- Y - Dependent variable;
- $\beta_0$  e  $\beta_1$  - Unknown coefficients determined by the model.

$\beta_0$  e  $\beta_1$  coefficients are determined in a way minimizes the sum of the squared errors of prediction.

Each regressing straight has a coefficient of determination ( $R^2$ ) defined by the ratio of the explained variation to the total variation.

The coefficient of determination can be analysed as a percent. It gives the information of how many data points fall within the linear regression straight. The higher the coefficient, the higher percentage of points the straight passes through [71]. It can be used as a quality measure for the model adjustment to the variables data, meaning that the model is perfectly adjusted for  $R^2=1$ , and poorly adjusted when  $R^2=0$ .

There are many methodologies to determine the correlation between variables. This study uses the Pearson correlation coefficient. This coefficient measures the linear dependence

(correlation) between two variables. It is determined by dividing the covariance of two variables by the product of their standard deviations [72].

Table 1. Correlation coefficients classification.

[0,9; 1]	Very strong positive correlation.
[0,7; 0,9[	Strong positive correlation.
[0,5; 0,7[	Moderate positive correlation.
[0,3; 0,5[	Low positive correlation.
[0; 0,3[	Negligible correlation.

Source: Adapted from [73].

Technically one can calculate a correlation coefficient from a sample of 2. There is no problem having a small sample size. The only difficult thing is to observe or recognise possibly relevant deviations from these assumptions with small samples. But this does not invalidate the test because the test remains valid under these assumptions [74].

## 4.5 Conclusion

In the reviewed literature for this chapter, it was found virtually no studies of multi-criteria decision analysis models that enable managers to measure the performance and efficiency of any airport not only in a global perspective but also to peer-benchmark it within a set of direct competitors or to self-benchmark itself during a certain time period. MACBETH mathematical foundations allowed the development of a PESA-AGB model incorporating a total of forty-two key performance indicators for a global analysis of airport performance and efficiency.

Linear regressions and Pearson correlation coefficients are used to correlate LCCs' traffic with PESA-AGB model outputs, in order to understand the degree of influence that they have in airport's performance.

The methodologies characterized in this chapter are suitable for study in this thesis and they are applying in a set of case studies depicted in the next chapter 5.

# Chapter 5

## Case Studies

### 5.1 Introduction

### 5.2 Airport 1 (Case 1)

#### 5.2.1 LCCs' Traffic Evolution

#### 5.2.2 PESA-AGB Model Outputs

#### 5.2.3 Airport's 1 Performance Correlation with LCCs' Traffic

### 5.3 Airport 2 (Case 2)

#### 5.3.1 LCCs' Traffic Evolution

#### 5.3.2 PESA-AGB Model Outputs

#### 5.3.3 Airport's 2 Performance Correlation with LCCs' Traffic

### 5.4 Airport 3 (Case 3)

#### 5.4.1 LCCs' Traffic Evolution

#### 5.4.2 PESA-AGB Model Outputs

#### 5.4.3 Airport's 3 Performance Correlation with LCCs' Traffic

### 5.5 Analysis of Airport 1, 2 and 3 Case Studies

### 5.6 Conclusion



## 5.1 Introduction

This chapter depicts three main case studies consisting of the performance analysis of three airports and in a correlation analysis between each airport LCCs' traffic (movements and passengers) and its KPAs and overall performance and efficiency scores. These three main case studies follow the same process as described in Figure 5.1.

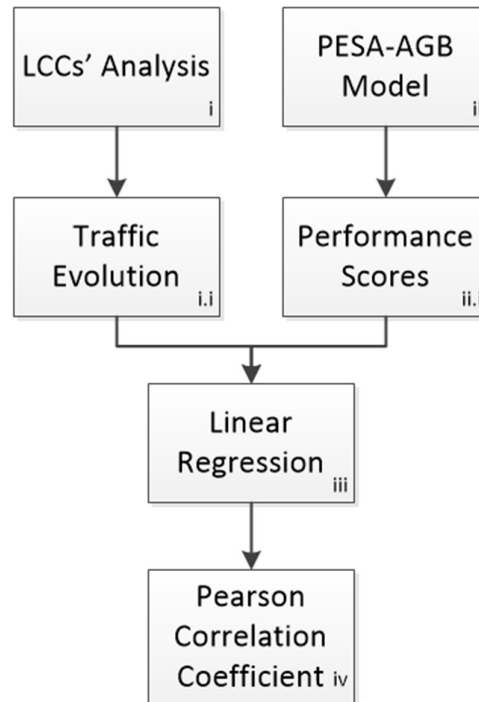


Figure 5.1 - Case studies process.  
Source: Own elaboration.

This process was constructed taking in considerations the scientific questions defined in section 1.2.

***“How airlines traffic evolved? In what way the LCCs’ market share changed?” (Question 4)***

Firstly, to respond to question 4 an LCCs’ traffic analysis is done (i) to characterise the evolution of movements and passengers in each airport (i.i). These two parameters analysis is important because despite some key performance indicators depend on the number of passengers, others depend on the number of movements. Parallel to this step, PESA-AGB model (ii) is applied to a group of three airports in order to obtain its KPAs and overall scores (ii.i), answering to question 5:

***“How airports’ performance and efficiency progressed over the years? Does it follow the same tendency of LCCs’ traffic evolution?” (Question 5)***

***“Is LCCs’ traffic evolution correlated with each airport performance and efficiency scores? In what degree?” (Question 6)***

With steps (i.i) and (ii.i) outputs it possible to answer question 6. For this, a set of linear regressions is tested to identify the possible correlations between the variables (iii), using Microsoft Excel. In the case of significant correlation, an SPSS analysis is done to determine the Pearson correlation coefficients between the variables, answering to the final question (question 7):

***“Do the three case studies produced the same correlation results among the airports?” (Question 7)***

Steps (iii) and (iv) follow a bottom-up process (Figure 5.2), like PESA-AGB model. For the case studies in this work, only step 2 and 3 were conducted. Therefore, Steps (iii) and (iv) start by studying the relation between each airport KPAs scores and LCCs’ traffic and only then studying the relation between each airport overall scores and LCCs’ traffic.

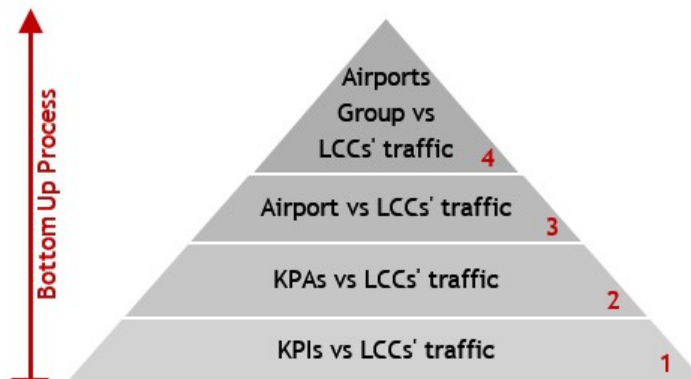


Figure 5.2 - Bottom-up process used to conduct steps (iii) and (iv) analysis.  
Source: Own elaboration.

## **5.2 Airport 1 (Case 1)**

Airport 1 is a fictitious airport comparable to Lisbon airport. It is not considered Lisbon airport due to lack of complete data for all the KPIs of PESA-AGB model. Airport’s 1 data comprises partial data of Lisbon airport, retrieved from public reports, with data from other airports which have a similar dimension in size and operations. (Note that the majority of the data refers to Lisbon airport).

Airport 1 represents the biggest airport in a three-airport group in terms of passengers’ numbers and in strategic relevance for the group managers. It is considered as a hub airport, mainly focused on legacy carriers’ market.

The time-span analysed in this study is eleven years, from 2003 to 2013.

## 5.2.1 LCCs' Traffic Evolution

For LCCs' traffic evolution analysis, all the data refers to Lisbon airport traffic [75]-[83]. Table 5.1 presents all the data collected for the number of passengers and movements, differentiating them by type of carrier from 2003 to 2013.

Table 5.1 - Airport 1 number of passengers and movements from 2003 to 2013.

	Passengers					Movements				
	LCCs		Others		Total	LCCs		Others		Total
2003	150357	2%	9486043	98%	9636400	1277	1%	111223	99%	112500
2004	289417	3%	10159108	97%	10448525	2352	2%	127180	98%	129532
2005	565491	5%	10414605	95%	10980096	4317	3%	126291	97%	130608
2006	1387798	11%	10945750	89%	12333548	11320	8%	125789	92%	137109
2007	2070594	15%	11348153	85%	13418747	16651	11%	128149	89%	144800
2008	2216745	16%	11409613	84%	13626358	18235	13%	126536	87%	144771
2009	1987512	15%	11240447	85%	13227959	15413	11%	120873	89%	136286
2010	1911013	14%	12177943	86%	14088956	14713	10%	127970	90%	142683
2011	2030364	14%	12780803	86%	14811166	14879	10%	128451	90%	143330
2012	2338979	15%	12975767	85%	15314746	17081	12%	127539	88%	144620
2013	2601608	16%	13423347	84%	16024955	18278	12%	128083	88%	146361

Source: Own elaboration based on [75]-[83].

LCCs' traffic in airport 1 doesn't have a big significance in the overall number of passengers and movements. In 2003, LCCs represented 2% and 1% of airport's 1 passengers and movements, respectively. At the end of the time-span analysed LCCs' passengers have grown to 16% and the movements to 12%. Although LCCs' traffic had a visible growth, Figure 5.3 depicts that LCCs' passengers and movements (orange line) present a decline between 2009 and 2011 despite the large growth through 2005, 2006 and 2007.

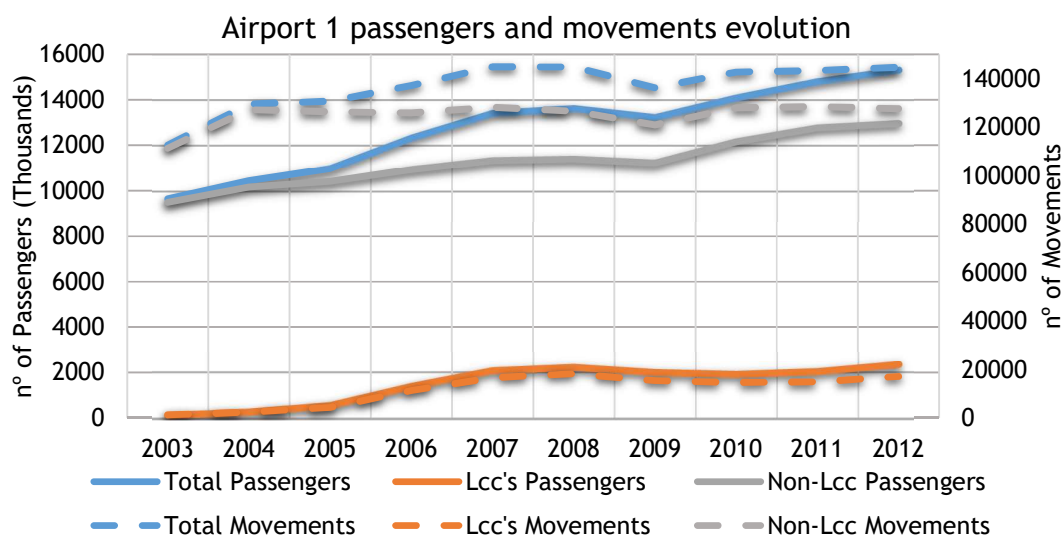


Figure 5.3 - Airport 1 passengers and movements evolution distributed by type of airline.

Source: Own elaboration based on [75]-[83].

From Figure 5.3 we can conclude that, although LCCs contribute for the airport overall traffic (blue line) improvement, it is not the one affecting airport traffic trend. In other words, Non-LCCs' traffic (grey line) is the one defining airport's 1 traffic evolution tendency (direction).

### 5.2.2 PESA-AGB Model Outputs

To assess airport's 1 efficiency throughout an eleven-year span, a large data collection was conducted in order to fill the options table for each of the 41 KPIs [84]-[108].

Conducting all the steps of PESA-AGB model, described in section 4.3, the following scores in Table 5.2 were obtained. Figure 5.4 depicts in a graphic form the scores presented in Table 5.2 and display the ranking of global performance for airport 1 in each year (option).

Table 5.2 - Airport 1 scores table.

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

Source: Adapted from annexe 2.

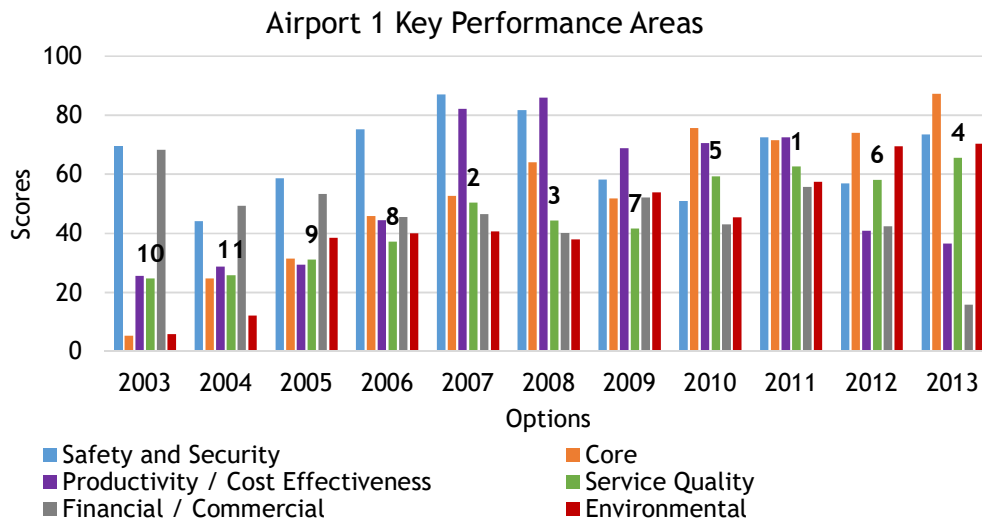


Figure 5.4 - Airport 1 KPAs scores and overall ranking by year.

Source: Adapted from annexe 2.

Table 5.2 and Figure 5.4 depict the efficiency of each KPA from 2003 to 2013. It is possible to identify that in 2011 airport 1 had the highest efficiency score and in 2004 the lowest. This analysis helps understanding airport overall score evolution and to identify the trends in scores variation, as shown in Figure 5.5.

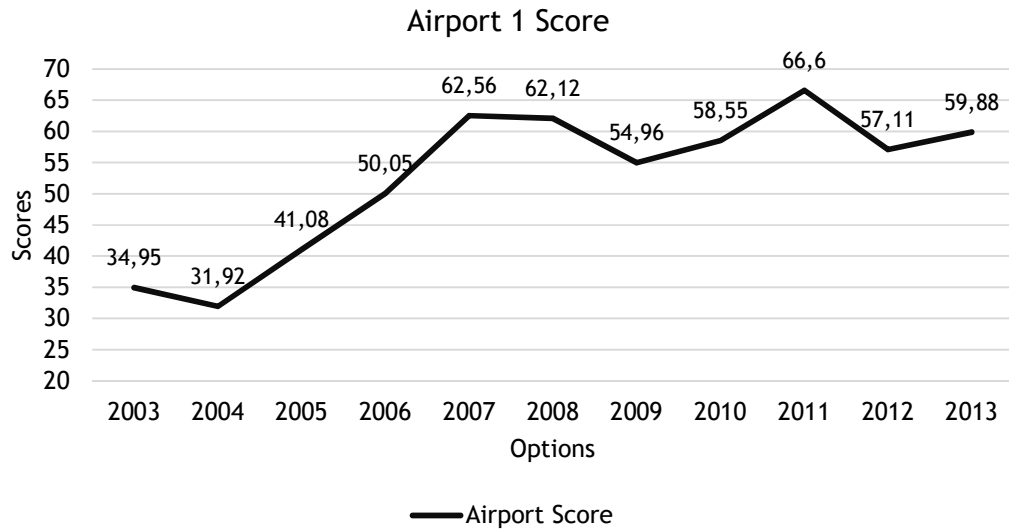


Figure 5.5 - Airport 1 overall scores evolution.

Source: Own elaboration.

Airport 1 scores had the biggest improvement in efficiency from 2004 to 2007, nearly doubling its performance score in just 3 years. This score stabilised between 2007 and 2008. In 2009 there was a decline in of almost 12% in performance being that 2011 register the highest performance score in the time-span analysed, corresponding to 66,60 points.

### 5.2.3 Airport's 1 Performance Correlation with LCCs' Traffic

After analysing airport's 1 traffic and performance evolution was carried out a parameters correlation using linear regressions. This part of the study focuses on identifying the possible correlations between LCCs' traffic data and each one of the airport's 1 KPAs evidenced before.

(i) Safety and Security

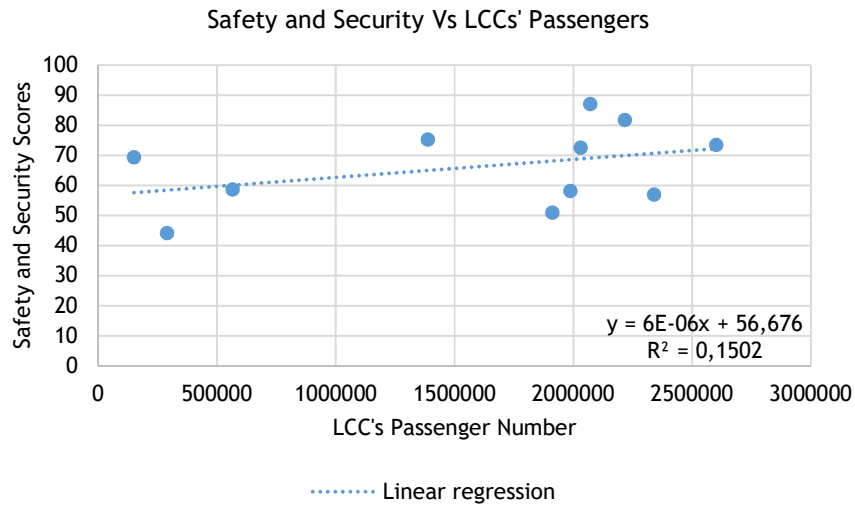


Figure 5.6 - Airport's 1 safety and security KPA scores vs number of LCCs' passengers.

Source: Own elaboration.

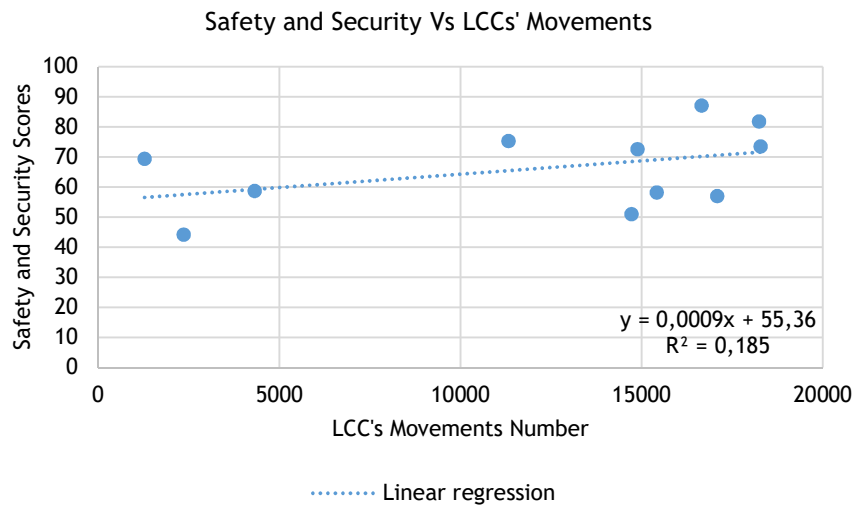


Figure 5.7 - Airport's 1 safety and security KPA scores vs number of LCCs' movements.

Source: Own elaboration.

For both LCCs' passengers (Figure 5.6) and movements (Figure 5.7), it's noticeable that the linear regression straight is far from a 45° angle. The coefficient of determination, in both cases, is lower than 0,19 meaning that only less than 19% of safety and security efficiency scores can be explained by LCCs' traffic variation. Therefore, LCCs' traffic doesn't have or have a very marginal, implication on safety and security scores.

(ii) Core

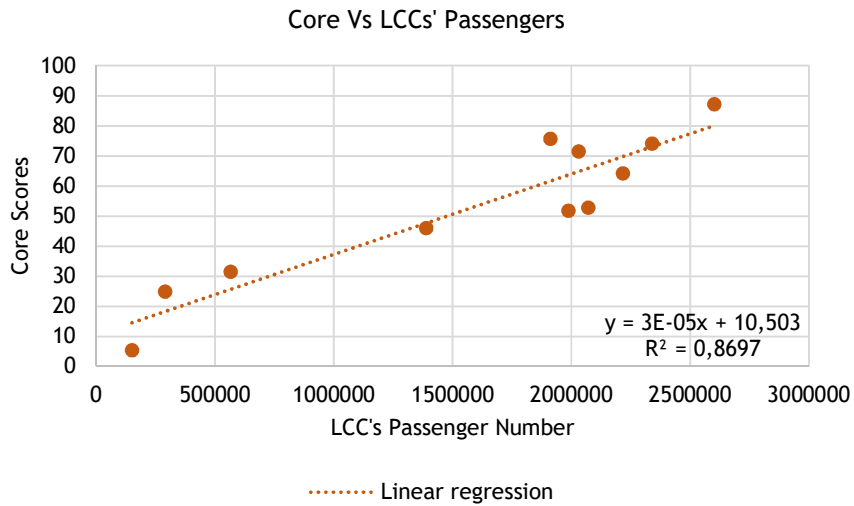


Figure 5.8 - Airport's 1 core KPA scores vs number of LCCs' passengers.

Source: Own elaboration.

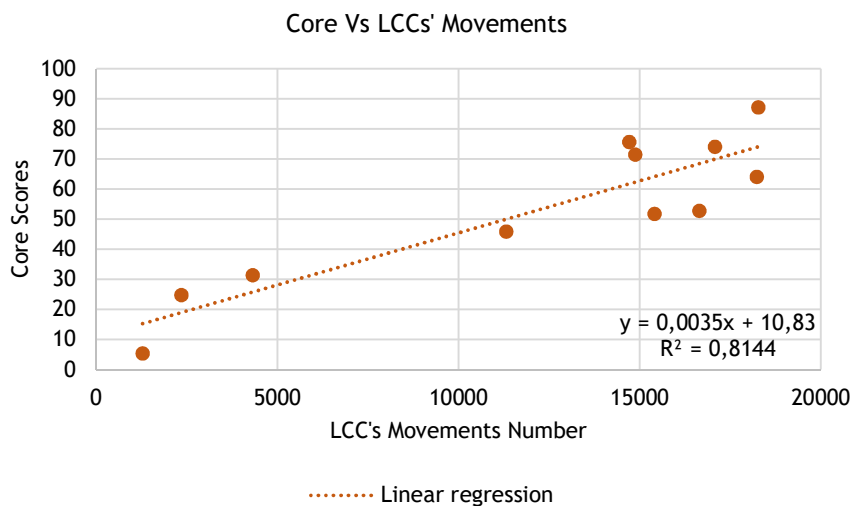


Figure 5.9 - Airport's 1 core KPA scores vs number of LCCs' movements.

Source: Own elaboration.

For both LCCs' parameters analysed (Figure 5.8 and Figure 5.9) the linear regression straight approaches a 45° angle. The coefficient of determination, in both cases, is higher than 0,80 meaning that more than 80% of core efficiency scores can be explained by LCCs' traffic variation. Thus, we can say that LCCs' traffic has a high correlation with core scores.

(iii) Productivity/Cost Effectiveness

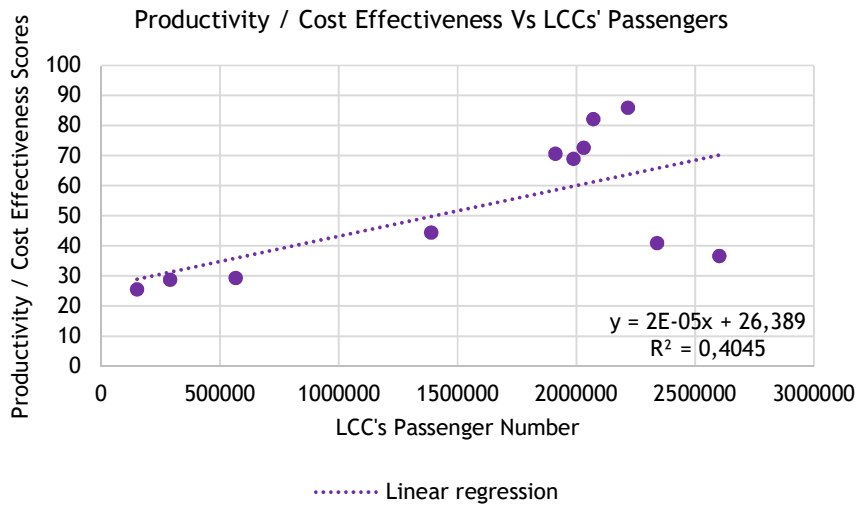


Figure 5.10 - Airport's 1 productivity/cost effectiveness KPA scores vs number of LCCs' passengers.

Source: Own elaboration.

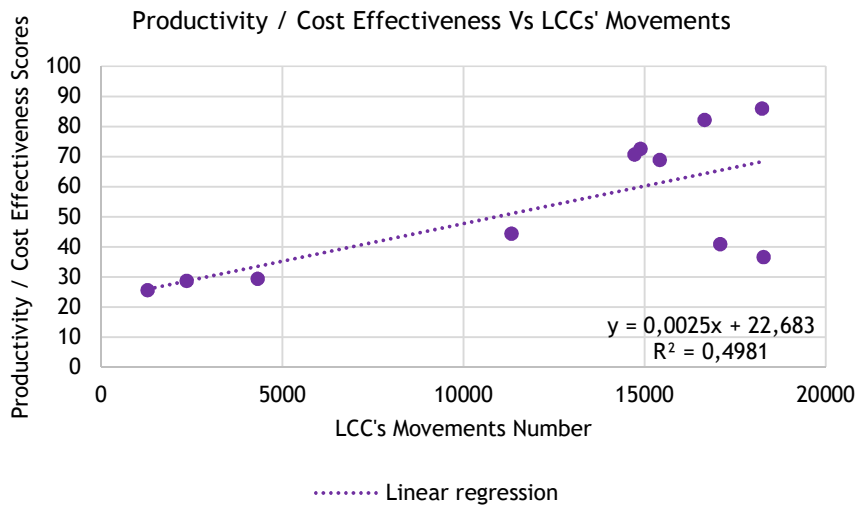


Figure 5.11 - Airport's 1 productivity/cost effectiveness KPA scores vs number of LCCs' movements.

Source: Own elaboration.

The linear regression straight for LCCs' passengers (Figure 5.10) depicts a low coefficient of determination of 0,40. Linear regression of LCCs' movements (Figure 5.11) presents a low-moderate positive coefficient of determination (0,50). This means that in both cases less than 50% of productivity/cost effectiveness efficiency scores can be explained by LCCs' traffic variation. Therefore, LCCs' traffic has a low correlation with productivity/cost effectiveness scores.

## (iv) Service Quality

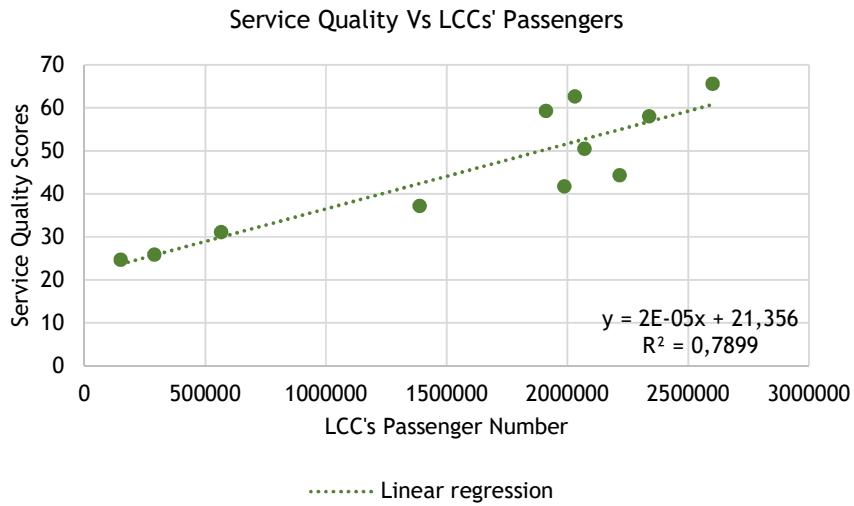


Figure 5.12 - Airport's 1 service quality KPA scores vs number of LCCs' passengers.

Source: Own elaboration.

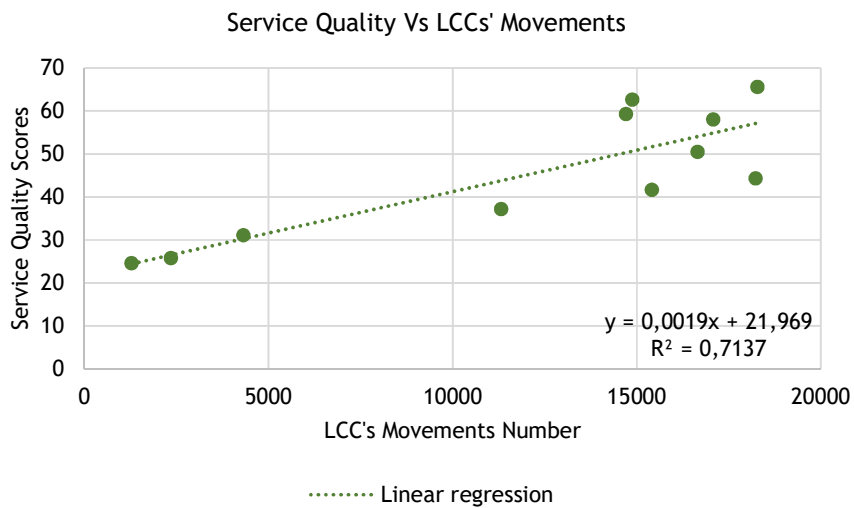


Figure 5.13 - Airport's 1 service quality KPA scores vs number of LCCs' movements.

Source: Own elaboration.

For both LCCs' parameters analysed (Figure 5.12 and Figure 5.13) the linear regression straight have a coefficient of determination higher than 0,71. This means that more than 71% of service quality efficiency scores can be explained by LCCs' traffic variation. Thus, we can say that LCCs' traffic has a strong positive correlation with service quality scores.

(v) Financial/Commercial

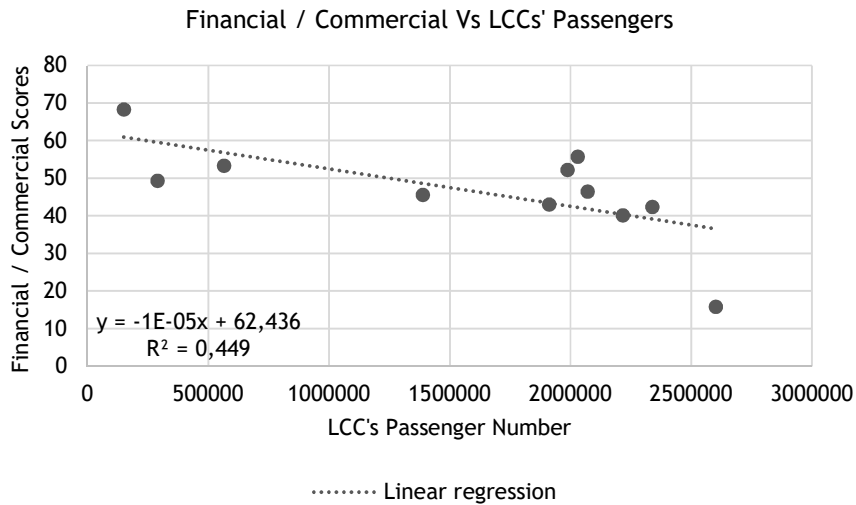


Figure 5.14 - Airport's 1 financial/commercial KPA scores vs number of LCCs' passengers.

Source: Own elaboration.

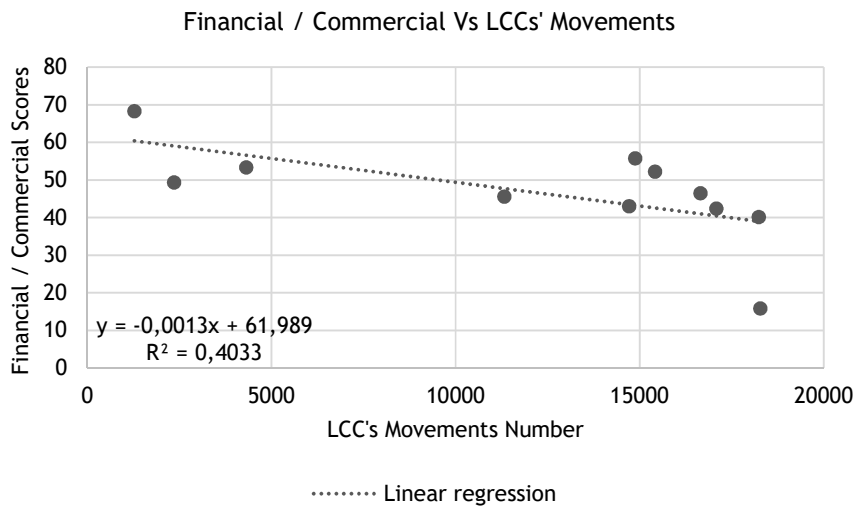


Figure 5.15 - Airport's 1 financial/commercial KPA scores vs number of LCCs' movements.

Source: Own elaboration.

Both linear regression straights of LCCs' passengers (Figure 5.14) and movements (Figure 5.15) depict a negative parameters relation. The coefficient of determination, in both cases, is lower than 0,45 meaning that less than 45% of financial/commercial efficiency scores can be explained by LCCs' traffic variation. Therefore, LCCs' traffic has a low negative correlation with financial/commercial scores.

## (vi) Environmental

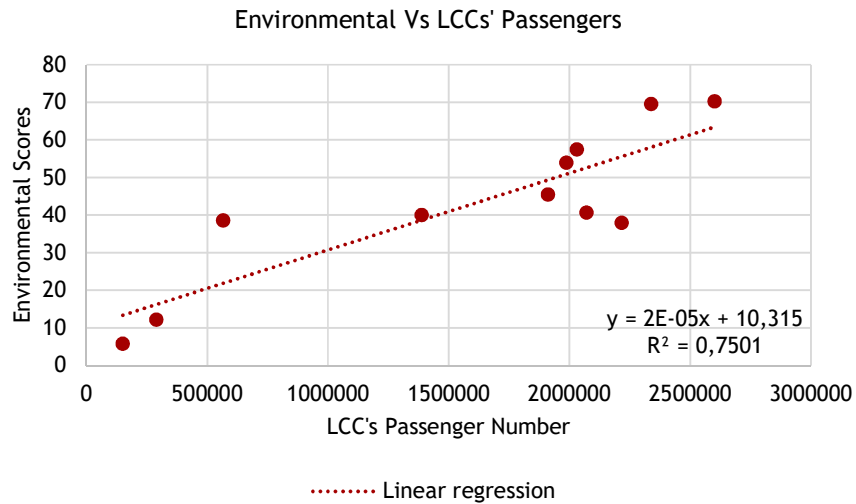


Figure 5.16 - Airport's 1 environmental KPA scores vs number of LCCs' passengers.

Source: Own elaboration.

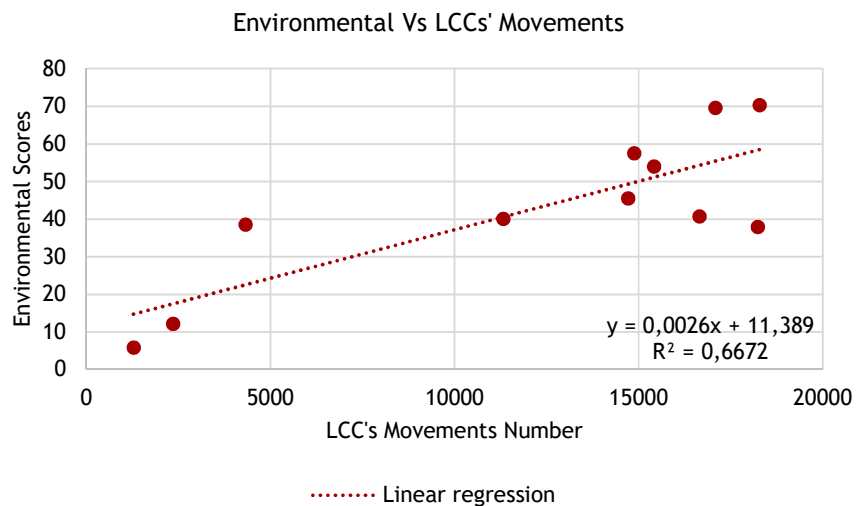


Figure 5.17 - Airport's 1 environmental KPA scores vs number of LCCs' movements.

Source: Own elaboration.

Linear regression straight of LCCs' passengers (Figure 5.16) has a coefficient of determination of 0,75, while the linear regression straight of LCCs' movements (Figure 5.17) depicts a coefficient of determination of 0,67. This means that 75% of environmental efficiency scores can be explained by LCCs' passengers, and 67% of environmental efficiency scores can be explained by LCCs' movements. Thus, we can say that LCCs' traffic has a strong and a moderate positive correlation with environmental scores, for passengers and movements respectively.

(vii) Airport 1 (considering all six KPAs)

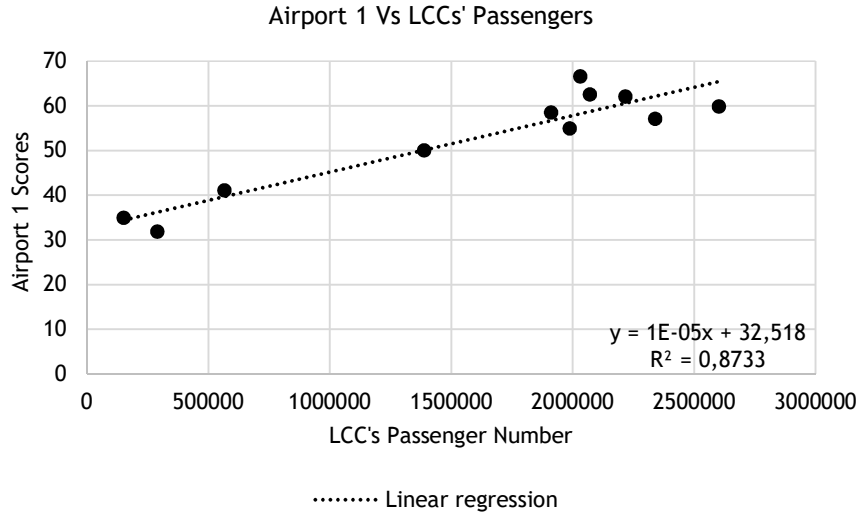


Figure 5.18 - Airport's 1 overall scores vs number of LCCs' passengers.

Source: Own elaboration.

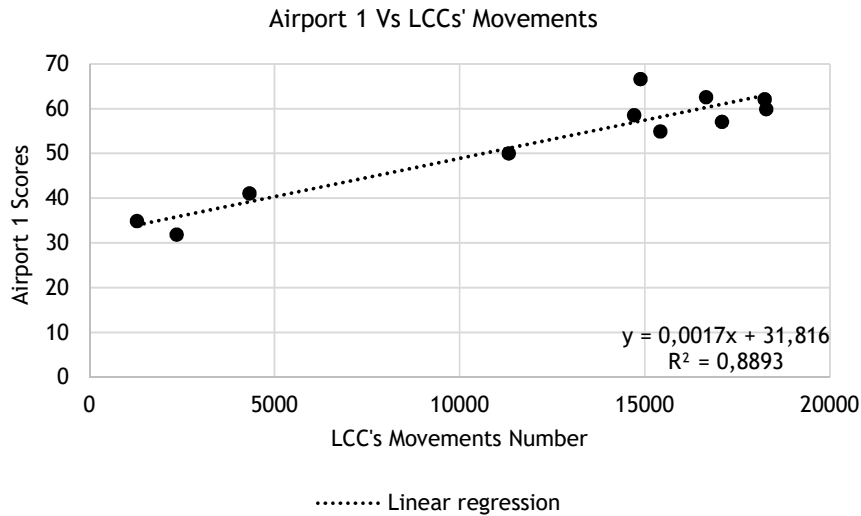


Figure 5.19 - Airport's 1 overall scores vs number of LCCs' movements.

Source: Own elaboration.

For both LCCs' parameters analysed (Figure 5.18 and Figure 5.19) the linear regression straights have a coefficient of determination higher than 0,87. This means that more than 87% of airport's 1 performance and efficiency scores can be explained by LCCs' traffic variation. Thus, we can say that LCCs' traffic has a strong positive correlation with airport's 1 scores.

Table 5.3 resumes all the linear regressions between LCCs' traffic and airport's 1 KPAs and overall scores.

Table 5.3 - Linear correlation between LCCs' traffic and airport's 1 KPAs and overall scores.

	LCCs' Passengers		LCCs' Movements	
	Linear Regression	R <sup>2</sup>	Linear Regression	R <sup>2</sup>
Safety and Security	$y = 6E-06x + 56,676$	0,15	$y = 0,0009x + 55,36$	0,19
Core	$y = 3E-05x + 10,503$	0,87	$y = 0,0035x + 10,83$	0,81
Productivity / Cost Effectiveness	$y = 2E-05x + 26,389$	0,40	$y = 0,0025x + 22,683$	0,50
Service Quality	$y = 2E-05x + 21,356$	0,79	$y = 0,0019x + 21,969$	0,71
Financial / Commercial	$y = -1E-05x + 62,436$	0,45	$y = -0,0013x + 61,989$	0,40
Environmental	$y = 2E-05x + 10,315$	0,75	$y = 0,0026x + 11,389$	0,67
Airport's 1 Overall Score	$y = 1E-05x + 32,518$	0,87	$y = 0,0017x + 31,816$	0,89

Source: Own elaboration.

As considered before, only core, service quality and environmental KPAs' regressions present a significant adjustment to the data, that is, only these airport's 1 KPAs can be considered as having a correlation with LCCs' traffic using this analysis.

When examining airport's 1 overall score linear regression, we can identify a strong adjustment of the model, with the coefficients of determination being 0,87 and 0,89 for LCCs' passengers and movements, respectively.

### 5.3 Airport 2 (Case 2)

Airport 2 is a fictitious airport similar to Porto airport. It is not considered Porto airport due to lack of complete data for all PESA-AGB model KPIs. Airport's 2 data comprises partial data of Porto airport, retrieved from public reports, with data from other airports which have a similar dimension in size and operations (note that the majority of the data refers to Porto airport).

Airport 2 represents the second biggest airport in a three-airport group in terms of passenger's numbers and in strategic relevance for the group managers. It is considered as an airport with mix carriers' market, having both LCCs and legacy carriers.

The time-span analysed in this study is eleven years, from 2003 to 2013.

### 5.3.1 LCCs' Traffic Evolution

For LCCs' traffic evolution analysis, all the data refers to Porto airport traffic [81]-[83], [109]-[116]. Table 5.4 presents all the data collected for the number of passengers and movements, differentiating them by type of carrier from 2003 to 2013.

Table 5.4 - Airport 2 number of passengers and movements from 2003 to 2013.

	Passengers					Movements				
	LCCs		Others		Total	LCCs		Others		Total
2003	0	0%	2675800	100%	2675800	0	0%	41200	100%	41200
2004	22855	1%	2837751	99%	2860606	443	1%	47985	99%	48428
2005	336909	11%	2693201	89%	3030110	2187	4%	47355	96%	49542
2006	679605	20%	2724924	80%	3404529	4689	9%	46862	91%	51551
2007	1247114	31%	2741274	69%	3988388	9015	17%	44396	83%	53411
2008	1821749	40%	2714064	60%	4535813	13059	22%	45076	78%	58135
2009	1972573	44%	2536777	56%	4509350	13709	25%	40398	75%	54107
2010	2628135	50%	2655226	50%	5283361	18270	32%	39020	68%	57290
2011	3247188	54%	2757401	46%	6004589	22074	36%	39573	64%	61647
2012	3354013	55%	2697035	45%	6051048	21944	37%	37271	63%	59215
2013	3623134	57%	2750912	43%	6374046	23189	38%	37057	62%	60246

Source: Own elaboration based on [81]-[83], [109]-[116].

The literature and reports analysed, characterise airport 2 LCCs' traffic as being negligible before 2004. For that reason, in 2003, LCCs' passengers and movements represent 0% of airport's 2 traffic. After 2004, LCCs' passengers increased their market share at an approximately 10% rate per year until 2008. By the end of 2013, LCCs' movements only represented 38% of airport's 2 total movements. However, LCCs' passengers already accounted for more than 50 % of airport's 2 total passengers.

In Table 5.4 is also possible to see that non-LCCs' movements decreased in almost ten thousand movements, while the numbers of non-LCCs' passengers depict very small variations.

However, the number of LCCs' passengers presented a bigger and more rapid growth than LCCs' movements, Figure 5.20 depicts a similar growth trend between LCCs' passengers and movements (orange line).

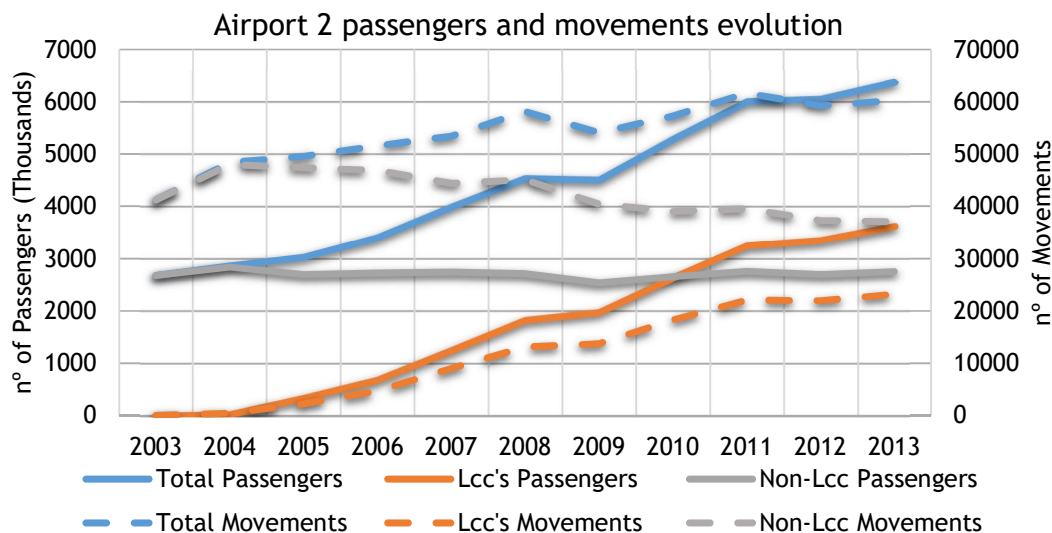


Figure 5.20 -Airport 2 passengers and movements evolution distributed by type of airline.

Source: Own elaboration based on [81]-[83], [109]-[116].

From Figure 5.20 we can also conclude that airport's 2 total number of passengers (blue line) follow the same tendency as LCCs' passengers. This is mainly caused due to the consistent number of non-LCCs' passengers (grey line).

### 5.3.2 PESA-AGB Model Outputs

To assess airport's 2 efficiency throughout an eleven-year span, a large data collection was conducted in order to fill the options table for each of the 41 KPIs [84]-[108].

Conducting all the steps of PESA-AGB model, described in section 4.3, the following Table 5.5 scores were obtained. Figure 5.21 depicts in a graphic form the scores obtained in Table 5.5 and display the ranking of global performance for airport 2 in each year (option).

Table 5.5 - Airport 2 scores table.

	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

	Safety and Security	Core	Productivity / Cost Effectiveness	Service Quality	Financial / Commercial	Environmental	Airport Score
2013	71,35	80,99	52,07	66,16	61,64	90,58	70,11
Weights	21,95%	19,51%	17,07%	14,63%	14,63%	12,20%	

Source: Adapted from annexe 2.

### Airport 2 Key Performance Areas

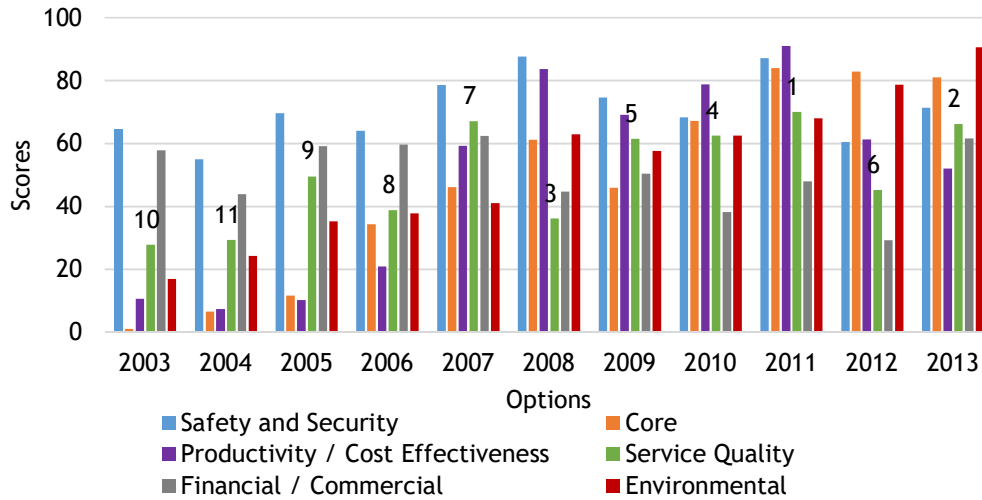


Figure 5.21 - Airport 2 KPAs scores and overall ranking by year.

Source: Adapted from annexe 2.

Table 5.5 and Figure 5.21 depict the efficiency of each airport's 2 KPA from 2003 to 2013. It is possible to identify that, like airport 1, airport 2 had the highest efficiency score in 2011 and the lowest in 2004. This analysis helps understanding airport's overall score evolution and to identify the trends in scores variation, as shown in Figure 5.22.



Figure 5.22 - Airport 2 overall scores evolution.

Source: Own elaboration.

Airport 2 increased its performance scores in more than 35 points between 2004 and 2008, more than doubling its score in 5 years. In 2011, it achieved the highest score of 76,62 points in the time-span analysed. 2011-2012 time period corresponds to the biggest loss in performance score for airport 2, decreasing scores from 76,62 to 60,46 points.

### 5.3.3 Airport's 2 Performance Correlation with LCCs' Traffic

As done in case 1, a parameters correlation using linear regressions was carried out after analysing airport's 2 traffic and performance evolution. This part of the study focuses on identifying the possible correlations between LCCs' traffic data and each one of the airport's 2 KPAs evidenced before.

#### (i) Safety and Security

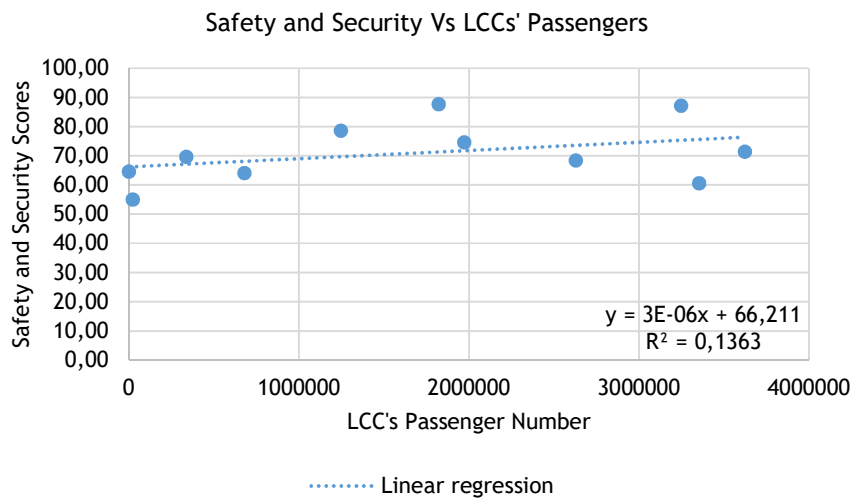


Figure 5.23 - Airport's 2 safety and security KPA scores vs number of LCCs' passengers.

Source: Own elaboration.

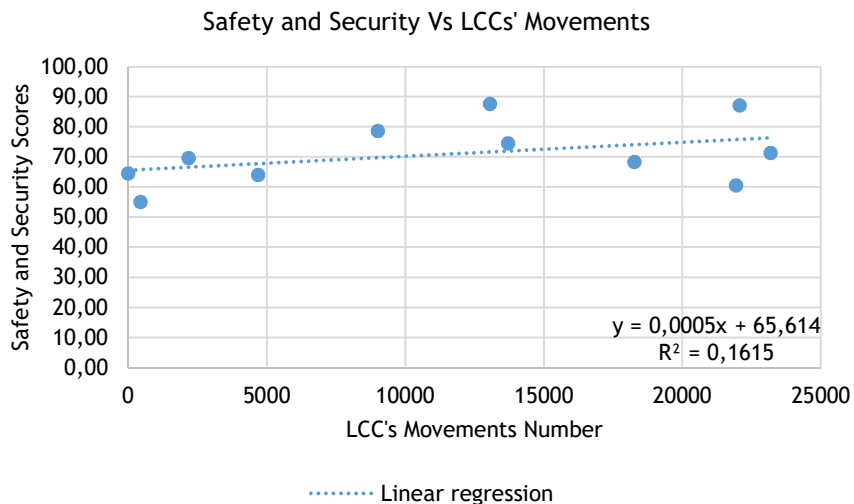


Figure 5.24 - Airport's 2 safety and security KPA scores vs number of LCCs' movements.

Source: Own elaboration.

For both LCCs' passengers (Figure 5.23) and movements (Figure 5.24), it's noticeable that the linear regression straight is far from a 45° angle. The coefficient of determination, in both cases, is lower than 0,17 meaning that less than 17% of safety and security efficiency scores can be explained by LCCs' traffic variation. Therefore, LCCs' traffic doesn't have a significant implication on safety and security scores.

(ii) Core

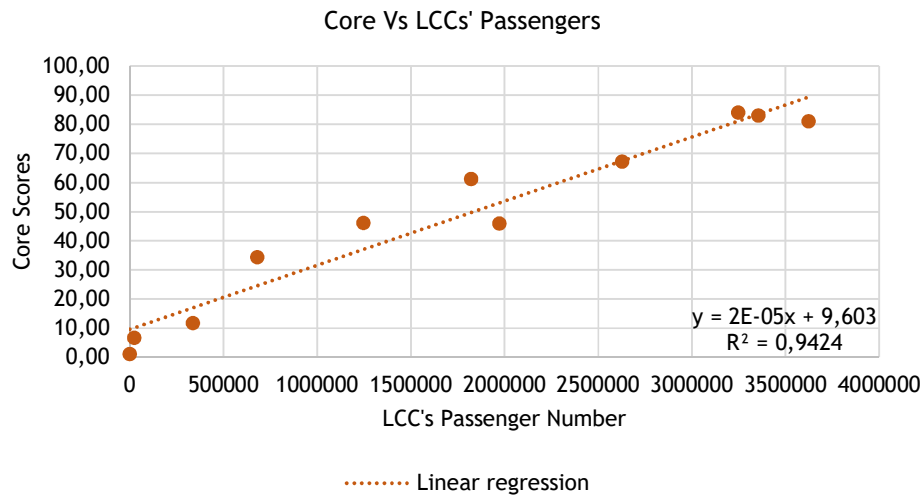


Figure 5.25 - Airport's 2 core KPA scores vs number of LCCs' passengers.

Source: Own elaboration.

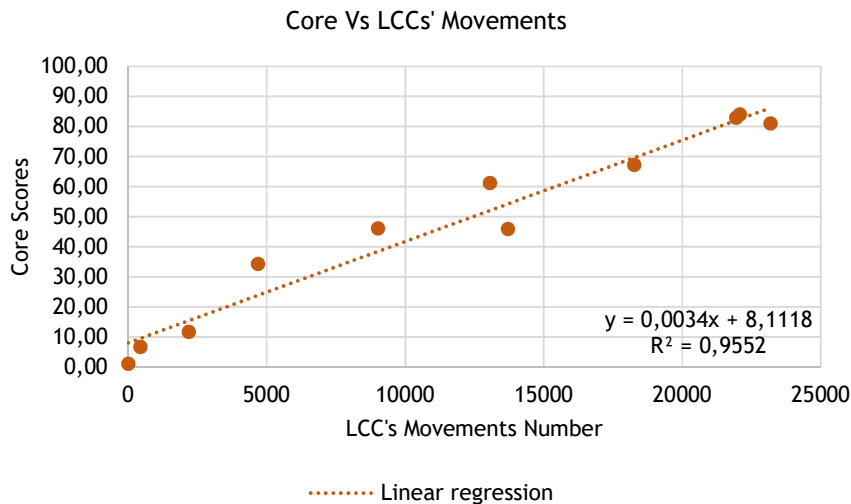


Figure 5.26 - Airport's 2 core KPA scores vs number of LCCs' movements.

Source: Own elaboration.

For both LCCs' parameters analysed (Figure 5.25 and Figure 5.26), the linear regression straight is very close to a 45° angle. The coefficient of determination, in both cases, is higher than 0,94 meaning that more than 94% of core efficiency scores can be explained by LCCs' traffic variation. Thus, we can say that LCCs' traffic has a very strong correlation with core scores.

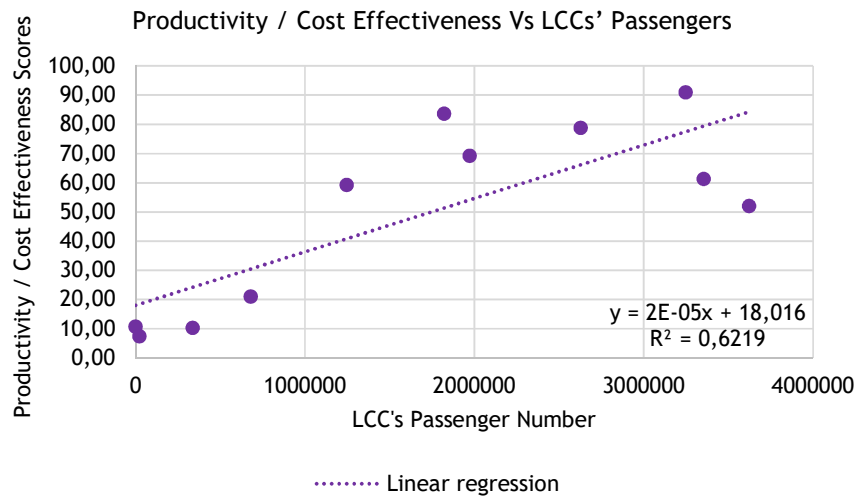
**(iii) Productivity/Cost Effectiveness**

Figure 5.27 - Airport's 2 productivity/cost effectiveness KPA scores vs number of LCCs' passengers.

Source: Own elaboration.

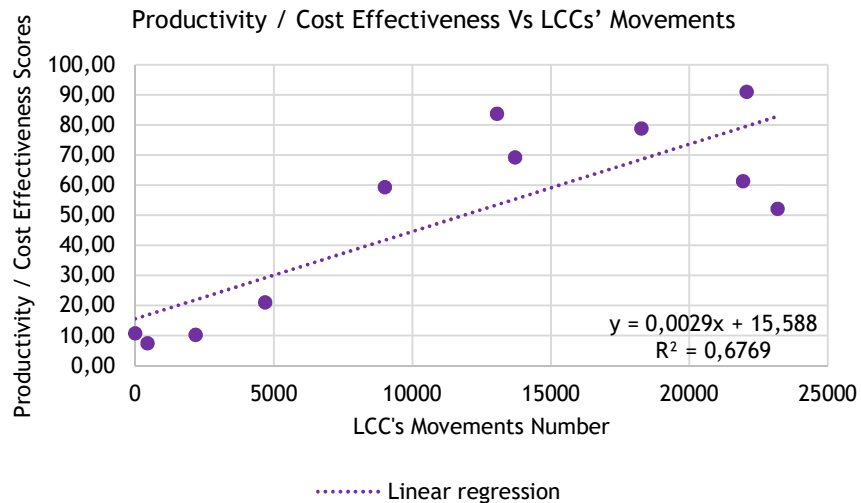


Figure 5.28 - Airport's 2 productivity/cost effectiveness KPA scores vs number of LCCs' movements.

Source: Own elaboration.

The linear regression straight for LCCs' passengers (Figure 5.27) depicts a moderate coefficient of determination, of 0,62. Following, LCCs' movements regression (Figure 5.28) presents a slightly higher moderate coefficient of determination, 0,68. This means that in both cases more than 60% of productivity/cost effectiveness efficiency scores can be explained by LCCs' traffic variation. Therefore, LCCs' traffic has a moderate correlation with productivity/cost effectiveness scores.

(iv) Service Quality

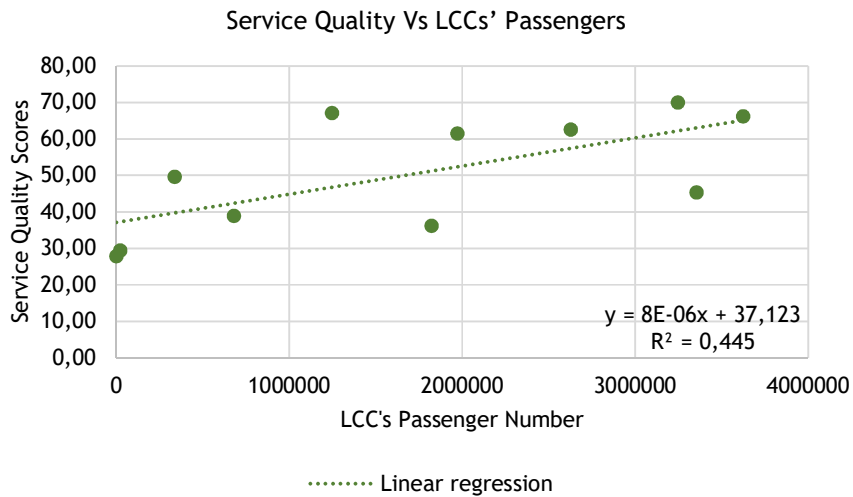


Figure 5.29 - Airport's 2 service quality KPA scores vs number of LCCs' passengers.

Source: Own elaboration.

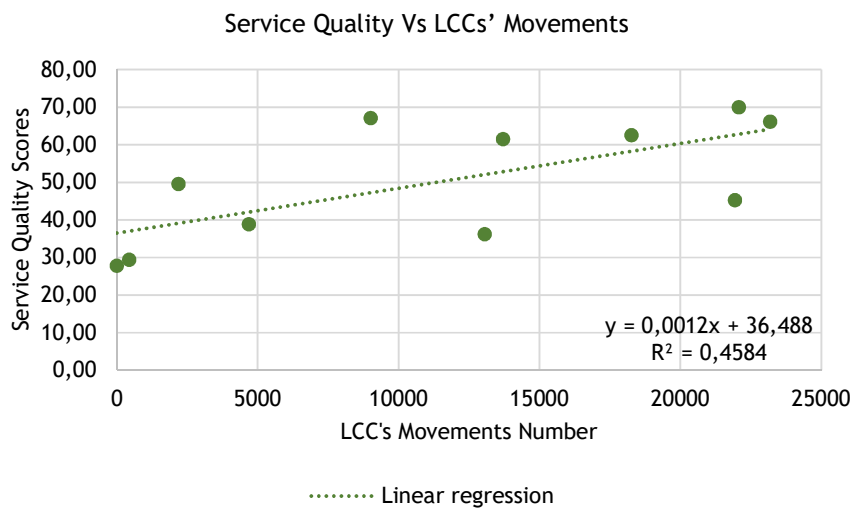


Figure 5.30 - Airport's 2 service quality KPA scores vs number of LCCs' movements.

Source: Own elaboration.

For both LCCs' parameters analysed (Figure 5.29 and Figure 5.30) the linear regression straight have a coefficient of determination of approximately 0,45. This means that 45% of service quality efficiency scores can be explained by LCCs' traffic variation. Thus, we can say that LCCs' traffic has a low positive correlation with service quality scores.

## (v) Financial/Commercial

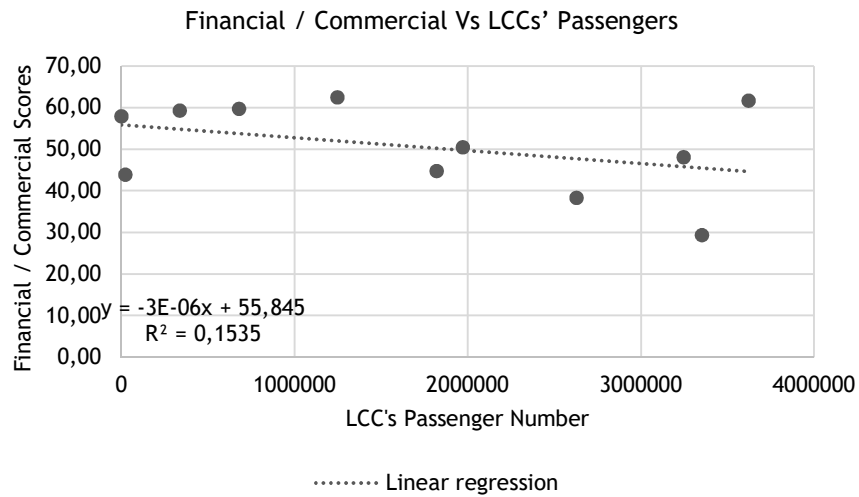


Figure 5.31 - Airport's 2 financial/commercial KPA scores vs number of LCCs' passengers.

Source: Own elaboration.

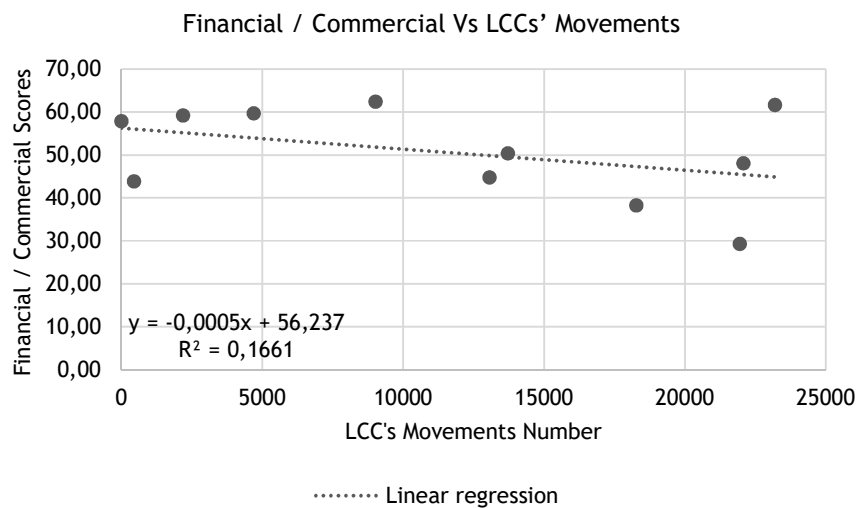


Figure 5.32 - Airport's 2 financial/commercial KPA scores vs number of LCCs' movements.

Source: Own elaboration.

Both linear regression straights of LCCs' passengers (Figure 5.31) and movements (Figure 5.32) depict a negative parameters relation. The coefficient of determination, in both cases, is lower than 0,17 meaning that less than 17% of financial/commercial efficiency scores can be explained by LCCs' traffic variation. Therefore, LCCs' traffic has a low negative correlation with financial/commercial scores.

(vi) Environmental

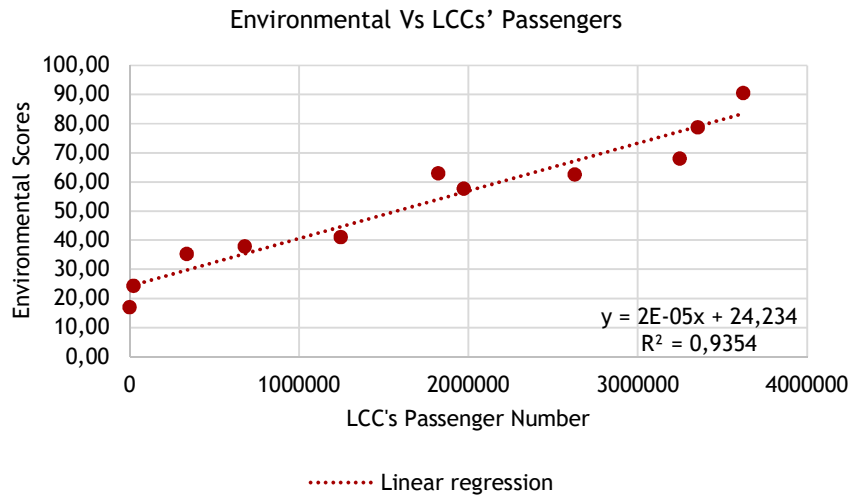


Figure 5.33 - Airport's 2 environmental KPA scores vs number of LCCs' passengers.

Source: Own elaboration.

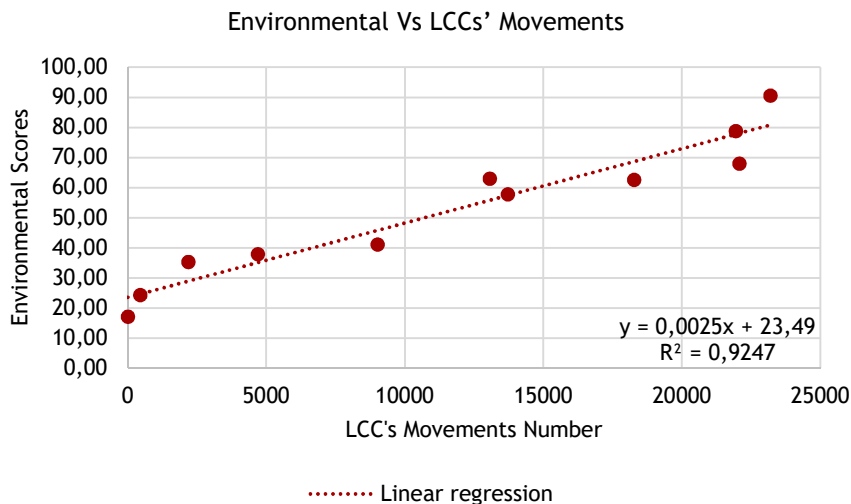


Figure 5.34 - Airport's 2 environmental KPA scores vs number of LCCs' movements.

Source: Own elaboration.

Linear regression straight of LCCs' passengers (Figure 5.33) has a coefficient of determination is of approximately 0,94, while the linear regression straight of LCCs' movements (Figure 5.34) depicts a coefficient of determination of 0,92. This means that 94% of environmental efficiency scores can be explained by LCCs' passengers, and 92% of environmental efficiency scores can be explained by LCCs' movements. Thus, we can say that LCCs' traffic has a very strong positive correlation with environmental scores, for both numbers of passengers and movements.

(vii) Airport 2 (considering all six KPAs)

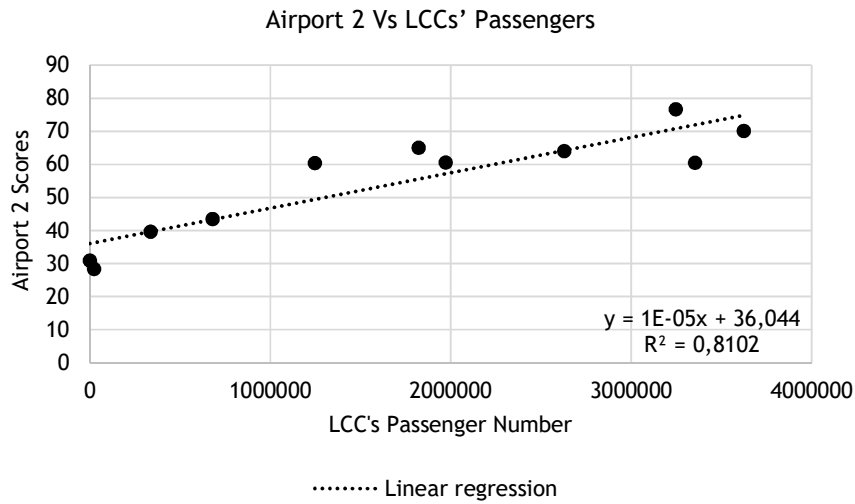


Figure 5.35 - Airport's 2 overall scores vs number of LCCs' passengers.

Source: Own elaboration.

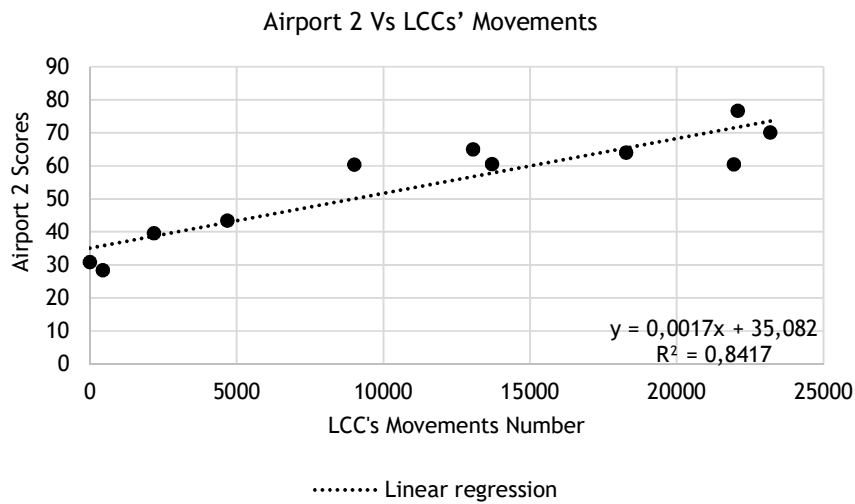


Figure 5.36 - Airport's 2 overall scores vs number of LCCs' Movements.

Source: Own elaboration.

For both LCCs' parameters analysed (Figure 5.35 and Figure 5.36) the linear regression straight have a coefficient of determination higher than 0,81. This means that more than 81% of airport's 2 performance and efficiency scores can be explained by LCCs' traffic variation. Thus, we can say that LCCs' traffic has a strong positive correlation with airport's 2 scores.

Table 5.6 resumes all the linear regressions between LCCs' traffic and airport's 3 KPAs and overall scores.

Table 5.6 -Linear correlation between LCCs' traffic and airport's 2 KPAs and overall scores.

	LCCs' Passengers		LCCs' Movements	
	Linear Regression	R <sup>2</sup>	Linear Regression	R <sup>2</sup>
Safety and Security	$y = 3E-06x + 66,211$	0,14	$y = 0,0005x + 65,614$	0,16
Core	$y = 2E-05x + 9,603$	0,94	$y = 0,0034x + 8,1118$	0,96
Productivity / Cost Effectiveness	$y = 2E-05x + 18,016$	0,62	$y = 0,0029x + 15,588$	0,68
Service Quality	$y = 8E-06x + 37,123$	0,45	$y = 0,0012x + 36,488$	0,46
Financial / Commercial	$y = -3E-06x + 55,845$	0,15	$y = -0,0005x + 56,237$	0,17
Environmental	$y = 2E-05x + 24,234$	0,94	$y = 0,0025x + 23,49$	0,92
Airport's 2 Overall Score	$y = 1E-05x + 36,044$	0,81	$y = 0,0017x + 35,082$	0,84

Source: Own elaboration.

As considered before, only core, productivity/cost effectiveness and environmental KPAs' regressions straights present a significant adjustment to the data, that is, only this airport's 2 KPAs can be considered has having a correlation with LCCs' traffic.

When examining airport's 2 overall scores linear regression, we can identify a strong adjustment of the model, with the coefficients of determination being 0,81 and 0,84 for LCCs' passengers and movements, respectively.

## 5.4 Airport 3 (Case 3)

Airport 3 is a fictitious airport analogous to Faro airport. It is not considered Faro airport due to lack of complete data for all PESA-AGB model KPIs. Airport's 3 data comprises partial data of Faro airport, retrieved from public reports, with data from other airports which have a similar dimension in size and operations (Note that the majority of the data refers to Faro airport).

Airport 3 represents the third biggest airport in a three-airport group in terms of passenger numbers and in strategic relevance for the group managers. It is considered as a base airport mainly focused on LCCs' market.

The time-span analysed in this study is eleven years, from 2003 to 2013.

### 5.4.1 LCCs' Traffic Evolution

For LCCs' traffic evolution analysis, all the data refers to Faro airport traffic [81]-[83], [117]-[122]. Table 5.7 presents all the data collected for the number of passengers and movements, separating them by type of carrier from 2003 to 2013.

Table 5.7 - Airport 3 number of passengers and movements from 2003 to 2013.

	Passengers					Movements				
	LCCs		Others		Total	LCCs		Others		Total
2003	566236	12%	4129764	88%	4696000	4792	15%	27108	85%	31900
2004	1399528	31%	3153229	69%	4552757	13138	38%	21206	62%	34344
2005	2010655	43%	2647771	57%	4658426	17251	48%	18927	52%	36178
2006	2676064	53%	2334571	47%	5010635	21331	55%	17452	45%	38783
2007	3312780	61%	2156209	39%	5468989	23960	60%	16307	40%	40266
2008	3700375	68%	1746825	32%	5447200	25709	65%	14080	35%	39789
2009	3493334	69%	1568467	31%	5061801	23841	64%	13487	36%	37328
2010	4020252	75%	1322455	25%	5342707	27765	70%	11864	30%	39629
2011	4315649	77%	1299931	23%	5615580	29287	72%	11172	28%	40459
2012	4055356	71%	1617021	29%	5672377	26199	66%	13242	34%	39441
2013	4397475	74%	1583973	26%	5981448	28401	69%	13009	31%	41410

Source: Own elaboration based on [81]-[83], [117]-[122].

Airport 3 is the airport analysed which presents the biggest change in traffic from 2003 to 2013. Airport 3 was the first airport of the group to operate with LCCs, representing in 2003 a 12% market share of total passengers and a 15% market share of total movements.

The year 2006 represents the moment when LCCs' traffic, both passengers and movements, surpass the 50% market share of airport's 3 total passengers and movements. LCCs' traffic market share continued to grow, and by 2013 the number of LCCs' passengers represented 74% of airport's 3 total passengers. At that time, the number of LCCs movements achieved a 69% market share.

Figure 5.37 depicts airport 3 number of passengers and movements variation from 2003 to 2013.

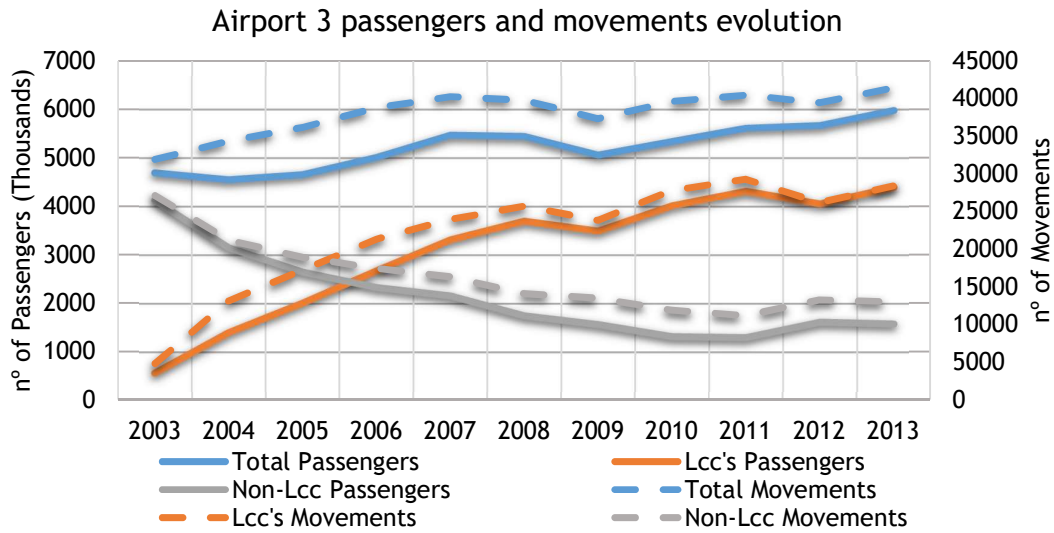


Figure 5.37 - Airport's 3 passengers and movements evolution distributed by type of airline.

Source: Own elaboration based on [81]-[83], [117]-[122].

In

Figure 5.37 we can recognise a rapid LCCs' traffic (orange line) growth from 2003 to 2008. LCCs' traffic also depicts a slight decrease in two time periods: 2008-2009 and 2011-2012. From 2003 to 2013, non-LCCs' traffic (grey line) exhibits a slow, but constant, reduction, except for 2011-2012 period, depicting an opposite evolution of LCCs' traffic. It's also possible to observe that passengers or movements (orange line) seem to be defining airport 3 overall number of passengers and movements (blue line).

### 5.4.2 PESA-AGB Model Outputs

To assess airport's 3 efficiency throughout an eleven-year span, a large data collection was conducted in order to fill the options table for each of the 41 KPIs [84]-[108].

Conducting all the steps of PESA-AGB model, described in section 4.3, the following scores of Table 5.8 were obtained. Figure 5.38 depicts in a graphic form the scores obtained in Table 5.8 and display the ranking of global performance for airport 3 in each year (option).

Table 5.8 - Airport 3 scores table.

	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

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

Source: Adapted from annexe 2.

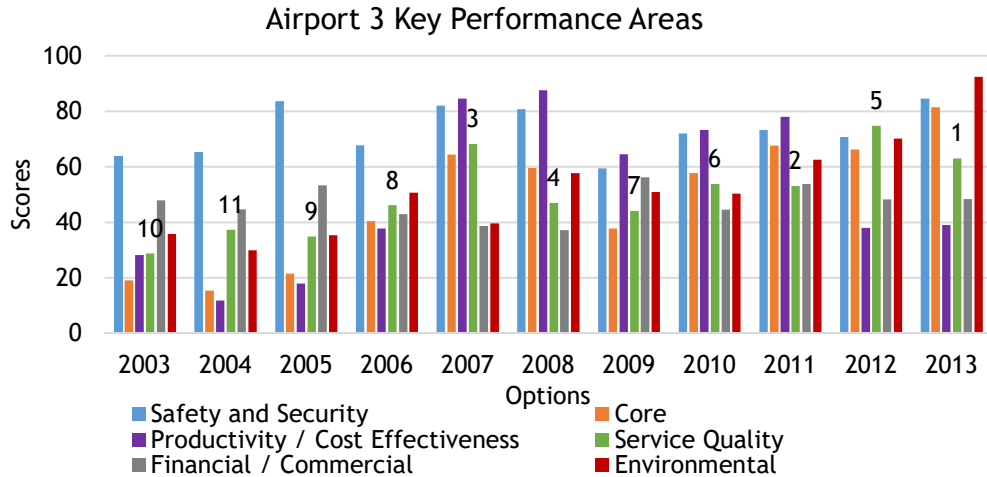


Figure 5.38 - Airport 3 KPAs scores and overall ranking by year.

Source: Adapted from annexe 2.

Table 5.8 and Figure 5.38 depict the efficiency of each KPA from 2003 to 2013. It is possible to identify that in 2013 airport 3 had the highest efficiency score and in 2004 the lowest. This analysis helps understanding airport’s overall score evolution and to identify the trends in scores variation, as shown in Figure 5.39.

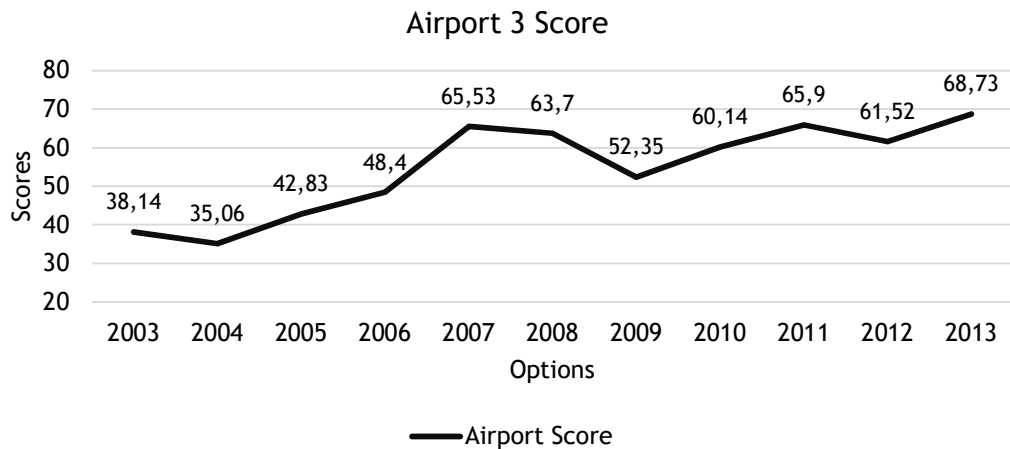


Figure 5.39 - Airport 3 overall scores evolution.

Source: Own elaboration.

Airport 3 scores had the biggest improvement from 2004 to 2007, increasing more than 30 points in just 3 years. After 2007, airport score decreased approximately 20% during two years until 2009. Airport 3 achieved the highest score in 2013, corresponding to 68,73 points.

### 5.4.3 Airport's 3 Performance Correlation with LCCs' Traffic

A parameters correlation using linear regressions was carried out after analysing airport's 3 traffic and performance evolution. This part of the study focuses on identifying the possible correlations between LCCs' traffic data and each one of the airport's 3 KPAs evidenced before.

#### (i) Safety and Security

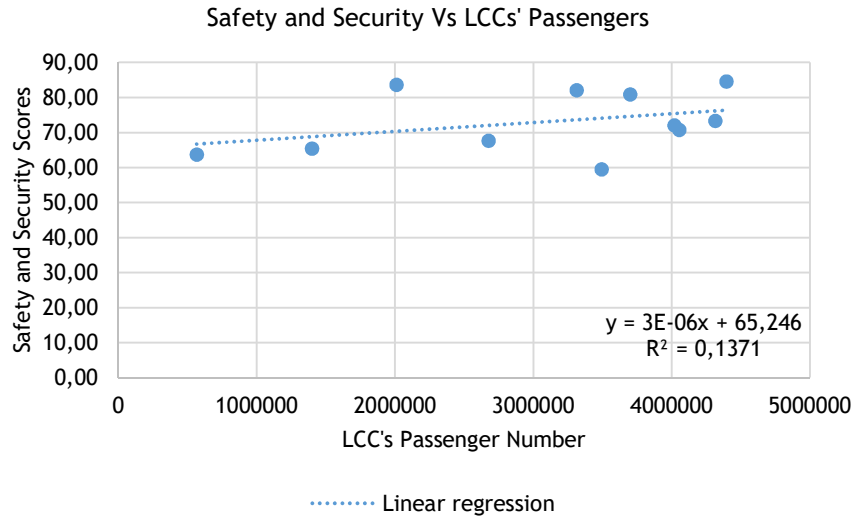


Figure 5.40 - Airport's 3 safety and security KPA scores vs number of LCCs' passengers.

Source: Own elaboration.

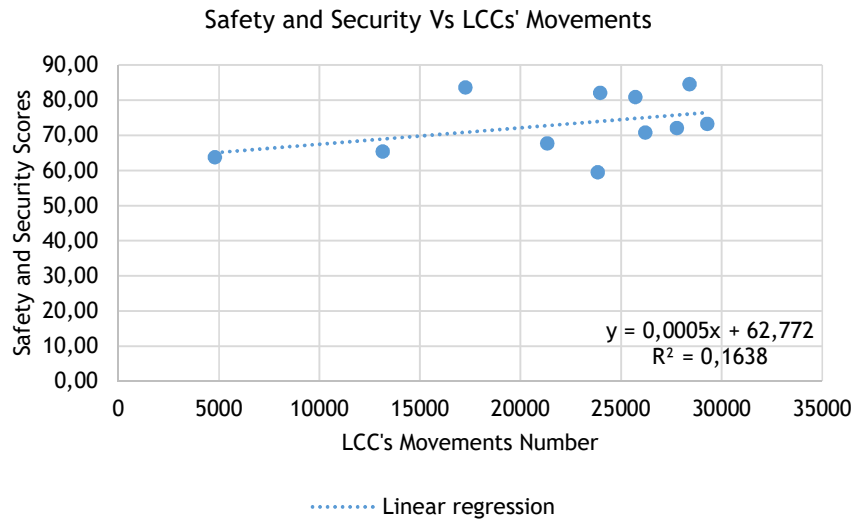


Figure 5.41 - Airport's 3 safety and security KPA scores vs number of LCCs' movements.

Source: Own elaboration.

For both LCCs' passengers (Figure 5.40) and movements (Figure 5.41), it's noticeable that the linear regression straight is far from a 45° angle. The coefficient of determination, in both cases, is lower than 0,17 meaning that only less than 17% of safety and security efficiency scores can be explained by LCCs' traffic variation. Therefore, LCCs' traffic doesn't have a significant implication on safety and security scores.

(ii) Core

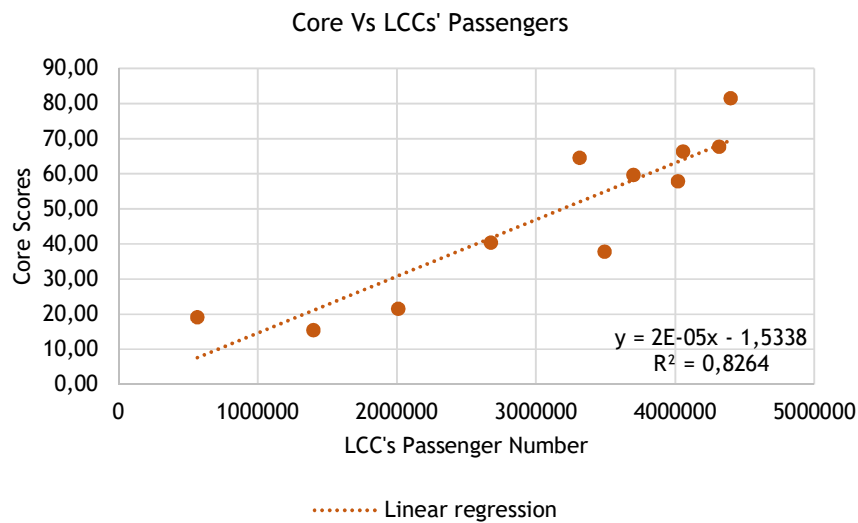


Figure 5.42 - Airport's 3 core KPA scores vs number of LCCs' passengers.

Source: Own elaboration.

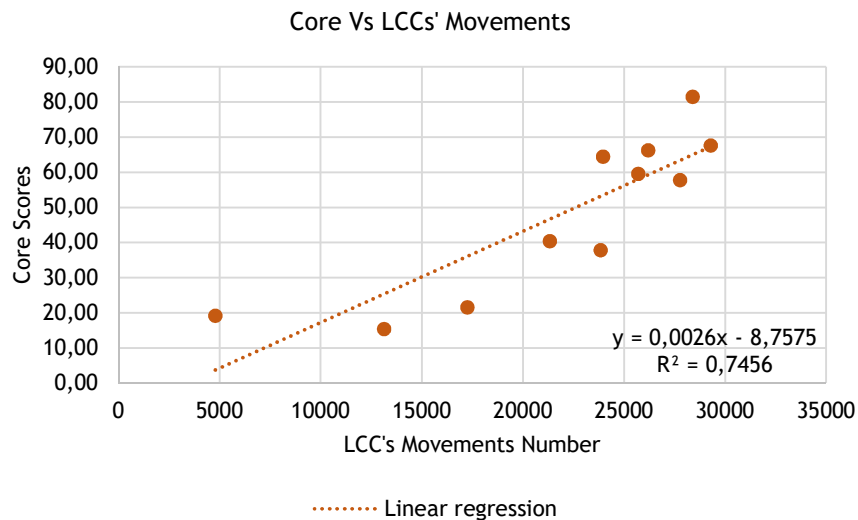


Figure 5.43 - Airport's 3 core KPA scores vs number of LCCs' movements.

Source: Own elaboration.

Linear regression straight of LCCs' passenger (Figure 5.42) has a coefficient of determination is of approximately 0,83, while the linear regression straight of LCCs' movements (Figure 5.43) depicts a coefficient of determination of 0,75. This means that 83% of core efficiency scores

can be explained by LCCs' passengers, and 75% of core efficiency scores can be explained by LCCs' movements. Thus, we can say that LCCs' traffic has a moderate positive correlation with core scores, for both numbers of passengers and movements.

**(iii) Productivity/Cost Effectiveness**

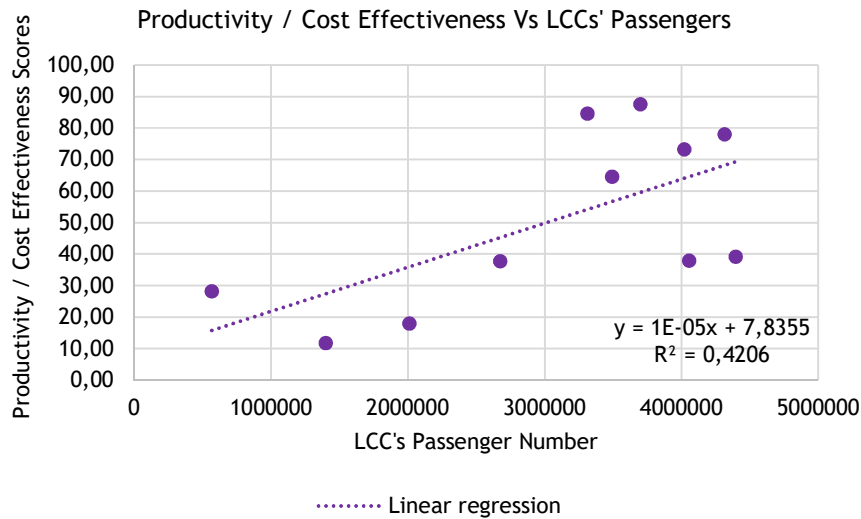


Figure 5.44 - Airport's 3 productivity/cost effectiveness KPA scores vs number of LCCs' passengers.

Source: Own elaboration.

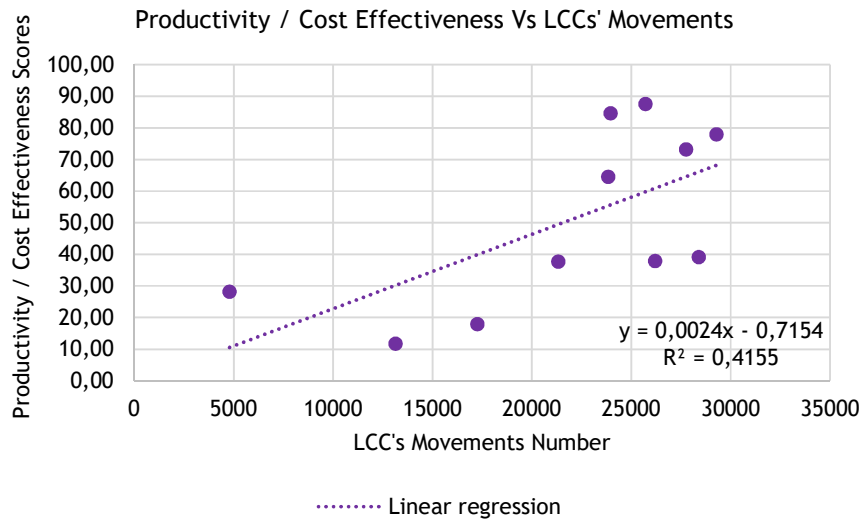


Figure 5.45 - Airport's 3 productivity/cost effectiveness KPA scores vs number of LCCs' movements.

Source: Own elaboration.

The linear regression straights for LCCs' passengers (Figure 5.44) and movements (Figure 5.45) depict a low coefficient of determination, of approximately 0,42. This means that in both cases 42% of productivity/cost effectiveness efficiency scores can be explained by LCCs' traffic

variation. Therefore, LCCs' traffic has a low correlation with productivity/cost effectiveness scores.

(iv) Service Quality

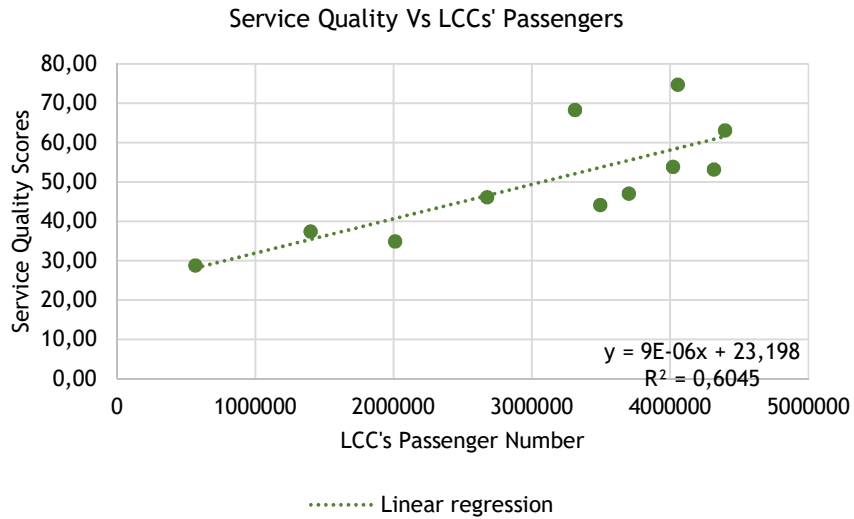


Figure 5.46 - Airport's 3 service quality KPA scores vs number of LCCs' passengers.

Source: Own elaboration.

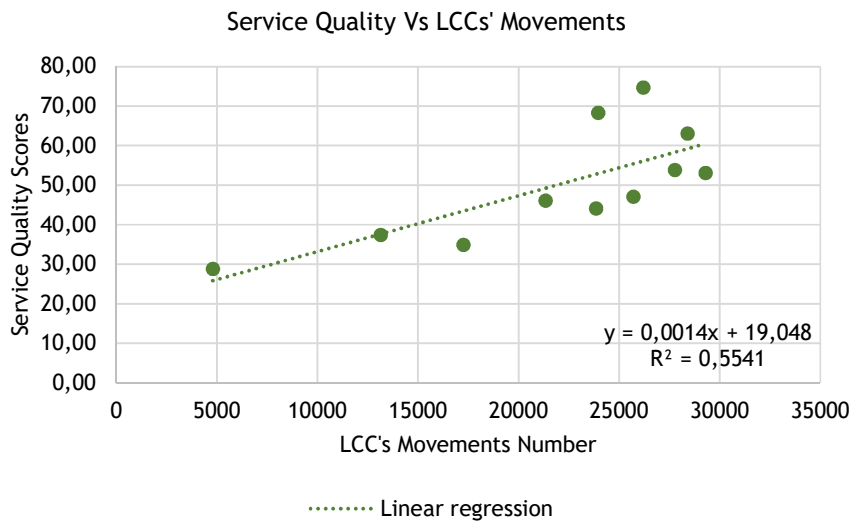


Figure 5.47 - Airport's 3 service quality KPA scores vs number of LCCs' movements.

Source: Own elaboration.

For both LCCs' parameters analysed (Figure 5.46 and Figure 5.47) the linear regression straight have a coefficient of determination is higher than 0,55. This means that more than 55% of service quality efficiency scores can be explained by LCCs' traffic variation. Thus, we can say that LCCs' traffic has a moderate positive correlation with service quality scores.

(v) Financial/Commercial

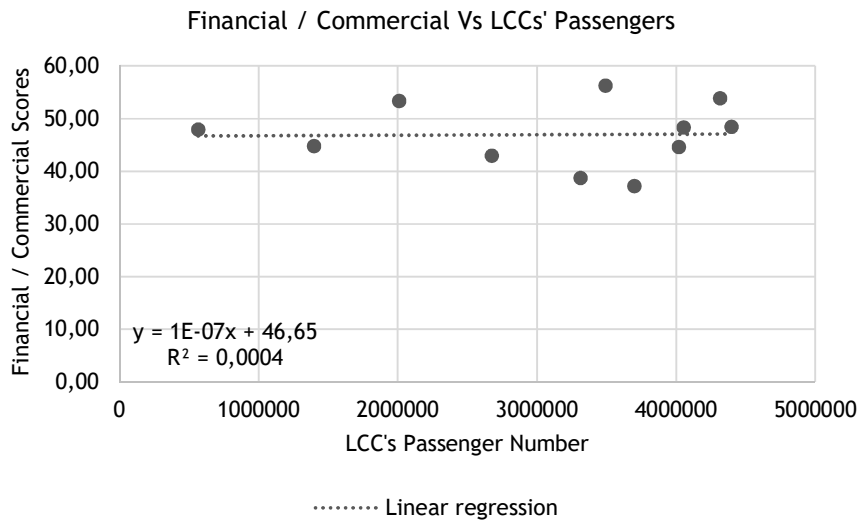


Figure 5.48 - Airport's 3 financial/commercial KPA scores vs number of LCCs' passengers.

Source: Own elaboration.

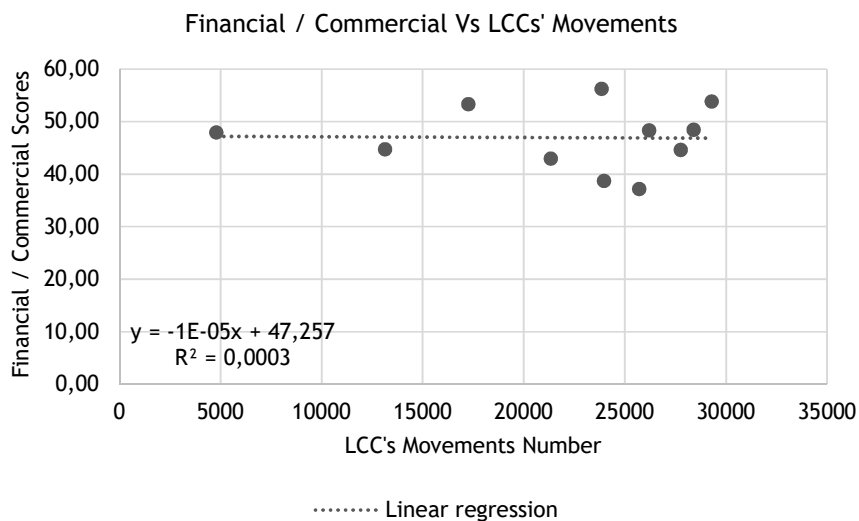


Figure 5.49 - Airport's 3 financial/commercial KPA scores vs number of LCCs' movements.

Source: Own elaboration.

Both LCCs' passengers (Figure 5.48) and movements (Figure 5.49) linear regression straights depict a coefficient of determination of approximately 0, meaning that LCCs' traffic explains none of the variability of financial/commercial scores.

## (vi) Environmental

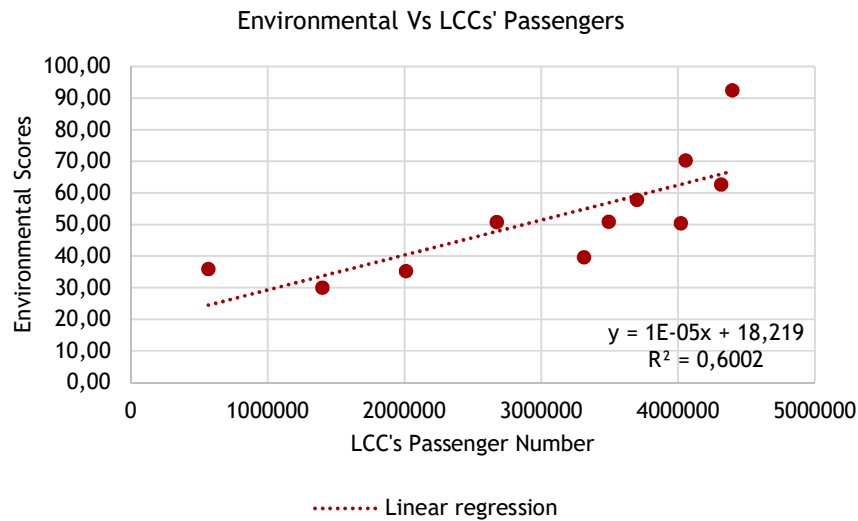


Figure 5.50 - Airport's 3 environmental KPA scores vs number of LCCs' passengers.

Source: Own elaboration.

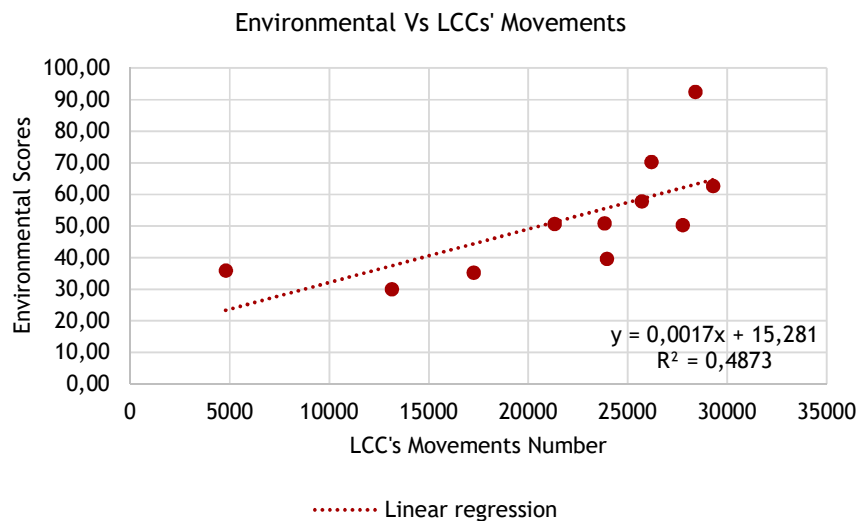


Figure 5.51 - Airport's 3 environmental KPA scores vs number of LCCs' movements.

Source: Own elaboration.

Linear regression straight of LCCs' passengers (Figure 5.50) has a coefficient of determination of 0,60, while the linear regression straight of LCCs' movements (Figure 5.51) depicts a coefficient of determination of 0,49. This means that 60% of environmental efficiency scores can be explained by LCCs' passengers, and 49% of environmental efficiency scores can be explained by LCCs' movements. Thus, we can say that LCCs' traffic has a moderate and a low positive correlation with environmental scores, for passengers and movements respectively.

(vii) Airport 3 (considering all six KPAs)

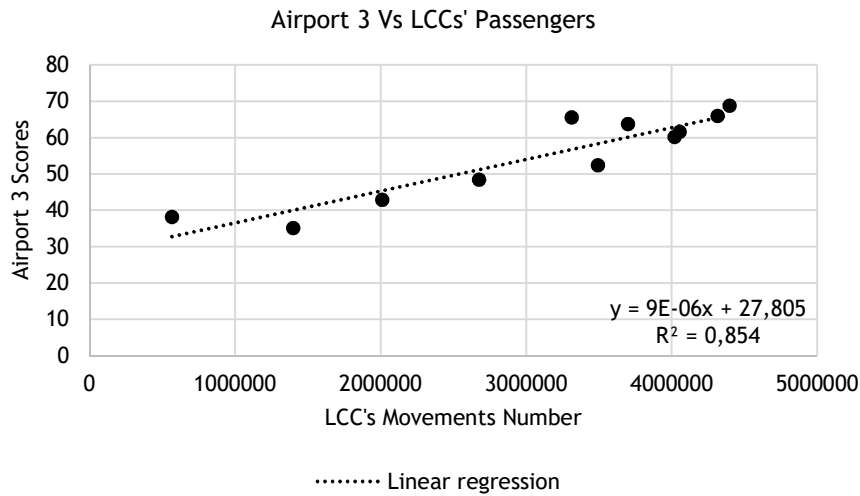


Figure 5.52 - Airport's 3 overall scores vs number of LCCs' passengers.

Source: Own elaboration.

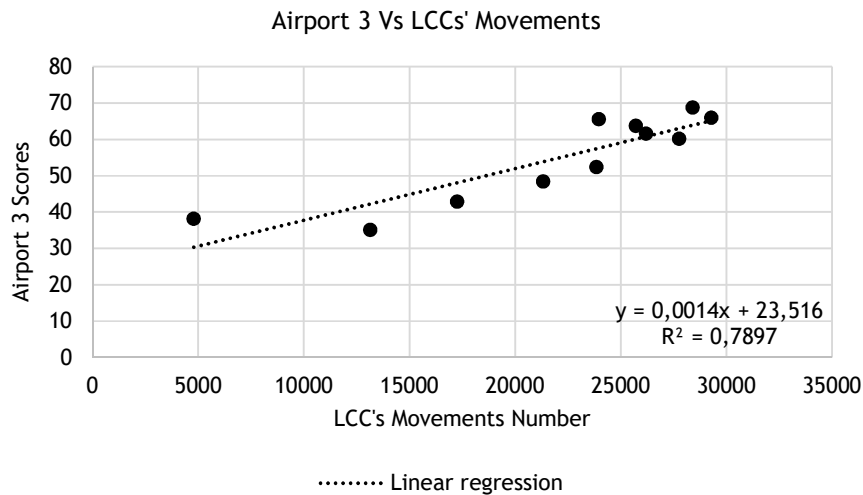


Figure 5.53 - Airport's 3 overall scores vs number of LCCs' movements.

Source: Own elaboration.

For both LCCs' parameters analysed (Figure 5.52 and Figure 5.53) the linear regression straight have a coefficient of determination higher than 0,79. This means that more than 79% of airport's 3 performance and efficiency scores can be explained by LCCs' traffic variation. Thus, we can say that LCCs' traffic has a strong positive correlation with airport's 3 scores.

Table 5.9 resumes all the linear regressions between LCCs' traffic and airport's 3 KPAs and overall scores.

Table 5.9 -Linear correlation between LCCs' traffic and airport's 3 KPAs and overall scores.

	LCCs' Passengers		LCCs' Movements	
	Linear Regression	R <sup>2</sup>	Linear Regression	R <sup>2</sup>
Safety and Security	$y = 3E-06x + 65,246$	0,14	$y = 0,0005x + 62,772$	0,16
Core	$y = 2E-05x - 1,5338$	0,83	$y = 0,0026x - 8,7575$	0,75
Productivity / Cost Effectiveness	$y = 1E-05x + 7,8355$	0,42	$y = 0,0024x - 0,7154$	0,42
Service Quality	$y = 9E-06x + 23,198$	0,60	$y = 0,0014x + 19,048$	0,55
Financial / Commercial	$y = 1E-07x + 46,65$	0,00	$y = -1E-05x + 47,257$	0,00
Environmental	$y = 1E-05x + 18,219$	0,60	$y = 0,0017x + 15,281$	0,49
Airport's 3 Overall Score	$y = 9E-06x + 27,805$	0,85	$y = 0,0014x + 23,516$	0,79

Source: Own elaboration.

As considered before, only core, service quality and environmental KPAs' regressions present a significant adjustment to the data, that is, only these airport's 3 KPAs can be considered as having a correlation with LCCs' traffic using this analysis. When examining airport's 3 overall scores linear regression, we can identify a strong adjustment of the model, with the coefficients of determination being 0,85 and 0,79 for LCCs' passengers and movements, respectively.

## 5.5 Analysis of Airport 1, 2 and 3 Case Studies

Resuming the results of the previous three case studies, we start by analysing LCCs' traffic evolution in all the airports in Figure 5.54.

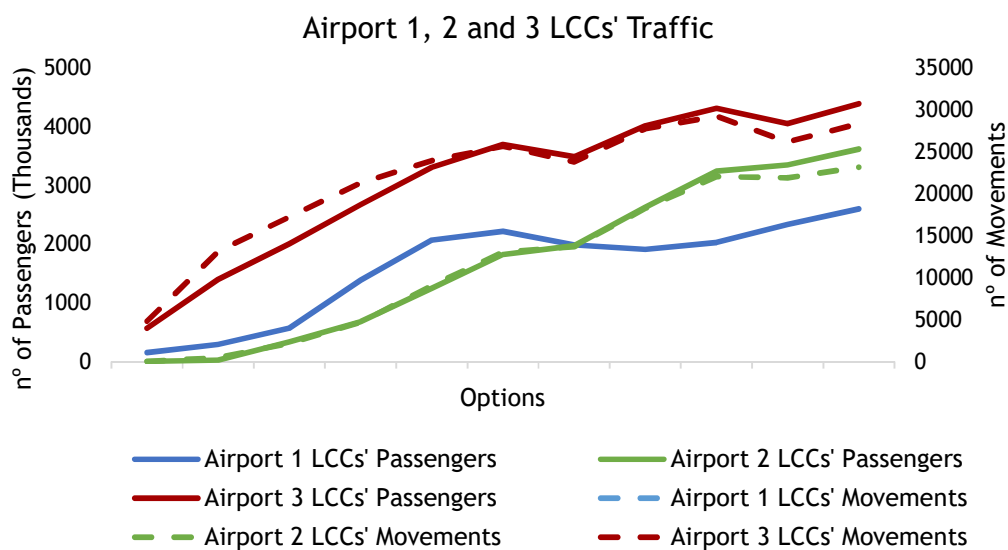


Figure 5.54 - Airport 1, 2 and 3 LCCs' traffic evolution.

Source: Own Elaboration.

Regarding the airports' performance and efficiency scores obtained in PESA-AGB model, Figure 5.55 compares each airport overall scores.

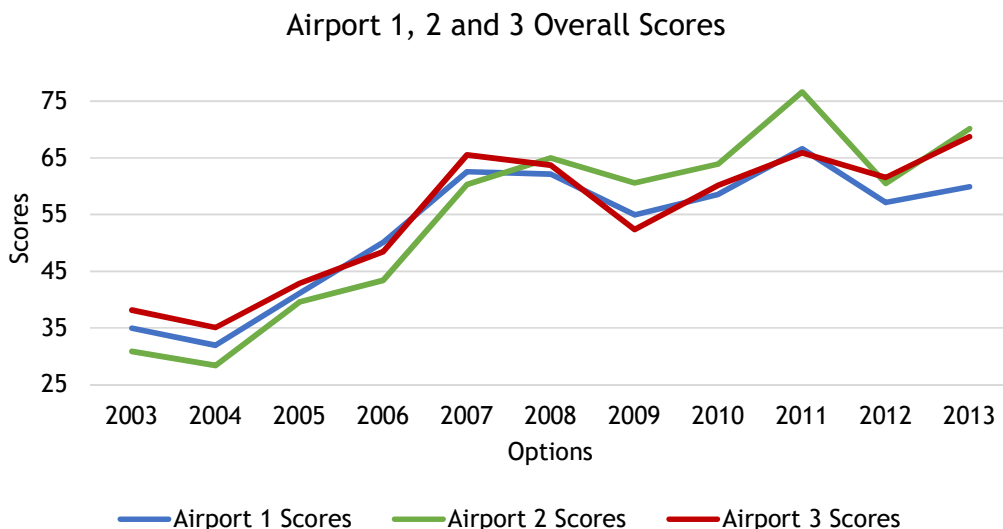


Figure 5.55 - Airport 1, 2 and 3 overall scores.

Source: Own elaboration.

Comparing Figure 5.54 and Figure 5.55, we can determine that there is a tendency similarity between each airport and its LCCs' traffic.

Both airport 1 and airport 3 present a similar traffic trend, with constant growth from 2003 to 2013 aside from 2008-2009 period which represents the biggest traffic decreased, probably due to world financial crisis of 2007-2008. Airport 2 was the only airport from the group to have a continuous traffic growth throughout all 2003-2013 period. However, we can also see that in the 2008-2009 period the growth of LCCs' traffic in airport 3 had a big slow down.

An interesting observation about LCCs' traffic is that, in the previous case studies, LCCs' seems to be more vulnerable to the economic changes in the international markets, but they are also the type of carrier that shows a better recovery.

In terms of performance and efficiency scores, all three airports depict the same evolution tendency. The 2004-2007 period represents the biggest performance increase for all airports. Furthermore, the analysed airports display the same three periods (2003-2004, 2008-2009 and 2011-2012) where their performance and efficiency score went down.

As seen in LCCs' traffic evolution, one of the more probable causes for the decrease in traffic and airport performance is the global financial crises: in 2003 starting as an energy crisis due the inflation of the crude oil price, affecting world economic markets including the air transport market; in 2008 with the 2007-2008 global financial crisis caused initially by the mortgage

market in the USA; and in 2011 with an international stock market crash while the economic market was still affected by the 2007-2008 financial crisis.

Since 2003 until 2007, airport 3 had the best performance and efficiency of the group and airport 2 the lowest. The 2007-2008 global financial crisis had an impact on airports performance and efficiency, leading to a complete game change in these 3 airports group rank in terms of performance and efficiency scores. After this period, the previously lowest performance and efficiency score airport (airport 2) became the airport with the highest score of the group, achieving 76,62 in 2011. A possible reason for this change can be explained by the fact that while airport 1 and 3 traffic had a significant decreased, airport 2 LCCs' traffic continued to grow.

As a result of these observations, a correlation analysis using Microsoft Excel linear regression was used in the previous case studies to identify possible correlations between LCCs' traffic and the airports' KPAs and overall performance and efficiency scores.

Table 5.10 depicts the coefficients of determination between LCCs' traffic and airport 1, 2 and 3 KPAs and overall scores, obtained using Microsoft Excel.

Table 5.10 - Coefficient of determination for linear regressions between LCCs' traffic and airport 1, 2 and 3 KPAs and overall scores.

	Coefficient of Determination (R <sup>2</sup> )					
	Airport 1		Airport 2		Airport 3	
	LCCs' Passengers	LCCs' Movements	LCCs' Passengers	LCCs' Movements	LCCs' Passengers	LCCs' Movements
Safety and Security	0,15	0,19	0,14	0,16	0,14	0,16
Core	0,87	0,81	0,94	0,96	0,83	0,75
Productivity / Cost Effectiveness	0,40	0,50	0,62	0,68	0,42	0,42
Service Quality	0,79	0,71	0,45	0,46	0,60	0,55
Financial / Commercial	0,45	0,40	0,15	0,17	0,00	0,00
Environmental	0,75	0,67	0,94	0,92	0,60	0,49
Airport Score	0,87	0,89	0,81	0,84	0,85	0,79

Source: Own elaboration.

From these results, it's possible to identify core KPA as the only one where more than 75% of its scores can be explained by LCCs' traffic in all three airports. These results were expected since the KPIs of this KPA strongly depend on the two LCCs' parameters analysed.

Airport 1 linear regression straights present a good model adjustment for core, service quality and environmental KPAs, with the coefficients of determination always higher than 0,70.

Airport 2 linear regression straights present a very good model adjustment for core and environmental KPAs, with the coefficients of determination always higher than 0,90. For productivity/cost effectiveness KPA it's also possible to consider a moderate model adjustment since that both LCCs' parameters had a coefficient of determination higher than 0,60.

However, airport 3 only depict a good model adjustment for core KPA, being the coefficients of determination 0,83 and 0,75 for LCCs' passengers and movements, respectively. Service quality and Environmental KPAs exhibit a moderate model adjustment.

Analysing the three airports' overall performance and efficiency score, it's possible to verify that all present a good model adjustment with LCCs' traffic. In general, airport 1 had the highest coefficients of determination, followed by airport 2 and airport 3. All the coefficients of determination were higher than 0,79, meaning that more than 79% of airports overall performance and efficacy scores can be explained by LCCs' traffic.

A new analysis using SPSS Statistical software was conducted in order to obtain not only more reliable results but also to obtain the Pearson correlation coefficient (annexe 4). From this analysis, we obtained the adjusted coefficient of determination ( $R_a^2$ ) for the linear regressions between LCCs' traffic and airport 1, 2 and 3 KPAs and overall scores, as shown in Table 5.11. This new coefficient can be used to better check the adjustment quality of the variables in the model and can also be interpreted as a measure of the model capacity to adapt to other samples of the same population.

Table 5.11 - Adjusted coefficient of determination for linear regressions between LCCs' traffic and airport 1, 2 and 3 KPAs and overall scores.

	Adjusted Coefficient of Determination ( $R_a^2$ )		
	LCCs' Traffic		
	Airport 1	Airport 2	Airport 3
Safety and Security	0,11	0,30	-0,01
Core	0,88	0,95	0,83
Productivity / Cost Effectiveness	0,73	0,97	0,28
Service Quality	0,86	0,35	0,52
Financial / Commercial	0,39	0,04	-0,19
Environmental	0,84	0,92	0,68
Airport Score	0,86	0,89	0,84

Source: Own elaboration based on annexe 4.

Regarding the adjusted coefficients of determination, airport 1 core, productivity/cost effectiveness, service quality and environmental KPAs have a good model adjustment. When compared with the results from Microsoft Excel, SPSS introduced productivity/cost effectiveness KPA in the group of KPAs with a good adjustment.

For airport 2, the KPAs of core, productivity/cost effectiveness and environmental present a very good model adjustment, with the adjusted coefficients of determination being higher than 0,92. Previously, Microsoft Excel determined that productivity/cost effectiveness have a moderate model adjustment, but with the adjusted coefficient of determination 97% of this KPA scores can be explained by LCCs' traffic. This was the highest  $R_a^2$  obtained in this analysis.

Airport 3 continues to only have a good model adjustment for core KPA. However, the adjusted coefficient of determination for environmental KPA is now 0,68, meaning that this KPA has now a moderate model adjustment.

The overall performance and efficiency scores of each airport maintain a good model adjustment. With the adjusted coefficients of determination being 0,86, 0,89 and 0,84 for airport 1, 2 and 3, respectively, we can conclude that at least 84% of the airports' scores can be explained by LCCs' traffic.

All these statistical analyses are associated with a standard error of the estimate. Table 5.12 detail the standard error of the estimate obtain in each analysis.

Table 5.12 - Standard error of the estimate for the linear regressions between LCCs' traffic and airport 1, 2 and 3 KPAs and overall scores.

	Standard Error of the Estimate		
	LCCs' Traffic		
	Airport 1	Airport 2	Airport 3
Safety and Security	12,59%	8,64%	8,73%
Core	8,51%	6,77%	9,45%
Productivity / Cost Effectiveness	12,02%	5,90%	23,30%
Service Quality	5,61%	12,73%	9,84%
Financial / Commercial	10,08%	10,59%	6,64%
Environmental	8,08%	6,35%	10,35%
Airport Score	4,36%	5,45%	4,86%

Source: Own elaboration based on annexe 4.

To quantify the correlation between the studied variables, the Pearson correlation coefficient was determined for each case. Table 5.13 feature all the Pearson correlation coefficients obtain

for each correlation analysis between LCCs' traffic and airport 1, 2 and 3 KPAs and overall scores.

Table 5.13 - Pearson correlation coefficient for linear regressions between LCCs' traffic and airport 1, 2 and 3 KPAs and overall scores.

	Pearson Correlation Coefficient					
	Airport 1		Airport 2		Airport 3	
	LCCs' Passengers	LCCs' Movements	LCCs' Passengers	LCCs' Movements	LCCs' Passengers	LCCs' Movements
Safety and Security	0,39	0,43	0,37	0,40	0,37	0,41
Core	0,93	0,90	0,97	0,98	0,91	0,86
Productivity / Cost Effectiveness	0,64	0,71	0,79	0,82	0,65	0,65
Service Quality	0,89	0,85	0,67	0,68	0,78	0,74
Financial / Commercial	-0,67	-0,64	-0,39	-0,41	0,02	-0,02
Environmental	0,87	0,82	0,97	0,96	0,78	0,70
Airport Score	0,934	0,943	0,90	0,92	0,92	0,89

Source: Own elaboration based on annexe 4.

Airport 1 core KPA have a very strong positive correlation with LCCs' traffic, with the coefficients being 0,93 and 0,90 for LCCs' passengers and movements, respectively. Both service quality and environmental KPAs have a strong positive correlation with LCCs' traffic. Productivity/cost effectiveness KPA has a positive moderate (0,64) and a strong (0,71) correlation with LCCs' passengers and movements respectively. An unexpected result was the correlation coefficients of financial/commercial KPA, presenting a negative moderate correlation with LCCs' traffic. The negative values represent an inverse correlation between the variables, that is, the increase in LCCs' traffic result in the decrease of financial /commercial KPA scores.

Regarding airport 2, core and environmental KPAs have a very strong, almost total, positive correlation with LCCs' traffic, with the coefficients being higher than 0,96. Productivity/cost effectiveness and service quality KPAs have a positive strong and a moderate correlation with LCCs' traffic.

In airport 3 analysis were determined significant correlation for core, productivity/cost effectiveness, service quality and environmental KPAs. Core KPA depict a positive very strong (0,91) and strong (0,86) correlation with LCCs' passengers and movements, respectively. Productivity/cost effectiveness have a positive moderate correlation with LCCs' traffic, while both service quality and environmental KPAs exhibit a strong positive correlation with LCCs' traffic.

Analysing the correlation with LCCs' traffic at an airport overall scores level, we determined that all three airport scores display a very strong positive correlation, despite airport 3 correlation with LCCs' movements which was classified as strong positive correlation. However, this correlation coefficient is 0,89 which despite being in a different classification category is very close to a very strong positive correlation.

## 5.6 Conclusion

The application of PESA-AGB model to the airport data combined with the traffic analysis conducted allowed to obtain the variables needed for this study. The eleven-year period studied represent the period of market entry and bigger expansion of LCCs operation in the three similar main Portuguese airports.

The results indicate a clear correlation between LCCs' traffic and all airports' overall performance and efficiency scores. At KPA level, each airport depicts different KPAs that can be correlated with LCCs' traffic. The KPA which presented the best correlation was core KPA, a resulted already expected due to the KPIs that integrate this KPA.

All three airports analysed depicted the same results trend, evidencing similar levels of correlation in almost all KPAs. However, Airport 1 is the airport that evidence a higher level of correlation between LCCs' traffic and each KPA and overall scores. Airport 3 is the airport with lower correlation coefficients. Nevertheless, the correlation founded between LCCs' traffic and this airport KPAs and overall scores are still alight with the results obtain in the other airports.



# **Chapter 6**

## **Conclusions**

### **6.1 Dissertation Summary**

### **6.2 Concluding Remarks**

### **6.3 Areas for Future Work**



## 6.2 Dissertation Summary

Since the airline market deregulation in Europe, LCCs have been growing at a fast rate and it's expected that this growth continues in the next years. Also, this change in the European airline market has affected the way many airports operate and it's likely that this change impacts not only airports business model but also the way they operate affecting, subsequently its performance and efficiency.

To structure this study, it was initially defined the dissertation objects as being airport's performance and efficiency and LCC's traffic evolution with the main objective of identifying the possible correlations between these two parameters, LCCs' traffic and airport's performance and efficiency.

To accomplish the dissertation main objective, a set of specific objectives were defined in the structure of seven scientific questions:

Question 1 - What is an airport-airline relationship? How did it evolve throughout the years?  
And why?

Question 2 - Why it's necessary to benchmark airports? Which methodologies are currently used and what's their contribution?

Question 3 - How to assess airports' overall performance and efficiency? What statistical analysis is used to determine correlations between variables?

Question 4 - How airlines traffic evolved? In what way the LCCs' market share changed?

Question 5 - How airports' performance and efficiency progressed over the years? Does it follow the same tendency of LCCs' traffic evolution?

Question 6 - Is LCCs' traffic evolution correlated with each airport performance and efficiency scores? In what degree?

Question 7 - Do the three case studies produced the same correlation results among the airports?

To answer question 1 and question 2, a contextualization of the dissertation object was done and divided in two state of the art reviews (chapter 2 and chapter 3). Firstly, it was studied how the air transportation is structured and who are different actors (sectors) in this sector. Each sector of the air transport industry has a specific integration with the other actors. For this study, the most important interaction is the airline-airport relationship. Understanding how this relationship is structured and how it evolved helped to comprehend how airlines can influence business model changes in the airports and the other way around.

In chapter 2 it's also studied the European liberalisation process and how it enables new market opportunities, which reflected on the appearance of LCCs' business models. These models have very specific characteristics that differentiate these carriers from the others, thus a description of the way that LCCs' operate is also made in this chapter.

Being the airports' performance and efficiency also the object of this dissertations, chapter 3 does a characterization of the airport infrastructure and operations. Several factors influence the airports' operations identified in chapter 2, lead to an increased airport competitiveness creating the need for airport benchmarking. As a result, an extensive study defining benchmarking and airport performance analysis are conducted in order to understand the common benchmarking methodologies used to evaluate airports. By analysing each methodologies advantages and disadvantages helped determine the method that best adjusted the objectives of the dissertation.

To later answer questions 4, 5 and 6 it was necessary to define a methodology to assess airport performance and efficiency. An MCDA model (PESA-AGB) was built based on MACBETH mathematical foundations. Chapter 4 presents the mathematical foundations of PESA-AGB model. Moreover, a detailed description of the six steps of PESA-AGB is done. Later in this chapter, it's defined the methodology used to obtain the linear regression and Pearson correlation coefficients.

With the methodologies defined, in chapter 5 are constructed three case studies, one for each airport. The airports chosen for this case studies were based on the three main airports of Portugal (Lisbon, Porto and Faro Airports). Each case study followed the same structure, firstly analysing LCCs' traffic evolution and then applying PESA-AGB model to the airport data to obtain the performance and efficiency scores. With these two variables, a correlation analysis is performed identifying and quantifying the correlations between each airport KPA and LCCs' traffic. The same correlation analysis is repeated but instead of using the KPAs scores as a variable, it's used the airport overall performance and efficiency score.

After analysing the results of each case study, several correlations were determined to answer questions 4, 5 and 6. This study has proven the existence of several correlations between airports performance and efficiency and LCCs' traffic, helping to understand the implication of LCCs' growth on an airport performance level.

### **6.3 Concluding Remarks**

The airline industry liberalisation proved to be a game-change in the air transportation. It created the conditions for a new and more aggressive airline business model to emerge. During the last decades, LCCs have depicted an extreme growth and high profitability. Their operation characteristics centred in cost reductions and high productivity levels have changed the airline-airport relationship. This is one of the factors changing the way airports operate, creating the need for them to increase their performance and efficiency.

Although benchmarking is not a new concept, its application in the air transportation level is somehow scarce, being most the studies focused on only the integration of only some KPAs

and/or KPIs. MCDA allows the analysis airports' performance and efficiency at a global level, considering a large group of KPAs and KPIs.

There is a need for exploration of these methodologies and how they can be improved in order to reduce their weaknesses.

One of the goals of this dissertation was the development and application of an MCDA model that allowed to assess airports' performance and efficiency considering all airport KPA. However, this model has some disadvantages. PESA-AGB model uses a limited group of KPAs and KPIs that allow having a global view of the airport performance but it can still be improved by including a broader set of KPIs. Other disadvantage of PESA-AGB model concerns to the MACBETH methodology used. MACBETH mathematical foundations use a selection of rankings and classifications based on experts' experience and own judgment, therefore the results may be affected by subjective factors. However, this disadvantage can also be considered as an innovative and differentiative factor of the model, because it adds the human factor to the analysis, which other methodologies fail to accomplish. This experts' judgments were obtained through an online survey send for more than 500 specialists from the six KPA of PESA\_AGB model, having received 81 answers with a 95% confidence level and a 10% margin of error. Although this does not affect the quality of the answers received, every increased in answers rate helps to have a broader view of the subjects and to reduce the subjectivity of the judgements.

Another difficulty faced during this work was the collection of data for the 42 KPIs of each airport analysed with of PESA-AGB model. The airports' reports with public access have limited information and their collaboration with this type of studies is very hard to get. Moreover, when the analysis comprising 42 KPIs many of which have a very sensitive nature, as the case of safety and security indicators. However, this difficulty was surpassed by compiling a large group of reports and using reports from similar airports in size and operations.

Regarding the analysis of LCCs' passengers and movements evolution, the data was more accessible helping a rapid characterization of this variables. However, the examined reports depicting the evolution of LCCs' passengers and movements for Porto and Lisbon airports, considered the number of LCC's traffic irrelevant in 2003 and previous years. By using the number 0 even when the variation of data is small, it can induce statistical errors in the correlation analysis. Considering the correlation analysis conducted in the case studies, a limitation identified was the small sample size used. Although the literature does not define a minimum sample size to apply Pearson correlation coefficient, the size sample of 11 is not big enough to represent a big significance of LCCs' traffic and airports' performance and efficiency scores trends.

Nonetheless, passing by all of these difficulties identified during the dissertations, this studies helps to understand how a specific type of airline can be correlated with airport's performance and efficiency and in what KPAs these correlations can be more significant. PESA-AGB showed to be a very useful tool with big versatility, capable of processing big volumes of data and adapting to any type of airport, either in size or in the type of operation.

## 6.4 Prospects for Future Work

Due to the work developed and the acquired knowledge the prospects of future work should be focused on the following items:

- I. Future versions of PESA-AGB model analysis should include new KPAs, as the case of the Hinterland;
- II. Study new statistical methodologies regarding the determination of correlations;
- III. Consider the operational variation of LCC's traffic when analysing its influence in airports' performance and efficiency. One of the factors that should be analysed in future studies is the LCCs' operation seasonality, to understand the differences between airports' performance and efficiency in the high and low seasons;
- IV. Extend the case studies to the other levels of the bottom-up process, understating not only the level of correlation between LCCs' traffic and each one of the 42 KPIs but also with an airports' group overall performance scores;
- V. Introduce also to the correlation study the correlations between LCCs' traffic and socio-economic and tourism KPIs of the airports' hinterland
- VI. Understand how to identify and assess the direct impacts (negative or positive) that LCCs' have in the airports' KPAs and overall performance and efficiency identified has having a correlation;
- VII. Knowing the direct impacts of LCCs' operation in airports' performance and efficiency, construct a predictive model to determine the expected impacts in each KPI, KPA and airport performance and efficacy score due to the introduction of LCCs' operations.

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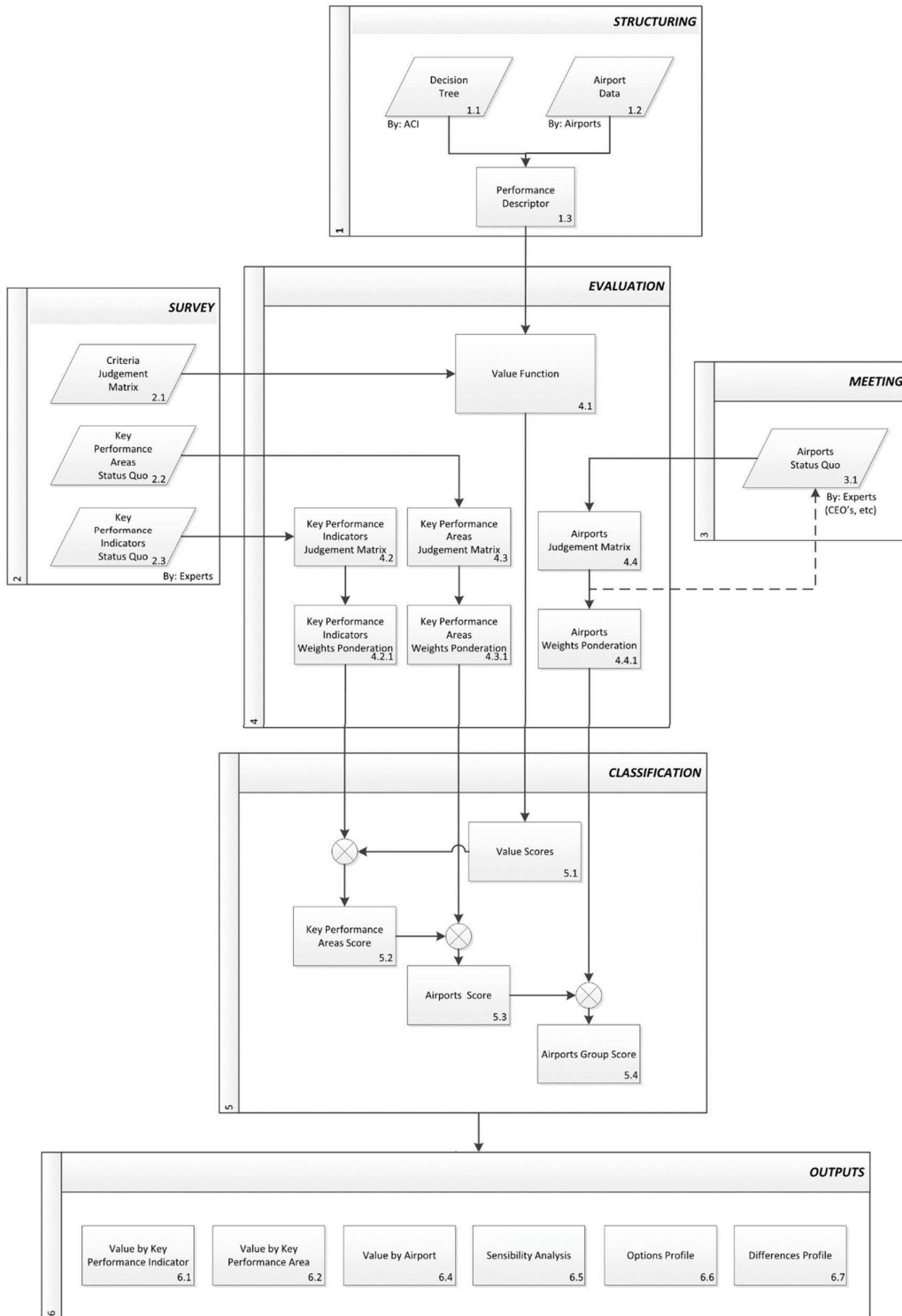
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## **Annexe 1**

### **PESA-AGB Model Flowchart**



## **Annexe 2**

### **PESA-AGB: Scores Outputs**



# PESA-AGB

Score Outputs

Produced by:



Supported by:



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
Weights	21,57%	19,61%	17,65%	15,69%	13,73%	11,76%	

**Core**

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

**Productivity / Cost Effectiveness**

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

**Service Quality**

	Customer Satisfaction	Gate Departure Delay	Baggage Delivery Time	Taxi Departure Delay	Security Clearing Time	Border Control Clearing Time	Check-in to Gate Time	Practical Hourly Capacity	Key Performance Area Score
2003	0,00	39,13	34,81	12,24	12,30	57,14	29,33	18,75	24,64
2004	15,52	0,00	44,68	0,00	2,46	51,13	68,27	43,75	25,83
2005	4,31	22,36	36,36	57,14	29,92	75,19	22,12	9,38	31,09
2006	13,79	91,61	15,06	24,49	0,00	100,00	0,00	57,81	37,23
2007	20,69	97,20	47,27	63,27	29,92	34,59	37,98	71,88	50,50
2008	30,17	54,04	0,00	100,00	11,07	46,62	100,00	18,75	44,32
2009	11,21	69,25	51,95	69,39	19,67	75,19	30,77	0,00	41,72
2010	57,33	100,00	61,04	40,82	100,00	63,91	21,15	9,38	59,34
2011	70,26	80,43	68,83	81,63	59,43	0,00	40,87	85,94	62,66
2012	75,43	7,45	100,00	93,88	3,69	43,61	79,81	57,81	58,06
2013	100,00	40,99	96,10	63,27	18,44	34,59	63,94	100,00	65,64
<b>Weights</b>	<b>15,96%</b>	<b>14,89%</b>	<b>13,83%</b>	<b>12,77%</b>	<b>11,70%</b>	<b>10,64%</b>	<b>10,64%</b>	<b>9,57%</b>	

**Financial / Commercial**

	Aeronautical Revenue per Passenger	Aeronautical Revenue per Movement	Non-Aeronautical Operating Revenue per Passenger	EBITDA per Passenger	Non-Aeronautical Operating Revenue as Percentage of Total	Debt to EBITDA Ratio	Debt Service as Percentage of Operating Revenue	Long-Term Debt per Passenger	Key Performance Area Score
2003	100,00	100,00	100,00	14,45	0,00	100,00	16,08	100,00	68,27
2004	73,83	57,65	63,30	0,00	17,85	88,21	0,00	91,40	49,34
2005	64,06	54,94	75,90	16,10	49,54	80,08	4,16	79,55	53,32
2006	44,19	24,91	47,04	23,36	60,46	81,00	18,25	78,49	45,58
2007	28,36	8,11	26,93	43,72	74,75	85,15	53,18	79,46	46,43
2008	23,62	0,00	17,34	42,36	70,63	79,79	41,25	73,48	40,15
2009	28,58	28,01	47,43	72,97	79,98	84,15	16,85	73,37	52,19
2010	17,06	8,11	18,02	61,60	76,76	83,94	28,82	75,03	42,98
2011	14,69	23,29	5,82	100,00	70,48	89,70	100,00	76,73	55,71
2012	9,01	21,13	7,46	20,88	89,96	90,89	47,32	89,53	42,36
2013	0,00	1,35	0,00	14,05	100,00	0,00	19,33	0,00	15,81
<b>Weights</b>	<b>16,18%</b>	<b>14,71%</b>	<b>13,24%</b>	<b>13,24%</b>	<b>11,76%</b>	<b>11,76%</b>	<b>10,29%</b>	<b>8,82%</b>	

**Environmental**

	Carbon Footprint (TONS/PAX)	Waste Recycling	Renewable Energy Purchased by the Airport (%)	Waste Reduction (%)	Utilities / Energy Usage per Square Meter of Terminal	Water Consumption per Passenger	Key Performance Area Score
2003	0,00	0,00	0,00	15,97	22,40	0,00	5,81
2004	23,75	7,14	3,89	19,89	10,42	4,26	12,15
2005	34,60	17,52	7,77	100,00	0,00	94,68	38,56
2006	52,41	14,41	11,66	0,00	100,00	74,47	40,03
2007	65,54	22,75	15,54	46,08	75,97	10,64	40,65
2008	70,96	35,04	19,43	20,60	56,47	10,64	37,92
2009	75,73	54,59	50,31	15,05	41,89	84,04	53,95
2010	80,87	72,51	58,90	3,82	6,87	23,40	45,50
2011	81,74	100,00	65,03	16,86	15,14	43,62	57,48
2012	90,23	53,19	71,17	38,92	79,01	81,91	69,55
2013	100,00	30,13	100,00	49,19	38,54	100,00	70,29
<b>Weights</b>	<b>21,21%</b>	<b>18,18%</b>	<b>18,18%</b>	<b>15,15%</b>	<b>15,15%</b>	<b>12,12%</b>	

**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
<b>Weights</b>	<b>21,57%</b>	<b>19,61%</b>	<b>17,65%</b>	<b>15,69%</b>	<b>13,73%</b>	<b>11,76%</b>	

**Core**

	Passengers	Aircraft Movements	Origin and Destination Passengers	Freight and Mail Loaded / Unloaded	Destinations - Nonstop	Key Performance Area Score
2003	0,00	0,00	0,00	6,64	0,00	1,14
2004	7,26	13,25	7,10	0,00	2,76	6,71
2005	11,70	18,55	11,43	8,46	5,53	11,77
2006	19,67	31,10	19,26	100,00	8,29	34,34
2007	35,46	50,58	35,15	98,40	11,06	46,16
2008	50,29	78,93	50,65	87,19	35,94	61,18
2009	49,57	58,26	50,23	43,41	16,59	45,92
2010	70,43	75,42	70,56	71,28	38,71	67,21
2011	90,02	100,00	90,01	53,96	75,12	83,99
2012	91,28	88,06	81,20	58,39	91,71	82,95
2013	100,00	87,50	100,00	5,78	100,00	80,99
<b>Weights</b>	<b>25,71%</b>	<b>22,86%</b>	<b>20,00%</b>	<b>17,14%</b>	<b>14,29%</b>	

**Productivity / Cost Effectiveness**

	Total Cost per Passenger	Total Cost per Movement	Operating Cost per Movement	Aircraft Movements per Gate	Total Cost per WLU	Operating Cost per WLU	Operating Cost per Passenger	Passengers Per Employee	Aircraft Movements per Employee	Key Performance Area Score
2003	0,00	0,00	30,70	0,00	10,34	37,93	17,10	0,00	0,00	10,71
2004	12,06	8,00	7,28	13,25	0,00	3,63	0,00	7,61	13,86	7,40
2005	21,53	13,83	2,59	18,55	5,36	0,00	0,49	11,05	15,96	10,26
2006	37,10	31,09	0,00	31,10	25,59	6,37	4,39	19,30	28,91	21,00
2007	55,23	59,65	89,74	50,58	33,70	76,56	78,70	34,88	47,10	59,27
2008	67,45	88,03	100,00	78,93	100,00	100,00	87,20	50,12	76,15	83,71
2009	64,74	54,53	99,88	58,26	57,34	90,19	92,34	48,52	53,03	69,19
2010	85,58	74,24	93,89	75,42	55,15	83,61	96,48	69,82	70,49	78,78
2011	100,00	100,00	94,17	100,00	52,65	78,08	100,00	92,11	100,00	90,99
2012	80,33	17,88	51,74	88,06	18,80	52,91	84,01	91,10	83,35	61,29
2013	83,49	3,90	19,23	87,50	12,23	27,47	73,35	100,00	82,78	52,07
<b>Weights</b>	<b>14,20%</b>	<b>13,10%</b>	<b>12,09%</b>	<b>10,99%</b>	<b>10,99%</b>	<b>10,99%</b>	<b>9,89%</b>	<b>8,70%</b>	<b>8,79%</b>	

**Service Quality**

	Customer Satisfaction	Gate Departure Delay	Baggage Delivery Time	Taxi Departure Delay	Security Clearing Time	Border Control Clearing Time	Check-in to Gate Time	Practical Hourly Capacity	Key Performance Area Score
2003	0,00	42,86	27,88	6,59	35,71	44,02	35,00	43,75	27,85
2004	20,31	58,40	0,00	26,37	0,00	55,60	0,00	85,94	29,45
2005	43,75	47,90	16,52	90,11	89,96	46,33	50,00	9,37	49,58
2006	48,44	0,00	40,28	39,56	45,76	86,10	30,00	29,69	38,90
2007	67,19	65,97	82,96	0,00	73,88	96,53	100,00	57,81	67,11
2008	34,38	81,09	19,62	19,78	16,07	75,68	32,50	0,00	36,19
2009	55,47	100,00	7,23	52,75	79,91	100,00	77,50	18,75	61,51
2010	50,78	69,75	56,80	100,00	27,68	82,63	42,50	71,88	62,54
2011	46,09	92,44	100,00	70,33	100,00	58,30	50,00	29,69	70,00
2012	41,41	50,42	49,57	26,37	65,85	0,00	72,50	57,81	45,29
2013	100,00	42,86	38,21	39,56	79,91	39,38	97,50	100,00	66,16
<b>Weighths</b>	<b>15,96%</b>	<b>14,89%</b>	<b>13,83%</b>	<b>12,77%</b>	<b>11,70%</b>	<b>10,64%</b>	<b>10,64%</b>	<b>9,57%</b>	

**Financial / Commercial**

	Aeronautical Revenue per Passenger	Aeronautical Revenue per Movement	Non-Aeronautical Operating Revenue per Passenger	EBITDA per Passenger	Non-Aeronautical Operating Revenue as Percentage of Total	Debt to EBITDA Ratio	Debt Service as Percentage of Operating Revenue	Long-Term Debt per Passenger	Key Performance Area Score
2003	100,00	46,29	100,00	76,88	0,00	83,38	16,08	0,00	57,86
2004	84,30	37,81	88,70	46,33	17,85	0,00	0,00	53,52	43,89
2005	76,72	35,76	91,98	81,97	49,54	50,22	4,16	72,22	59,23
2006	63,66	28,92	81,59	99,28	60,46	51,40	18,25	70,26	59,73
2007	41,04	17,49	56,40	100,00	74,75	87,25	53,18	90,39	62,42
2008	25,43	3,75	34,33	63,58	70,63	62,87	41,25	81,41	44,76
2009	25,82	13,67	39,96	95,95	79,98	68,25	16,85	80,16	50,42
2010	8,94	5,72	14,86	49,56	76,76	67,59	28,82	85,55	38,31
2011	0,16	0,00	0,00	66,90	70,48	100,00	100,00	100,00	48,05
2012	0,00	6,07	4,20	0,00	89,96	42,81	47,32	83,65	29,32
2013	54,26	100,00	1,45	52,91	100,00	78,44	19,33	90,45	61,64
<b>Weighths</b>	<b>16,18%</b>	<b>14,71%</b>	<b>13,24%</b>	<b>13,24%</b>	<b>11,76%</b>	<b>11,76%</b>	<b>10,29%</b>	<b>8,82%</b>	

**Environmental**

	Carbon Footprint (TONS/PAX)	Waste Recycling	Renewable Energy Purchased by the Airport (%)	Waste Reduction (%)	Utilities / Energy Usage per Square Meter of Terminal	Water Consumption per Passenger	Key Performance Area Score
2003	0,00	0,00	0,00	53,40	59,02	0,00	17,03
2004	16,30	10,42	3,89	39,19	76,71	5,78	24,32
2005	37,82	27,30	7,77	19,07	100,00	23,54	35,29
2006	43,31	43,04	11,66	22,53	47,84	66,50	37,85
2007	49,88	62,05	15,54	0,00	44,95	78,89	41,06
2008	66,58	75,45	19,43	100,00	48,81	74,76	62,98
2009	73,36	79,91	50,31	22,95	49,53	61,96	57,73
2010	85,29	97,77	58,90	42,91	0,00	78,07	62,54
2011	94,16	100,00	65,03	39,58	15,84	79,31	67,99
2012	95,94	97,77	71,17	61,33	50,63	88,39	78,74
2013	100,00	97,77	100,00	73,82	66,68	100,00	90,58
<b>Weights</b>	<b>21,21%</b>	<b>18,18%</b>	<b>18,18%</b>	<b>15,15%</b>	<b>15,15%</b>	<b>12,12%</b>	

**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
<b>Weights</b>	<b>21,57%</b>	<b>19,61%</b>	<b>17,65%</b>	<b>15,69%</b>	<b>13,73%</b>	<b>11,76%</b>	

**Core**

	Passengers	Aircraft Movements	Origin and Destination Passengers	Freight and Mail Loaded / Unloaded	Destinations - Nonstop	Key Performance Area Score
2003	3,89	0,00	4,82	100,00	0,00	19,11
2004	0,00	7,36	0,00	77,26	3,30	15,40
2005	8,22	24,19	8,86	54,11	19,78	21,52
2006	33,32	58,16	33,96	40,91	32,97	40,38
2007	61,79	87,83	61,35	40,22	65,38	64,47
2008	60,05	82,94	59,35	19,10	70,33	59,59
2009	31,24	57,08	32,52	23,84	42,86	37,79
2010	52,22	81,25	52,35	6,00	100,00	57,78
2011	72,64	91,44	73,65	2,60	90,11	67,63
2012	76,89	79,30	77,16	0,38	90,11	66,27
2013	100,00	100,00	100,00	0,00	90,11	81,44
<b>Weights</b>	<b>25,71%</b>	<b>22,86%</b>	<b>20,00%</b>	<b>17,14%</b>	<b>14,29%</b>	

**Productivity / Cost Effectiveness**

	Total Cost per Passenger	Total Cost per Movement	Operating Cost per Movement	Aircraft Movements per Gate	Total Cost per WLU	Operating Cost per WLU	Operating Cost per Passenger	Passengers Per Employee	Aircraft Movements per Employee	Key Performance Area Score
2003	57,86	38,33	32,85	0,00	10,34	37,93	53,11	4,10	0,00	28,21
2004	36,61	29,88	0,62	7,36	0,00	3,63	6,82	0,00	7,75	11,81
2005	42,36	45,76	0,00	24,19	5,36	0,00	0,00	6,51	23,28	17,95
2006	64,58	76,21	4,11	58,16	25,59	6,37	0,27	32,81	58,83	37,76
2007	100,00	100,00	100,00	87,83	33,70	76,56	100,00	62,65	89,87	84,63
2008	82,16	85,41	93,43	82,94	100,00	100,00	94,95	60,82	84,76	87,57
2009	42,82	56,25	94,63	57,08	57,34	90,19	94,62	30,63	57,69	64,58
2010	59,44	75,04	87,60	81,25	55,15	83,61	87,07	50,22	80,49	73,26
2011	78,72	79,23	78,16	91,44	52,65	78,08	82,44	71,50	91,10	78,00
2012	0,00	0,00	28,19	79,30	18,80	52,91	44,39	75,92	78,46	37,96
2013	15,62	9,07	7,34	100,00	12,23	27,47	19,05	100,00	100,00	39,13
<b>Weights</b>	<b>14,29%</b>	<b>13,19%</b>	<b>12,09%</b>	<b>10,99%</b>	<b>10,99%</b>	<b>10,99%</b>	<b>9,89%</b>	<b>8,79%</b>	<b>8,79%</b>	

**Service Quality**

	Customer Satisfaction	Gate Departure Delay	Baggage Delivery Time	Taxi Departure Delay	Security Clearing Time	Border Control Clearing Time	Check-in to Gate Time	Practical Hourly Capacity	Key Performance Area Score
2003	5,36	5,98	25,35	50,00	4,41	33,93	61,70	67,86	28,82
2004	14,29	35,88	48,29	21,43	33,82	48,21	73,67	35,71	37,38
2005	46,43	0,00	10,87	57,14	52,02	73,21	35,37	10,71	34,87
2006	41,07	45,85	61,97	35,71	12,13	0,00	80,85	100,00	46,11
2007	100,00	85,05	35,01	100,00	0,00	100,00	88,03	21,43	68,29
2008	0,00	73,09	0,00	57,14	70,22	78,57	54,52	67,86	47,05
2009	55,80	33,89	32,60	21,43	81,80	37,50	68,88	21,43	44,14
2010	67,86	100,00	25,35	89,29	60,29	17,86	40,16	0,00	53,85
2011	73,21	55,81	48,29	50,00	100,00	46,43	0,00	35,71	53,12
2012	62,50	88,04	100,00	67,86	75,18	51,79	92,82	51,79	74,72
2013	81,25	53,82	78,27	0,00	71,88	39,29	100,00	83,93	63,07
Weights	15,96%	14,89%	13,83%	12,77%	11,70%	10,64%	10,64%	9,57%	

**Financial / Commercial**

	Aeronautical Revenue per Passenger	Aeronautical Revenue per Movement	Non-Aeronautical Operating Revenue per Passenger	EBITDA per Passenger	Non-Aeronautical Operating Revenue as Percentage of Total	Debt to EBITDA Ratio	Debt Service as Percentage of Operating Revenue	Long-Term Debt per Passenger	Key Performance Area Score
2003	86,66	100,00	0,00	0,00	0,00	74,17	16,08	100,00	47,93
2004	100,00	93,94	34,68	0,34	17,85	0,00	0,00	91,09	44,76
2005	92,18	73,79	62,69	5,00	49,54	44,67	4,16	80,51	53,34
2006	58,09	33,14	48,10	7,64	60,46	45,72	18,25	78,78	42,97
2007	19,52	0,00	27,54	11,14	74,75	77,61	53,18	79,60	38,70
2008	24,62	7,75	36,50	12,23	70,63	55,92	41,25	73,15	37,16
2009	64,27	37,06	100,00	19,78	79,98	60,71	16,85	70,99	56,25
2010	36,51	10,73	70,38	17,99	76,76	60,12	28,82	72,33	44,63
2011	30,32	17,52	56,82	24,89	70,48	88,95	100,00	73,91	53,87
2012	28,11	34,35	74,02	11,32	89,96	38,08	47,32	85,22	48,35
2013	0,00	11,01	61,10	100,00	100,00	100,00	19,33	0,00	48,46
Weights	16,18%	14,71%	13,24%	13,24%	11,76%	11,76%	10,29%	8,82%	

**Environmental**

	Carbon Footprint (TONS/PAX)	Waste Recycling	Renewable Energy Purchased by the Airport (%)	Waste Reduction (%)	Utilities / Energy Usage per Square Meter of Terminal	Water Consumption per Passenger	Key Performance Area Score
2003	52,56	44,82	0,00	59,15	16,76	41,87	35,87
2004	0,00	70,47	3,89	72,54	0,00	45,62	30,04
2005	69,28	23,71	7,77	43,58	54,51	0,00	35,28
2006	97,22	53,59	11,66	39,59	35,18	56,87	50,71
2007	78,51	43,23	15,54	0,00	32,90	59,99	39,60
2008	100,00	23,51	19,43	100,00	36,83	66,24	57,78
2009	57,98	0,00	50,31	95,20	34,87	80,31	50,89
2010	64,40	45,47	58,90	46,86	6,14	79,68	50,32
2011	75,32	87,45	65,03	42,60	9,54	91,25	62,66
2012	96,37	31,57	71,17	75,32	53,80	95,31	70,24
2013	86,37	100,00	100,00	68,85	100,00	100,00	92,39
<b>Weights</b>	<b>21,21%</b>	<b>18,18%</b>	<b>18,18%</b>	<b>15,15%</b>	<b>15,15%</b>	<b>12,12%</b>	

**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
Weights	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
Weights	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
<b>Weights</b>	<b>21,95%</b>	<b>19,51%</b>	<b>17,07%</b>	<b>14,63%</b>	<b>14,63%</b>	<b>12,20%</b>	

**Airports Group Scores**

**Airports Group**

	Airport 1	Airport 2	Airport 3	Airports Group Score
2003	34,95	30,85	38,14	34,46
2004	31,92	28,35	35,06	31,57
2005	41,08	39,56	42,83	41,02
2006	50,05	43,39	48,40	47,80
2007	62,56	60,34	65,53	62,56
2008	62,12	65,00	63,70	63,28
2009	54,96	60,56	52,35	56,00
2010	58,55	63,95	60,14	60,43
2011	66,60	76,62	65,90	69,31
2012	57,11	60,46	61,52	59,01
2013	59,88	70,11	68,73	64,70
<b>Weights</b>	<b>50,00%</b>	<b>28,57%</b>	<b>21,43%</b>	



## **Annexe 3**

**PESA-AGB: Step by step example on how  
to obtain airport final score**

## Step by Step example on how to obtain airport final score with GDS model

### 1. Step – Structuring

#### a. KPI performance descriptor:

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

Table 1 – Waste recycling KPI data.

	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013
Waste Recycling	5,78	7,57	10,17	9,39	11,48	14,56	19,46	23,95	30,84	19,11	13,33

Using Table 1 we can identify that the best year as 2011 (30,84) and the worst year as 2003 (5,78). With this information, the performance descriptor is built as shown in Table 2.

Table 2 – Waste recycling KPI performance descriptor.

	Waste Recycling
L4 (Target)	30,84
L3	22,49
L2	14,13
L1 (Neutral)	5,78

### 2. Step – Survey

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

#### a. Thermometer Judgement Matrix

Table 3 – Waste recycling KPI thermometer judgement.

	Waste Recycling					
	AD	AC	BD	AB	BC	CD
No Difference	0	0	0	1	1	1
Very Weak	0	0	1	0	1	1
Weak	1	1	2	3	3	2
Moderate	1	3	1	1	1	1
Strong	2	2	3	3	2	3
Very Strong	3	2	1	0	0	0
Extreme	1	0	0	0	0	0
Weighted Arithmetic Mean	4,25	3,63	3,13	2,63	2,25	2,50
Difference of Attractiveness	Strong	Moderate-Strong	Moderate	Weak-Moderate	Weak	Weak

Table 3 depicts the experts answers to question 8 of the survey. This results 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 Environmental KPA.

	Carbon Footprint per Passenger	Waste Recycling	Waste Reduction Percentage	Renewable Energy Purchased by the Airport (%)	Utilities/Energy Usage per Square Meter of Terminal	Water Consumption per Passenger
Very Weak	0	0	0	0	0	0
Weak	0	1	0	0	0	1
Moderate	0	1	2	1	2	4
Strong	0	3	5	5	5	1
Very Strong	6	2	0	2	0	1
Extreme	2	1	1	0	1	1
Weighted Arithmetic Mean	5,25	4,13	4,00	4,13	4,00	3,63
All Worst	Very Strong	Strong	Strong	Strong	Strong	Moderate-Strong

Table 5 –Status quo of each KPI of environmental KPA.

Environmental	Status Quo
Carbon Footprint per Passenger	5,25
Waste Recycling	4,13
Renewable Energy Purchased by the Airport (%)	4,13
Waste Reduction Percentage	4,00
Utilities / Energy Usage per Square Meter of Terminal	4,00
Water Consumption per Passenger	3,63

Table 4 and Table 5 depict the experts answers to question 7 of the survey. This results will be later used to build KPI judgement matrix and weight ponderation. (Note: each KPA of the model follow this process).

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 experts answers to question 6 of the survey. This results will be later used to build KPI judgement matrix and weight ponderation.

### 3. Step – Meeting

This step follows the fame methodologies and of step 2 (surveys).

### 4. Step – Evaluation

This step use 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 –Waste recycling judgment matrix.

Waste Recycling					
L4	30,84		22,49	14,13	5,78
L3	22,49	30,84	Weak-Moderate	Moderate-Strong	Strong
L2	14,13		22,49	Weak	Moderate
L1	5,78			14,13	Weak

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 – Waste recycling 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. Key Performance Indicators Judgement Matrix and Weights Ponderation

This matrix (Table 9) is built for each one of the KPA using the expert’s judgments collected in Table 4 and Table 5.

Table 9 –Environmental KPI’s judgment matrix.

	Waste Recycling	Renewable Energy Purchased by the Airport (%)	Waste Reduction Percentage	Utilities / Energy Usage per Square Meter of Terminal	Water Consumption per Passenger	<b>All Worst</b>
Carbon Footprint per Passenger	Very Weak-Weak	Very Weak-Weak	Very Weak-Weak	Very Weak-Weak	Weak	Very Strong
	Waste Recycling	No	Very Weak	Very Weak	Very Weak	Strong
		Renewable Energy Purchased by the Airport (%)	Very Weak	Very Weak	Very Weak	Strong
			Waste Reduction Percentage	No	Very Weak	Strong
				Utilities / Energy Usage per Square Meter of Terminal	Very Weak	Strong
					Water Consumption per Passenger	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 environmental KPA.

Key Performance Indicators	Current Scale	Weight
Carbon Footprint per Passenger	7	21,21%
Waste Recycling	6	18,18%
Renewable Energy Purchased by the Airport (%)	6	18,18%
Waste Reduction Percentage	5	15,15%
Utilities / Energy Usage per Square Meter of Terminal	5	15,15%
Water Consumption per Passenger	4	12,12%

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 use the outputs of step 4 to obtain the final scores for each KPI, each KPA and airport

#### 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 –Waste recycling scores.

Waste recycling scores											
Options	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013
Scores	0	7,14	17,52	14,41	22,75	35,04	54,59	72,51	100	53,19	30,13

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 –Environmental KPA scores.

	Carbon Footprint (TONS/PAX)	Waste Recycling	Renewable Energy Purchased by the Airport (%)	Waste Reduction (%)	Utilities / Energy Usage per Square Meter of Terminal	Water Consumption per Passenger	Environmental Score
2003	0,00	0,00	0,00	15,97	22,40	0,00	5,81
2004	23,75	7,14	3,89	19,89	10,42	4,26	12,15
2005	34,60	17,52	7,77	100,00	0,00	94,68	38,56
2006	52,41	14,41	11,66	0,00	100,00	74,47	40,03
2007	65,54	22,75	15,54	46,08	75,97	10,64	40,65
2008	70,96	35,04	19,43	20,60	56,47	10,64	37,92
2009	75,73	54,59	50,31	15,05	41,89	84,04	53,95
2010	80,87	72,51	58,90	3,82	6,87	23,40	45,50
2011	81,74	100,00	65,03	16,86	15,14	43,62	57,48
2012	90,23	53,19	71,17	38,92	79,01	81,91	69,55
2013	100,00	30,13	100,00	49,19	38,54	100,00	70,29
Weights	21,21%	18,18%	18,18%	15,15%	15,15%	12,12%	

c. Airport scores

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

Table 15 – Airport 1 scores.

	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 4**

### **SPSS Analysis**

## Regression - Safety and Security - Airport 1

### Descriptive Statistics

	Mean	Std. Deviation	N
saf_sec	66,2073	13,36441	11
lcc_pax	1595443,455	867026,6587	11
lcc_mov	12228,7273	6480,86795	11

### Correlations

		saf_sec	lcc_pax	lcc_mov
Pearson Correlation	saf_sec	1,000	,388	,430
	lcc_pax	,388	1,000	,993
	lcc_mov	,430	,993	1,000
Sig. (1-tailed)	saf_sec	.	,119	,093
	lcc_pax	,119	.	,000
	lcc_mov	,093	,000	.
N	saf_sec	11	11	11
	lcc_pax	11	11	11
	lcc_mov	11	11	11

### Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate	Change Statistics		
					R Square Change	F Change	df1
1	,539 <sup>a</sup>	,290	,113	12,58653	,290	1,637	2

### Model Summary

Model	Change Statistics	
	df2	Sig. F Change
1	8	,254

a. Predictors: (Constant), lcc\_mov, lcc\_pax

## Regression - Core - Airport 1

**Descriptive Statistics**

	Mean	Std. Deviation	N
core	53,1445	24,84921	11
lcc_pax	1595443,455	867026,6587	11
lcc_mov	12228,7273	6480,86795	11

**Correlations**

		core	lcc_pax	lcc_mov
Pearson Correlation	core	1,000	,933	,902
	lcc_pax	,933	1,000	,993
	lcc_mov	,902	,993	1,000
Sig. (1-tailed)	core	.	,000	,000
	lcc_pax	,000	.	,000
	lcc_mov	,000	,000	.
N	core	11	11	11
	lcc_pax	11	11	11
	lcc_mov	11	11	11

**Model Summary**

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate	Change Statistics		
					R Square Change	F Change	df1
1	,952 <sup>a</sup>	,906	,883	8,51069	,906	38,625	2

**Model Summary**

Model	Change Statistics	
	df2	Sig. F Change
1	8	,000

a. Predictors: (Constant), lcc\_mov, lcc\_pax

**Regression - Productivity/Cost Effectiveness - Airport 1**

**Descriptive Statistics**

	Mean	Std. Deviation	N
prod_cost	53,2627	22,96236	11
lcc_pax	1595443,455	867026,6587	11
lcc_mov	12228,7273	6480,86795	11

**Correlations**

		prod_cost	lcc_pax	lcc_mov
Pearson Correlation	prod_cost	1,000	,636	,706
	lcc_pax	,636	1,000	,993
	lcc_mov	,706	,993	1,000
Sig. (1-tailed)	prod_cost	.	,018	,008
	lcc_pax	,018	.	,000
	lcc_mov	,008	,000	.
N	prod_cost	11	11	11
	lcc_pax	11	11	11
	lcc_mov	11	11	11

**Model Summary**

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate	Change Statistics		
					R Square Change	F Change	df1
1	,884 <sup>a</sup>	,781	,726	12,02226	,781	14,240	2

**Model Summary**

Model	Change Statistics	
	df2	Sig. F Change
1	8	,002

a. Predictors: (Constant), lcc\_mov, lcc\_pax

## Regression - Service Quality - Airport 1

**Descriptive Statistics**

	Mean	Std. Deviation	N
serv_qual	45,5482	14,79233	11
lcc_pax	1595443,455	867026,6587	11
lcc_mov	12228,7273	6480,86795	11

**Correlations**

		serv_qual	lcc_pax	lcc_mov
Pearson Correlation	serv_qual	1,000	,889	,845
	lcc_pax	,889	1,000	,993
	lcc_mov	,845	,993	1,000
Sig. (1-tailed)	serv_qual	.	,000	,001
	lcc_pax	,000	.	,000
	lcc_mov	,001	,000	.
N	serv_qual	11	11	11
	lcc_pax	11	11	11
	lcc_mov	11	11	11

**Model Summary**

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate	Change Statistics		
					R Square Change	F Change	df1
1	,941 <sup>a</sup>	,885	,856	5,61267	,885	30,730	2

**Model Summary**

Model	Change Statistics	
	df2	Sig. F Change
1	8	,000

a. Predictors: (Constant), lcc\_mov, lcc\_pax

## Regression - Financial/Commercial - Airport 1

**Descriptive Statistics**

	Mean	Std. Deviation	N
fina_commer	46,5582	12,87732	11
lcc_pax	1595443,455	867026,6587	11
lcc_mov	12228,7273	6480,86795	11

**Correlations**

		fina_commer	lcc_pax	lcc_mov
Pearson Correlation	fina_commer	1,000	-,670	-,635
	lcc_pax	-,670	1,000	,993
	lcc_mov	-,635	,993	1,000
Sig. (1-tailed)	fina_commer	.	,012	,018
	lcc_pax	,012	.	,000
	lcc_mov	,018	,000	.
N	fina_commer	11	11	11
	lcc_pax	11	11	11
	lcc_mov	11	11	11

**Model Summary**

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate	Change Statistics		
					R Square Change	F Change	df1
1	,714 <sup>a</sup>	,510	,388	10,07570	,510	4,167	2

**Model Summary**

Model	Change Statistics	
	df2	Sig. F Change
1	8	,058

a. Predictors: (Constant), lcc\_mov, lcc\_pax

**Regression - Environmental - Airport 1**

**Descriptive Statistics**

	Mean	Std. Deviation	N
environmental	42,8991	20,44514	11
lcc_pax	1595443,455	867026,6587	11
lcc_mov	12228,7273	6480,86795	11

**Correlations**

		environmental	lcc_pax	lcc_mov
Pearson Correlation	environmental	1,000	,866	,817
	lcc_pax	,866	1,000	,993
	lcc_mov	,817	,993	1,000
Sig. (1-tailed)	environmental	.	,000	,001
	lcc_pax	,000	.	,000
	lcc_mov	,001	,000	.
N	environmental	11	11	11
	lcc_pax	11	11	11
	lcc_mov	11	11	11

**Model Summary**

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate	Change Statistics		
					R Square Change	F Change	df1
1	,935 <sup>a</sup>	,875	,844	8,08219	,875	27,996	2

**Model Summary**

Model	Change Statistics	
	df2	Sig. F Change
1	8	,000

a. Predictors: (Constant), lcc\_mov, lcc\_pax

## Regression - Safety and Security - Airport 2

### Descriptive Statistics

	Mean	Std. Deviation	N
saf_sec	71,0382	10,35570	11
lcc_pax	1721206,818	1363112,050	11
lcc_mov	11689,0000	8967,01527	11

### Correlations

		saf_sec	lcc_pax	lcc_mov
Pearson Correlation	saf_sec	1,000	,369	,402
	lcc_pax	,369	1,000	,998
	lcc_mov	,402	,998	1,000
Sig. (1-tailed)	saf_sec	.	,132	,110
	lcc_pax	,132	.	,000
	lcc_mov	,110	,000	.
N	saf_sec	11	11	11
	lcc_pax	11	11	11
	lcc_mov	11	11	11

### Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate	Change Statistics		
					R Square Change	F Change	df1
1	,665 <sup>a</sup>	,443	,303	8,64298	,443	3,178	2

### Model Summary

Model	Change Statistics	
	df2	Sig. F Change
1	8	,096

a. Predictors: (Constant), lcc\_mov, lcc\_pax

## Regression - Core - Airport 2

**Descriptive Statistics**

	Mean	Std. Deviation	N
core	47,4873	30,90730	11
lcc_pax	1721206,818	1363112,050	11
lcc_mov	11689,0000	8967,01527	11

**Correlations**

		core	lcc_pax	lcc_mov
Pearson Correlation	core	1,000	,971	,977
	lcc_pax	,971	1,000	,998
	lcc_mov	,977	,998	1,000
Sig. (1-tailed)	core	.	,000	,000
	lcc_pax	,000	.	,000
	lcc_mov	,000	,000	.
N	core	11	11	11
	lcc_pax	11	11	11
	lcc_mov	11	11	11

**Model Summary**

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate	Change Statistics		
					R Square Change	F Change	df1
1	,981 <sup>a</sup>	,962	,952	6,76731	,962	100,294	2

**Model Summary**

Model	Change Statistics	
	df2	Sig. F Change
1	8	,000

a. Predictors: (Constant), lcc\_mov, lcc\_pax

**Regression - Productivity/Cost Effectiveness - Airport 2**

**Descriptive Statistics**

	Mean	Std. Deviation	N
prod_cost	49,5155	31,63372	11
lcc_pax	1721206,818	1363112,050	11
lcc_mov	11689,0000	8967,01527	11

**Correlations**

		prod_cost	lcc_pax	lcc_mov
Pearson Correlation	prod_cost	1,000	,789	,823
	lcc_pax	,789	1,000	,998
	lcc_mov	,823	,998	1,000
Sig. (1-tailed)	prod_cost	.	,002	,001
	lcc_pax	,002	.	,000
	lcc_mov	,001	,000	.
N	prod_cost	11	11	11
	lcc_pax	11	11	11
	lcc_mov	11	11	11

**Model Summary**

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate	Change Statistics		
					R Square Change	F Change	df1
1	,986 <sup>a</sup>	,972	,965	5,90144	,972	139,666	2

**Model Summary**

Model	Change Statistics	
	df2	Sig. F Change
1	8	,000

a. Predictors: (Constant), lcc\_mov, lcc\_pax

**Regression - Service Quality - Airport 2**

**Descriptive Statistics**

	Mean	Std. Deviation	N
serv_qual	50,4164	15,78269	11
lcc_pax	1721206,818	1363112,050	11
lcc_mov	11689,0000	8967,01527	11

**Correlations**

		serv_qual	lcc_pax	lcc_mov
Pearson Correlation	serv_qual	1,000	,667	,677
	lcc_pax	,667	1,000	,998
	lcc_mov	,677	,998	1,000
Sig. (1-tailed)	serv_qual	.	,012	,011
	lcc_pax	,012	.	,000
	lcc_mov	,011	,000	.
N	serv_qual	11	11	11
	lcc_pax	11	11	11
	lcc_mov	11	11	11

**Model Summary**

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate	Change Statistics		
					R Square Change	F Change	df1
1	,692 <sup>a</sup>	,479	,349	12,73345	,479	3,681	2

**Model Summary**

Model	Change Statistics	
	df2	Sig. F Change
1	8	,074

a. Predictors: (Constant), lcc\_mov, lcc\_pax

## Regression - Financial/Commercial - Airport 2

**Descriptive Statistics**

	Mean	Std. Deviation	N
fina_commer	50,5118	10,77774	11
lcc_pax	1721206,818	1363112,050	11
lcc_mov	11689,0000	8967,01527	11

**Correlations**

		fina_commer	lcc_pax	lcc_mov
Pearson Correlation	fina_commer	1,000	-,392	-,408
	lcc_pax	-,392	1,000	,998
	lcc_mov	-,408	,998	1,000
Sig. (1-tailed)	fina_commer	.	,117	,107
	lcc_pax	,117	.	,000
	lcc_mov	,107	,000	.
N	fina_commer	11	11	11
	lcc_pax	11	11	11
	lcc_mov	11	11	11

**Model Summary**

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate	Change Statistics		
					R Square Change	F Change	df1
1	,477 <sup>a</sup>	,228	,035	10,58903	,228	1,180	2

**Model Summary**

Model	Change Statistics	
	df2	Sig. F Change
1	8	,356

a. Predictors: (Constant), lcc\_mov, lcc\_pax

**Regression - Environmental - Airport 2**

**Descriptive Statistics**

	Mean	Std. Deviation	N
environmental	52,3736	23,04406	11
lcc_pax	1721206,818	1363112,050	11
lcc_mov	11689,0000	8967,01527	11

**Correlations**

		environmental	lcc_pax	lcc_mov
Pearson Correlation	environmental	1,000	,967	,962
	lcc_pax	,967	1,000	,998
	lcc_mov	,962	,998	1,000
Sig. (1-tailed)	environmental	.	,000	,000
	lcc_pax	,000	.	,000
	lcc_mov	,000	,000	.
N	environmental	11	11	11
	lcc_pax	11	11	11
	lcc_mov	11	11	11

**Model Summary**

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate	Change Statistics		
					R Square Change	F Change	df1
1	,969 <sup>a</sup>	,939	,924	6,34517	,939	61,948	2

**Model Summary**

Model	Change Statistics	
	df2	Sig. F Change
1	8	,000

a. Predictors: (Constant), lcc\_mov, lcc\_pax

## Regression - Safety and Security - Airport 3

### Descriptive Statistics

	Mean	Std. Deviation	N
saf_sec	73,0436	8,67442	11
lcc_pax	3086154,909	1271105,839	11
lcc_mov	21970,3636	7507,12173	11

### Correlations

		saf_sec	lcc_pax	lcc_mov
Pearson Correlation	saf_sec	1,000	,370	,405
	lcc_pax	,370	1,000	,985
	lcc_mov	,405	,985	1,000
Sig. (1-tailed)	saf_sec	.	,131	,109
	lcc_pax	,131	.	,000
	lcc_mov	,109	,000	.
N	saf_sec	11	11	11
	lcc_pax	11	11	11
	lcc_mov	11	11	11

### Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate	Change Statistics		
					R Square Change	F Change	df1
1	,436 <sup>a</sup>	,190	-,012	8,72845	,190	,938	2

### Model Summary

Model	Change Statistics	
	df2	Sig. F Change
1	8	,430

a. Predictors: (Constant), lcc\_mov, lcc\_pax

## Regression - Core - Airport 3

**Descriptive Statistics**

	Mean	Std. Deviation	N
core	48,3073	22,57975	11
lcc_pax	3086154,909	1271105,839	11
lcc_mov	21970,3636	7507,12173	11

**Correlations**

		core	lcc_pax	lcc_mov
Pearson Correlation	core	1,000	,909	,863
	lcc_pax	,909	1,000	,985
	lcc_mov	,863	,985	1,000
Sig. (1-tailed)	core	.	,000	,000
	lcc_pax	,000	.	,000
	lcc_mov	,000	,000	.
N	core	11	11	11
	lcc_pax	11	11	11
	lcc_mov	11	11	11

**Model Summary**

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate	Change Statistics		
					R Square Change	F Change	df1
1	,927 <sup>a</sup>	,860	,825	9,45341	,860	24,525	2

**Model Summary**

Model	Change Statistics	
	df2	Sig. F Change
1	8	,000

a. Predictors: (Constant), lcc\_mov, lcc\_pax

**Regression - Productivity/Cost Effectiveness - Airport 3**

**Descriptive Statistics**

	Mean	Std. Deviation	N
prod_cost	50,9873	27,40628	11
lcc_pax	3086154,909	1271105,839	11
lcc_mov	21970,3636	7507,12173	11

**Correlations**

		prod_cost	lcc_pax	lcc_mov
Pearson Correlation	prod_cost	1,000	,648	,645
	lcc_pax	,648	1,000	,985
	lcc_mov	,645	,985	1,000
Sig. (1-tailed)	prod_cost	.	,015	,016
	lcc_pax	,015	.	,000
	lcc_mov	,016	,000	.
N	prod_cost	11	11	11
	lcc_pax	11	11	11
	lcc_mov	11	11	11

**Model Summary**

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate	Change Statistics		
					R Square Change	F Change	df1
1	,649 <sup>a</sup>	,422	,277	23,30152	,422	2,917	2

**Model Summary**

Model	Change Statistics	
	df2	Sig. F Change
1	8	,112

a. Predictors: (Constant), lcc\_mov, lcc\_pax

## Regression - Service Quality - Airport 3

**Descriptive Statistics**

	Mean	Std. Deviation	N
serv_qual	50,1291	14,26797	11
lcc_pax	3086154,909	1271105,839	11
lcc_mov	21970,3636	7507,12173	11

**Correlations**

		serv_qual	lcc_pax	lcc_mov
Pearson Correlation	serv_qual	1,000	,777	,744
	lcc_pax	,777	1,000	,985
	lcc_mov	,744	,985	1,000
Sig. (1-tailed)	serv_qual	.	,002	,004
	lcc_pax	,002	.	,000
	lcc_mov	,004	,000	.
N	serv_qual	11	11	11
	lcc_pax	11	11	11
	lcc_mov	11	11	11

**Model Summary**

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate	Change Statistics		
					R Square Change	F Change	df1
1	,787 <sup>a</sup>	,619	,524	9,84115	,619	6,510	2

**Model Summary**

Model	Change Statistics	
	df2	Sig. F Change
1	8	,021

a. Predictors: (Constant), lcc\_mov, lcc\_pax

**Regression - Financial/Commercial - Airport 3**

**Descriptive Statistics**

	Mean	Std. Deviation	N
fina_commer	46,9473	6,08551	11
lcc_pax	3086154,909	1271105,839	11
lcc_mov	21970,3636	7507,12173	11

**Correlations**

		fina_commer	lcc_pax	lcc_mov
Pearson Correlation	fina_commer	1,000	,020	-,017
	lcc_pax	,020	1,000	,985
	lcc_mov	-,017	,985	1,000
Sig. (1-tailed)	fina_commer	.	,476	,480
	lcc_pax	,476	.	,000
	lcc_mov	,480	,000	.
N	fina_commer	11	11	11
	lcc_pax	11	11	11
	lcc_mov	11	11	11

**Model Summary**

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate	Change Statistics		
					R Square Change	F Change	df1
1	,215 <sup>a</sup>	,046	-,192	6,64437	,046	,194	2

**Model Summary**

Model	Change Statistics	
	df2	Sig. F Change
1	8	,827

a. Predictors: (Constant), lcc\_mov, lcc\_pax

**Regression - Environmental - Airport 3**

**Descriptive Statistics**

	Mean	Std. Deviation	N
environmental	52,3436	18,14180	11
lcc_pax	3086154,909	1271105,839	11
lcc_mov	21970,3636	7507,12173	11

**Correlations**

		environmental	lcc_pax	lcc_mov
Pearson Correlation	environmental	1,000	,775	,698
	lcc_pax	,775	1,000	,985
	lcc_mov	,698	,985	1,000
Sig. (1-tailed)	environmental	.	,003	,008
	lcc_pax	,003	.	,000
	lcc_mov	,008	,000	.
N	environmental	11	11	11
	lcc_pax	11	11	11
	lcc_mov	11	11	11

**Model Summary**

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate	Change Statistics		
					R Square Change	F Change	df1
1	,860 <sup>a</sup>	,740	,675	10,34962	,740	11,363	2

**Model Summary**

Model	Change Statistics	
	df2	Sig. F Change
1	8	,005

a. Predictors: (Constant), lcc\_mov, lcc\_pax

## Regression - Airport 1 - Overall Scores

### Descriptive Statistics

	Mean	Std. Deviation	N
airport1	52,7073	11,74059	11
lcc_pax	1595443,455	867026,6587	11
lcc_mov	12228,7273	6480,86795	11

### Correlations

		airport1	lcc_pax	lcc_mov
Pearson Correlation	airport1	1,000	,934	,943
	lcc_pax	,934	1,000	,993
	lcc_mov	,943	,993	1,000
Sig. (1-tailed)	airport1	.	,000	,000
	lcc_pax	,000	.	,000
	lcc_mov	,000	,000	.
N	airport1	11	11	11
	lcc_pax	11	11	11
	lcc_mov	11	11	11

### Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate	Change Statistics		
					R Square Change	F Change	df1
1	,943 <sup>a</sup>	,890	,862	4,36327	,890	32,201	2

### Model Summary

Model	Change Statistics	
	df2	Sig. F Change
1	8	,000

a. Predictors: (Constant), lcc\_mov, lcc\_pax

## Regression - Airport 2 - Overall Scores

### Descriptive Statistics

	Mean	Std. Deviation	N
airport2	54,4718	16,21309	11
lcc_pax	1721206,818	1363112,050	11
lcc_mov	11689,0000	8967,01527	11

### Correlations

		airport2	lcc_pax	lcc_mov
Pearson Correlation	airport2	1,000	,900	,917
	lcc_pax	,900	1,000	,998
	lcc_mov	,917	,998	1,000
Sig. (1-tailed)	airport2	.	,000	,000
	lcc_pax	,000	.	,000
	lcc_mov	,000	,000	.
N	airport2	11	11	11
	lcc_pax	11	11	11
	lcc_mov	11	11	11

### Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate	Change Statistics		
					R Square Change	F Change	df1
1	,954 <sup>a</sup>	,910	,887	5,45011	,910	40,248	2

### Model Summary

Model	Change Statistics	
	df2	Sig. F Change
1	8	,000

a. Predictors: (Constant), lcc\_mov, lcc\_pax

## Regression - Airport 3 - Overall Score

### Descriptive Statistics

	Mean	Std. Deviation	N
airport3	54,7545	12,01131	11
lcc_pax	3086154,909	1271105,839	11
lcc_mov	21970,3636	7507,12173	11

### Correlations

		airport3	lcc_pax	lcc_mov
Pearson Correlation	airport3	1,000	,924	,889
	lcc_pax	,924	1,000	,985
	lcc_mov	,889	,985	1,000
Sig. (1-tailed)	airport3	.	,000	,000
	lcc_pax	,000	.	,000
	lcc_mov	,000	,000	.
N	airport3	11	11	11
	lcc_pax	11	11	11
	lcc_mov	11	11	11

### Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate	Change Statistics		
					R Square Change	F Change	df1
1	,932 <sup>a</sup>	,869	,836	4,85844	,869	26,560	2

### Model Summary

Model	Change Statistics	
	df2	Sig. F Change
1	8	,000

a. Predictors: (Constant), lcc\_mov, lcc\_pax

## **Annexe 5**

### **Publication Abstracts**

## AIRPORT BENCHMARKING PROCESS AND THE KEY PERFORMANCE AREA OF SAFETY/SECURITY

Paulo Marchão<sup>1</sup>, Maria Emília Baltazar<sup>1</sup>, Tiago Rosa<sup>1</sup> and Jorge Silva<sup>1</sup>

### Abstract

The utility of the airport benchmarking process is widely recognized in a world where competition among airports is becoming more than ever a reality. Therefore there is a need for a wide consensus to establish and construct reliable databases for measuring airport performance and consequently to evaluate the development and the implementation of even more accurate management systems.

There have been several studies focused on airport benchmarking processes but mainly based on economical and productivity factors. However there is a lack of studies focused on the airport as a whole, in areas and/or sets of areas that must be addressed too to achieve a truly global analysis, (ATRS, 2004).

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

The results evidence the importance of this type of evaluation to understand how airports deal with Safety/Security issues and how this key performance area may impact in any benchmarking process.

**KEYWORDS:** Airport benchmarking, Safety and Security, Multi-Criteria Decision Analysis

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# MCDA Modelling of Airport Impacts due to LCC's Operation

Tiago Rosa, Maria E. Baltazar, Jorge Silva

## Abstract

The growth of the low-cost carriers (LCC's) change how airports are managed and their performance. This study focuses on the literature review of the low-cost carriers growth, airport performance, multiple-criteria decision analysis (MCDA) and future work.

In this study we model the airport key performance areas and key performance indicators in a multi-criteria decision analysis model called MACBETH that allows the evaluation of options in a multiple criteria scenario and describes every step to model the airport performance in Macbeth software. A case study was conducted in order to analyse the impact that low-cost carriers had in an airport performance on service quality during a period of six years.

Future work will consist in presenting a more complete modelling of the impacts taking into account not only the Operational, Economical and Environmental key performance areas of the airports, but also the Hinterland and the impacts in the regional economy. The final objective is to apply this modelling to one or two airports where the rapid growth of low-cost carriers can be easily seen during the last 10 years.

*Keywords: LCC's, Airports Performance, MCDA, Macbeth*

# Low-Cost Carriers Impacts on Airport Performance. An MCDA Model

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**ABSTRACT:** Due to the deregulation of the airline market in Europe, Low-Cost Carriers (LCC's) have shown a fast growth in the last decade and it is expectable that this growth continues in the next years. This new change in the European airline market has affected the way many airports operate and it's expected that this has impacts in airports performance and efficiency.

This paper presents a study focused on the identification and scale of airports impacts due to LCC's operation during an eleven years' period. The study assesses an airport performance and efficiency through a self-benchmark with a Multi Criteria Decision Analyses (MCDA), applied with MACBETH (Measuring Attractiveness by a Categorical Based Evaluation Technique).

Airport Council International (ACI) reports where used to define the criteria analysed by the model, which consisted in six key performance areas: Core; Safety and Security; Service Quality; Productivity/Cost Efficiency; Financial/Commercial; and Environmental. Each key performance area is associated with several key performance indicators, a total of forty-two.

The goal of this model is to enabled the airport decision makers to, by a global self-benchmark, identify what were the key performance areas and key performance indicators affected by the growth of LCC's, and if the impacts identified were negative or positive for the airports global performance and efficiency scores.

*Keywords: LCC, Airports Performance and Efficiency, MCDA, Macbeth*

# Airport Benchmarking Process and 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 - in this particular, 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 and Security, Multi-Criteria Decision Analysis

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## **Impacto no Turismo da Área de Influência dos Aeroportos Portugueses devido à Operação de Companhias de Baixo Custo.**

### **Impact in Tourism of Portuguese Airports Hinterland due to Low-Cost Carriers Operation.**

**Resumo** | Devido à desregulamentação do transporte aéreo europeu, as LCC's têm mostrado um rápido crescimento na última década. Esta mudança no mercado tem afetado a maneira como muitos aeroportos operam e é esperado que isto influencie não só o desempenho dos aeroportos, mas também a sua área de influência. O desenvolvimento turístico é um dos principais beneficiários deste novo paradigma.

Este estudo foca-se na identificação dos possíveis impactos causados pela operação de LCC's no turismo, durante um período de sete anos, avaliando o desempenho aeroportuário através de um *self-benchmark* utilizando uma metodologia MCDA e comparando os resultados com a evolução de alguns indicadores turísticos da área de influência dos aeroportos portugueses.

**Palavras-chave** | Transporte Aéreo, Desempenho Aeroportuário, MCDA, Turismo, LCC

**Abstract** | Due to the deregulation of the airline market in Europe, LCC's have shown a fast growth in the last decade. This change in airline market has affected the way many airports operate and it's expected that this impacts not only in airport performance, but also in its hinterland. Tourism development is one of the main beneficiaries of this new paradigm.

This study focus on the identification of the possible impacts in tourism due to LCC's operation, during a seven years' period, by assessing airports performance through a self-benchmark with a MCDA methodology and comparing the results with some tourism indicators in the Portuguese airports hinterland.

**Keywords** | Air Transport, Airport Performance, MCDA, Tourism, LCC.

## Low-Cost Carriers Socio-Economic Impact in Tourism Development: The Case of Faro's Airport Hinterland.

Tiago Rosa, Maria E. Baltazar & Jorge Silva

### ABSTRACT

*Due to airline market deregulation in Europe LCC's (Low-Cost Carriers) depicts a fast growth in the last decade and it's expected that this growth continues in the next years. Also, this European airline market change has affected the way many airports operate and it's likely that this change impacts not only airports performance and efficiency, but also its hinterland. Tourism development is one of the main beneficiaries of this new paradigm.*

*Airport hinterland definition is very broad. Traditionally hinterland is measured by several kilometres' radius centred on the airport or a certain travel time from one point to the airport. However, this definition may be considered too simplistic because there are other indicators that can determine such influence area. Therefore, current literature prefers to do it in combination with certain pre-defined criteria: airport impact or effectiveness assessment, or a tourism destination perspective.*

*This paper presents a study on airport hinterland socio-economic activity, with emphasis on tourism development due to LCC operations. The study analyses socio-economic indicators from 2006 to 2012, a period which represents the full operation entry and evolution of LCC's in the Portuguese south airport of Faro.*

*Results are aligned with the expectations created by literature review as well by the empirical preliminary analysis from the case study, showing a possible correlation between LCC movements and some hinterland indicators with direct impact on the tourism sector.*

**Key Words:** *Airport Efficiency; Airport Hinterland; Low-Cost Carriers; Multi-Criteria Decision Analysis; Socio-Economic Impacts; Tourism Development.*

### Introduction

In the last decades, aviation has shown a continuous growth in aircraft movements but more important in transported passengers. There have been some temporarily interruptions due to extreme events like terrorism, economic crisis and war; however the overall growth has been positive and exponential (Liebert 2011). EUROCONTROL (2014) analysed IFR (Instrument Flight Rules) movements evolution from 2001 to 2013 and forecasted its growth for 2014-2021. This evolution is characterized by an exponential growth in IFR movements with two time periods showing a strong decline (2008-2009 and 2011-2012).

One of the major causes of the rapid growth in air traffic was air transport deregulation in the seventies in the United States of America. This led to market progressive deregulation which opened the door to new revolutionary

business model aiming to minimize airline operational costs. Because of lower operational costs airlines adopting this type of business models began decreasing their ticket prices, reaching customers market which previously couldn't afford legacy carriers high rates. Due to such operation characteristics these airlines are labelled LCC's (Low-Cost Carriers) (Rosa et al. 2015).

European Union liberalization packages began by removing regulation over fares and route entry in the mid-eighties causing LCC's revolution in Europe (ACI 2011), led by Ireland and United Kingdom with Ryanair and EasyJet, respectively.

Consequently, this revolutionary business models are expected to impact not only on airport financial and operational activities but also on airports hinterland, creating the need to assess these impacts and the related correlation.

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# Performance and Efficiency Support Analysis for Airport and Airlines Benchmarking

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## Abstract

This paper presents multi-criteria approach to the performance and efficiency support analysis for air transport sectors benchmarking, such as airports and airlines. The proposed structure resulted from the analysis and discussion of pre-defined KPA (Key Performance Areas) and KPI (Key Performance Indicators) recommended by international air transport organizations for airports and airlines analysis. With the results and comparison of a pre-set data, managers from air transport sectors can establishing new performance goals with new standards and measures. Therefore, a multi criteria decision analysis model, PESA-GB (Performance and Efficiency Support Analysis for Global Benchmarking), is proposed. This model is based on the MACBETH methodology and it enables managers to measure the performance and efficiency of any air transport sector not only in a global perspective, but also to peer-benchmark it during a certain period. PESA-GB is used in three air transportation sectors, three airports, Ryanair airline and Cargolux air cargo carrier, performing a benchmark of performance and efficiency analysis for the KPA and KPI criterias that were selected for each case study over the 2006-2012 period.

*Keywords: Air Transportation; Benchmarking; Efficiency; MACBETH; MDCA; Performance.*

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## 1. Introduction

Airport industry with all its inputs and outputs is a major influence in the global economy and it must find an optimal level for balancing the interests of the public in general, the stakeholders and all the airport operators. Understanding how we can determine if an airport will have the expected impact in the economy of a continent, a country, a region or even a town, it will help everybody to establish a decision criterion to build - or not, to improve - or not, such infrastructures. A benefit of benchmarking is that it can be a straightforward means to identify performance deficiencies or exceptional performance, without detailed and complex examination of processes. The benchmarking of airports is essential to give all stakeholders the appropriate tools to participate in the management process of such infrastructures.

To managed these complex infrastructures with all involved stakeholders and is the responsibility of decision makers that need to be informed how the airport is complying with the established strategies of the owner, either the government in a public ownership or the stakeholder in a private ownership or even both if it is a public private partnership (PPP). Airports are complex systems that aim to pursue efficiency in all areas taking in to account the cost considerations and the sustainability issues.

As many airports, have transformed from government operated public utilities to privately operated commercial enterprises, there has been an increased interest in utilizing benchmarking to assess and improve performance.

Also, the competition between airlines, has been increasing. The Low-Cost Carriers have had a major role in this. In Europe, Low Cost Carriers also put additional pressure on network carriers' operating costs by offering flights at reduced fares [1].

The process to identifying the best practices using performance benchmarking, enables the understanding and the adaptation of these practices to help the airport and airline management to improve their performance. The comparison of a pre-set data allows the airport or airline managers establishing new performance goals with new standards and measures. Over designated time frames, benchmarking can improve operating levels and lead to improved organizational efficiency and performance. Performance measures also have the responsibility of accommodating the needs and requirements of all airports, regardless of size or volumes.

ACI [2], summarizes the benchmarking process: first is about management and organizational change, and second is about measurement and technology. It provides a diagnostic tool to check whether all systems are in alignment and working properly. Self-Benchmarking (internal) basis is an excellent