

Air Transport Performance and Global Decision Analysis

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Dedictory

To my parents for the incredible support and belief all the way.

To my husband for the love, patience, and support.

To my daughter and son that inspired me with their love, to fulfil my dreams.

“Such a work is never really finished; you have to declare them to be ready when you have done everything possible to the time and circumstances.”

Johann Wolfgang von Goethe (1749-1832)

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“You never fail until you stop trying.”

Albert Einstein

Foreword

This thesis is the research work performed in the 3-year third cycle of aeronautical engineering studies and presents the contributions, conclusions, and future work. These research activities were accomplished with the Transportation Research Team (TRT) support of the Aerospace Sciences Department in the University of Beira Interior (UBI). The research work was supervised by Professor Jorge Miguel dos Reis Silva from the Aerospace Sciences Department. This study had no financial support.

This work includes the human perspective, which usually is not considered, in an area that always uses non-perceptive mathematical solutions. Using a user-friendly tool in Multi-Criteria Decision Analysis (MCDA) with Decision Support System (DSS) to access airport performance and efficiency analysis contributes to advancing knowledge in airport performance and efficiency assessment. With this practical approach, it was possible to validate methodologies and techniques and provide an oriented solution for all the stakeholders evolved in the analysis. Moreover, a certifying process for airports is suggested using graphical layout and respective regulation and implementation.

The Transportation Research Team (TRT) research centre laboratory developed the application of all the mathematical models and decision support systems in the decision-making processes of the Global Decision Analysis (GDA), combined with Performance and Efficiency System Analysis (PESA-AGB). The use of multi-criteria decision analysis was developed in cooperation with Bana Consulting S.A., in terms of a service that enables airport performance and efficiency analysis using an MCDA tool called Measuring Attractiveness by Categorical Based Technique (MACBETH). The Airport Label certification is conducted according to international regulations and standards.

The challenge of creating a system to apply a measurement model that can include all airports worldwide in distinct environments and cultures and its efficiency certification is the motivational research work developed and described in this thesis. The research activities were performed in academic and enterprise environments. Although it was not possible to work directly with the Portuguese airport, all diligence was made. Moreover, this unique experience was very fruitful, allowing the engagement in a European program, a COST action related to air transportation and regional development (ATARD). The articles were published in several international journals, conference proceedings and book chapters, thus establishing permanent challenges that enhanced my research capabilities and skills. Also, the research work was based on international

standards and guidelines by the International Civil Aviation Organization (ICAO), International Air Transport Association (IATA) and European Aviation Safety Agency (EASA).

List of Publications

Published articles resulting from this doctoral thesis:

1. Spanish airports performance and efficiency benchmark. A PESA-AGB study
Maria E. Baltazar, Tiago Rosa, Jorge Silva (2020). *Journal of Air Transport Management*, Volume 89, October 2020, <https://doi.org/10.1016/j.jairtraman.2020.101889>
2. Airport Performance and Efficiency – Label Development
Maria E. Baltazar and J. Silva (2018), Proceedings of 22nd Air Transport Research Society (ATRS) World Conference, South Korea, Seoul, COEX, July 2-5.
3. Global Decision Support for Airport Performance and Efficiency Assessment
Maria E. Baltazar, Tiago Rosa, Jorge Silva (2018). *Journal of Air Transport Management*, Volume 71, August 2018, Pages 220-242, <https://doi.org/10.1016/j.jairtraman.2018.04.009>.
4. Airport Benchmarking Process and the Key Performance Area of Safety/Security
Paulo Marchão, Maria E. Baltazar, Tiago Rosa, Jorge Silva (2015). 2nd International conference of the Airport Development Series (AIRDEV) Proceedings. Indian Institute of Science (IISc), Bengaluru, India, 4th to November 6 2015.
5. Air Transport Performance and Efficiency: MCDA vs DEA Approaches
Maria E. Baltazar, João Jardim, Pedro Alves and J. Silva (2014), *Procedia - Social and Behavioral Sciences* (Elsevier) 111 (2014) 790 – 799.
6. Airport Performance and Efficiency Assessment: A New Approach
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Resumo

Desde o início da aviação que os aeroportos detêm um papel fulcral na Engenharia Aeronáutica. O conceito de aeroporto modificou-se muito durante o último século passando de pequenos aeródromos para “hubs” internacionais. Assim estas infraestruturas aeroportuárias têm vindo a assumir um papel muito importante no que diz respeito ao desenvolvimento económico das regiões em que se inserem. O surgimento do conceito de cidade aeroporto, como um novo modelo organizacional de sucesso, sugere que para qualquer infraestrutura do género ser competitiva o deve adotar. A indústria aeroportuária, com todos os seus “inputs” e “outputs”, tem uma grande influência na economia global e os equilíbrios entre o interesse público em geral, os acionistas em particular, os operadores aeroportuários devem procurar ser conciliados.

Esta investigação procurou determinar se um aeroporto teria o impacto esperado na economia em diferentes escalas, nomeadamente à de um continente, um país, uma região ou mesmo uma cidade, para poder estabelecer quais os critérios de decisão para a construção de novas infraestruturas aeroportuárias assim como para efetuar melhorias nas mesmas. Na procura de ferramentas que permitissem uma avaliação apropriada dos processos de gestão de um aeroporto, a aferição da posição do aeroporto comparativamente aos seus congéneres (benchmarking) surgiu como essencial. No entanto, a complexidade dos modelos conhecidos em utilização torna as ferramentas pouco amigáveis para a administração aeroportuária, para além de que, o foco essencial deste tipo de estudos é o lado terra do aeroporto. Existem outros tipos de estudos para a avaliação do desempenho dos processos aeroportuários, mas, também estes são complexos e não envolvem todas as componentes operacionais, financeiras e dos agentes na vizinhança do aeroporto.

A construção de uma nova metodologia impõe que se tenha em consideração as infraestruturas aeroportuárias, lado terra e lado ar, os clientes, os acionistas e os operadores aeroportuários. Assim, uma análise bem fundamentada para uma decisão a nível global - o Global Decision Analysis (GDA), incorpora numa só ferramenta todas as interligações entre todos os intervenientes da infraestrutura. O GDA é, pois, mais amigável para os *stakeholders* tendo em vista a gestão e otimização das decisões baseado em um sistema de análise com base na metodologia multicritério MACBETH - o Performance and Efficiency Support Analysis for Airport Global Benchmarking (PESA-AGB), que foi construído e aplicado a um aeroporto com dimensões idênticas às do

aeroporto de Lisboa, demonstrando e comparando a evolução do desempenho e eficiência ao longo de 11 anos pelo período de 2003 a 2013 por 6 áreas chave de desempenho do aeroporto e os respetivos indicadores chave de desempenho.

Neste estudo, é apresentada e discutida uma implementação da Etiqueta Airport Performance and Efficiency Label (APE-Label), aplicada a qualquer aeroporto, independentemente de seu tamanho e localização. O principal obstáculo à implementação deste APE-Label é a heterogeneidade da infraestrutura aeroportuária, uma vez que esta difere no número de pistas para a propriedade pública, privada ou mesmo público-privada, entre outros. A principal proposta é fornecer uma APE-Label gráfica que informe a todas as partes interessadas qual é a avaliação da infraestrutura analisada através das seis áreas-chave de desempenho em cada ano que ajudarão a maximizar os padrões de desempenho e eficiência.

Para o caso de estudo, foi realizada uma análise de self-benchmarking para o aeroporto 1 com características específicas e um aeroporto internacional com as valências de carga e Low Cost Carriers (LCC), representando a principal infraestrutura aérea portuguesa. O aeroporto 1 é considerado o maior em termos de número de passageiros, movimentos e carga e está associado ao aeroporto de Lisboa. Por fim, são apresentados em dois painéis de análise visual os resultados do PESA-AGB e do GDA.

Palavras-Chave

Transporte aéreo; Análise Global para a Decisão; Desempenho Aeroportuário; Eficiência Aeroportuária; MCDA-PESA-AGB

Resumo Alargado

Introdução

Este capítulo contém descrição resumida do trabalho de investigação desenvolvido na tese de doutoramento na área das Ciências Aeronáuticas e Astronáuticas, em particular nos domínios da Economia do Transporte Aéreo, da Operação de Aeronaves, da Segurança de Voo, e da Gestão de Projetos Aeronáuticos, com o título Transporte Aéreo e Análise Global de Apoio à Decisão. Nesta secção descreve-se o enquadramento da tese, a definição do problema abordado e os objetivos do doutoramento, o argumento e as principais contribuições da tese e finaliza com a apresentação das principais conclusões e os possíveis trabalhos futuros de investigação.

Enquadramento da Tese

Desde o início da aviação que os aeroportos detêm um papel fulcral na Engenharia Aeronáutica. O conceito de aeroporto modificou-se muito durante o último século passando de pequenos aeródromos para *hubs* internacionais. Assim estas infraestruturas aeroportuárias têm vindo a assumir um papel muito importante no que diz respeito ao desenvolvimento económico das regiões em que se inserem. O surgimento do conceito de cidade aeroporto, como um novo modelo organizacional de sucesso, sugere que para qualquer infraestrutura do género ser competitiva o deve adotar.

A indústria aeroportuária tem uma grande influência na economia global e os equilíbrios entre o interesse público em geral, os acionistas em particular, e os operadores aeroportuários devem procurar ser conciliados.

O impacto esperado na economia por uma infraestrutura aeroportuária pode ter diferentes escalas, nomeadamente à de um continente, um país, uma região ou mesmo uma cidade. Estes impactos estabelecem quais os critérios de decisão para a construção (ou não) de novas infraestruturas aeroportuárias assim como para efetuar melhorias (ou não) nas mesmas.

A procura de ferramentas que permitissem uma avaliação apropriada dos processos de gestão de uma infraestrutura aeroportuária, a aferição da posição do aeroporto comparativamente aos seus congéneres (benchmarking) surge como a essencial; no entanto, a complexidade dos modelos utilizados tornam as ferramentas pouco amigáveis para a administração aeroportuária, para além de que o foco essencial deste tipo de estudos é normalmente parcelar e complexo e não envolvem todas as componentes operacionais, financeiras, ambientais e dos agentes na vizinhança do aeroporto. Estes condicionalismos reforçam a ideia de que é essencial o desenvolvimento de uma ferramenta global de análise para encontrar a perspetiva também global (lado ar, lado terra e agentes) do desempenho de qualquer aeroporto ultrapassando os desafios que se lhes colocarão num futuro próximo e realizando uma aferição completa com o dos seus competidores diretos.

A construção de uma nova metodologia impõe que se tenha em consideração as infraestruturas aeroportuárias, lado terra e lado ar, os clientes, os acionistas e os operadores aeroportuários.

Assim, uma análise bem fundamentada para uma Decisão a nível Global (GDA - Global Decision Analysis) irá incorporar numa só ferramenta todas as interligações entre todos os intervenientes da infraestrutura. O GDA será, pois, mais amigável para os *stakeholders* tendo em vista a gestão e otimização das decisões e necessariamente que terá de ser construída e validada sobre bases de dados muito precisas e atuais.

O benchmarking é uma ferramenta de autoaperfeiçoamento para qualquer organização permitindo identificar os próprios pontos fortes e fracos, compará-la com outras congéneres, e saber mais sobre como melhorar a sua eficiência. O benchmarking é uma forma simples de encontrar e adotar as melhores práticas para alcançar os resultados desejados. A aplicação de técnicas de benchmarking na indústria aeroportuária começou a ser aceite como uma ferramenta importante de gestão há (apenas) quinze a vinte anos, principalmente porque no passado as pressões sobre os negócios dentro do setor aeroportuário eram menos pronunciadas dado que os aeroportos estavam praticamente todos sob responsabilidade governamental.

O benchmarking de um aeroporto é uma componente chave no planeamento de vários procedimentos. Trata-se de uma ferramenta estatística (mas também contabilística) que permite monitorizar os indicadores de desempenho dos aeroportos. O benchmarking é fundamental para a implementação de um plano estratégico aeroportuário e a sua importância vai tão longe a ponto de identificar as melhores práticas para aumentar a eficiência e a qualidade.

Processos de benchmarking:

- São processos de gestão e mudança organizacional numa abordagem inicial, e evoluem para processos de medida e tecnológicos numa segunda fase;
- Oferecem uma ferramenta de diagnóstico para verificar se todos os sistemas estão alinhados e a funcionar corretamente;
- São uma ferramenta excelente da administração para monitorar as melhorias de desempenho numa base de autoavaliação do desempenho (self-benchmarking);
- São uma forma eficaz de identificar quer as melhores práticas utilizadas por outras infraestruturas congéneres para ver se aquelas podem ser incorporadas na organização, quer as práticas mais defeituosas para ver se estas podem ser eliminadas;
- São uma ferramenta muito útil para vincular metas estratégicas, potenciar o envolvimento e estimular a produtividade dos colaboradores.

Os principais interessados no processo de benchmarking aeroportuário são:

- Estado / Governo, por razões de regulação económica e ambiental;
- Companhias aéreas, para comparar custos e desempenho em diferentes aeroportos;
- Gestores, para executar o próprio negócio aeroportuário;

- Passageiros, para avaliar como eles mesmos são servidos;
- Proprietários, para entender o desempenho do negócio e como maximizar o investimento.

Existem vários trabalhos sobre a avaliação comparativa de aeroportos cada um utilizando diferentes indicadores de desempenho. Alguns deles usam indicadores simples (de desempenho) como, por exemplo, o número de posições de estacionamento de aeronaves (stands), enquanto outros consideram indicadores complexos (de eficiência) como, por exemplo, o número de passageiros por área do terminal de passageiros.

Pode afirmar-se que o benchmarking é atualmente, e em qualquer tipo de atividade, uma ferramenta essencial à vida das organizações. O meio aeronáutico em particular, marcado por uma competitividade crescente que começou nas companhias aéreas e que se estende já a todos os serviços de um aeroporto e da sua área envolvente, é um sector de atividade no qual só conseguem subsistir os que conseguem obter desempenhos e eficiências mais elevados. Portanto, faz todo o sentido que o benchmarking seja utilizado como meio de gestão e de planeamento.

Existem várias ferramentas de avaliação do desempenho de um aeroporto, nomeadamente:

- o Método da Medida Parcial - que usa dados parciais para comparar o desempenho do aeroporto-alvo numa única dimensão como, por exemplo, na vertente económica;
- a Análise Multicritério (MCDA) – é um dos métodos menos utilizados, cuja aplicação é subdividida em dois passos: o primeiro é a seleção dos indicadores e a atribuição dos seus pesos relativos, e o segundo é a classificação das diferentes opções;
- a Análise Paramétrica de Fronteira com Aproximação Estocástica (SFA), por vezes referida como Abordagem de Fronteira Econométrica - é um dos métodos paramétricos mais utilizados para avaliar a eficiência aeroportuária;
- a Análise Envoltória de Dados (DEA) - é uma abordagem não paramétrica que não requer suposições de forma funcional para calcular o desempenho de cada aeroporto relativamente a todos os outros e permite obter avaliações posteriores da eficiência relativa dos resultados, quer tenham sido planeados ou executados; e
- o Fator de Produtividade Total (TPF) - em economia o TFP é a variável que toma em consideração os efeitos na(s) saída(s) dos processos que não foram causados pela(s) entrada(s); o TPF permite a aferição dos impactos da rentabilidade e das diferenças de produtividade no desempenho do aeroporto; este método também pode ser utilizado para inferir acerca do impacto no desempenho das variações dos preços de entrada e saída.

Da análise cuidada sobre os diferentes métodos para avaliar o desempenho de um aeroporto, suas características, vantagens e desvantagens, aquele que parece compreender as características

ideais para desenvolver este trabalho, uma visão holística do aeroporto, é o da Análise Multicritério de Apoio à Decisão (MCDA).

O MCDA – MACBETH Medição da Atratividade por uma Técnica de Avaliação Baseada em Categorias (*Measuring Attractiveness by a Categorical Based Evaluation Technique*) é uma metodologia de apoio à tomada de decisão que permite avaliar opções tendo em conta múltiplos critérios. O que distingue este método de outros métodos de apoio à decisão é o fato de requer apenas julgamentos qualitativos sobre as diferenças de atratividade entre elementos, que por sua vez gera pontuações para as opções em cada critério e para ponderar critérios. O MACBETH tem a particularidade de introduzir sete categorias semânticas de diferença de atratividade: nula, muito fraca, fraca, moderada, forte, muito forte e extrema. Esta forma de categorizar as diferenças de atratividade dá origem ao nome do próprio método.

Deste modo este método permite ao avaliador expressar os julgamentos qualitativos, e uma vez validada a sua consistência, pode depois ser construído um modelo quantitativo de avaliação. Em sequência, é elaborada uma escala de pontuações em cada critério, onde os pesos relativos para os critérios podem ser manipulados. Por último, é calculada uma pontuação global para cada opção com a soma ponderada das suas pontuações nos múltiplos critérios, refletindo-se assim a atratividade da opção respetiva no conjunto de todos os critérios. Para uma melhor compreensão do problema a avaliar podem ser efetuadas diversas análises de sensibilidade e robustez dos resultados do modelo. Estas análises permitem não só indiciar ajustes ao modelo como também formar convicções sobre as prioridades a estabelecer ou quais as opções a selecionar quer em contextos de tomada de decisão individual quer em grupo.

Em regra, a avaliação do desempenho do aeroporto e da respetiva eficiência é feita utilizando dados operacionais e financeiros, como citado anteriormente, permitindo assim ao decisor conhecer a sua posição num conjunto de aeroportos. No entanto, esta metodologia pode não fornecer uma perceção fácil e imediata da(s) relação(ões) entre essa posição do aeroporto na classificação de conjunto e o valor gerado devido a essa posição dentro de um, ou vários, outros sistemas de negócios abrangendo toda a infraestrutura aeroportuária e/ou as inter-relações que ele pode estabelecer com a área circundante (*catchment area*).

A introdução de um sistema global de avaliação aeroportuária com a abrangência de seis áreas distintas e respetivos indicadores levanta diversos desafios. Primeiro, os diferentes perfis dos agentes envolvidos, tais como os clientes e os acionistas. Segundo o modo como os dados devem ser recolhidos, armazenados e disponibilizados. Terceiro de que modo se deve parametrizar, analisar e produzir decisões baseadas nos dados obtidos. Quarto, qual o modo a usar para informar todos os agentes sobre as decisões tomadas e por fim determinar o efeito causado pelo uso desta ferramenta global.

O âmbito desta tese é limitado a sistemas computadorizados de apoio à decisão que incluem bases de dados com informação sobre as infraestruturas aeroportuárias recorrentes da atividade desenvolvida em cada aeroporto, nomeadamente no que diz respeito a seis das suas aéreas chaves

de atividade: medidas fundamentais de atividade aeroportuária, como passageiros e operações, segurança, qualidade do serviço, produtividade e eficiência, financeira e comercial, e ambiental. O trabalho de investigação desenvolvido nesta tese foca-se nos desafios decorrentes da aplicação de rótulos da classificação anual de infraestruturas aeroportuárias que decorram de uma regulamentação baseada no uso da metodologia MCDA-MACBETH que permitam a integração de classificações de desempenho e eficiência e no benchmarking interno e externo destas infraestruturas. O trabalho de investigação apresentado nesta tese está focado no desafio da aplicação desta metodologia como instrumento holístico na gestão e classificação de infraestruturas aeroportuárias, mais concretamente num sistema que permita a integração dos dados aeroportuários com os sistemas de apoio à decisão. Finalmente, a decisão suportada através do modelo matemático implementado que é parte integrante do sistema de monitorização permite proceder a uma classificação de eficiência e desempenho anual de todas as áreas chave do aeroporto, esta classificação decorre da metodologia proposta de avaliação dos sistemas de infraestruturas aeroportuárias nas suas diferentes dimensões.

Descrição do Problema e Objetivos da Investigação

O problema abordado nesta tese de doutoramento é o diagnóstico holístico de uma infraestrutura aeroportuária utilizando um sistema de monitorização baseado em ferramentas multicritério de apoio à decisão, que deste modo garanta a obtenção de uma avaliação precisa e que contribua para uma melhoria da perceção por parte dos decisores nas decisões necessárias pelos profissionais envolvidos na gestão aeroportuária. Tendo em conta o impacto deste tipo de sistemas este estudo inicialmente teve como objetivo caracterizar os sistemas de apoio à decisão aeroportuária e as suas bases de dados existentes. As bases de dados existentes como a do Sistema de Gestão de Segurança (SMS), que é composto por um conjunto proativo, sistemático e prescritivo de diretrizes, políticas e práticas para gerir a segurança de uma operação relacionada com o aeroporto, a companhia aérea ou a aviação geral. A Administração Federal de Aviação (FAA) americana, define o SMS como uma ação de baixo custo e formal, idêntica a uma empresa, para a gestão do risco na segurança. Inclui atuações, práticas e políticas metódicas para a administração da segurança (incluindo gestão do risco na segurança, garantia de segurança, políticas de segurança, e promoção de segurança).

Uma infraestrutura aeroportuária é multidimensional, o que requer o acompanhamento por diversos profissionais em diferentes especialidades, e as organizações de aviação devem cumprir regulamentos, requisitos para sistemas de gestão, por exemplo, qualidade da segurança, ambiente e segurança no trabalho. Os padrões para a qualidade, ambiente e saúde e segurança ocupacional [1], [2] foram integrados entre si para permitir que os aeroportos alinhem ou integrem os vários sistemas de gestão caso o desejem [3]. Os requisitos comuns para os fornecedores de serviços de navegação aérea permitem que as organizações combinem os diferentes sistemas de gestão num sistema de gestão geral, pelo que é extremamente importante entender como os sistemas interagem dado que será desejável que a informação possa ser disponibilizada de forma fácil e

segura, evitando-se assim redundância de dados, rápida obtenção do historial do aeroporto nas diferentes dimensões e ainda permitir o armazenamento de dados de forma segura e permanente.

Infraestruturas complexas como aeroportos fornecem um desafio ao estabelecer um sistema de medição de desempenho apropriado. A medição de desempenho é uma atividade de gestão crítica, tanto no nível operacional de um aeroporto quanto em um nível mais amplo do sistema. O advento da comercialização e privatização de aeroportos e serviços relacionados requer uma avaliação correta para fornecer serviços de qualidade de forma eficiente em todas as dimensões operacionais do aeroporto [4]. Além disso, a conectividade entre software e o hardware, a complexidade da topologia da rede, a implementação, manutenção e custos são limitações adicionais ao uso um sistema de medição de desempenho na monitorização de infraestruturas aeroportuárias.

A tomada de decisão nas infraestruturas aeroportuárias enfrenta uma nova abordagem chamada Tomada de Decisão Colaborativa. Este conceito foi definido FAA como um valor cooperativo entre os vários integrantes do transporte aéreo para trocar esclarecimentos para uma melhor tomada de decisão, quer da indústria quer do governo. É considerado pela FAA um conceito-chave no futuro dos sistemas de transporte aéreo [5].

Na Europa, já existe um conjunto de 28 aeroportos europeus que cumprem o A-CDM, a tomada de decisões colaborativas aeroportuárias, como Amsterdão, Barcelona, Berlim Schönefeld, Bruxelas, Copenhague, Düsseldorf, Frankfurt, Genebra, Hamburgo, Helsinque, Londres Gatwick (troca de mensagens entre o aeroporto de Gatwick e o NMOC está temporariamente suspenso), Londres Heathrow, Lyon-Saint Exupéry, Madri, Milão Malpensa, Milão Linate, Munique, Nápoles, Paris CDG, Paris Orly, Oslo, Palma de Maiorca, Praga, Roma Fiumicino, Estocolmo Arlanda, Stuttgart, Veneza, Zurique [6]. O A-CDM tem uma série de objetivos, como reduzir atrasos, o melhorar a previsibilidade do sistema existente e otimizar recursos e reduzir os impactos ambientais ao implementá-lo [7].

Os sistemas de apoio à decisão propostos na literatura apresentam igualmente limitações, nomeadamente em termos de ubiquidade e acessibilidade. A complexidade do contexto aeroportuário levanta diversos desafios para o desenho, desenvolvimento e aplicação dos sistemas de apoio à decisão aeroportuária, essencialmente devido à dificuldade de modelação de problemas envolvendo um grande número de variáveis. Esta dificuldade resulta geralmente em sistemas pouco precisos devido à exigência na especialização ou à falta de dados, e conseqüentemente em avaliações incorretas e inadequadas.

O principal objetivo desta tese é o de apresentar um sistema holístico integrado para a monitorização de uma infraestrutura aeroportuária que ao mesmo tempo proporciona a integração da base de dados e o sistema de apoio à decisão e que permite obter a classificação de desempenho e eficiência anual. O sistema terá de ser capaz de monitorar o aeroporto nas suas áreas chave o que permite a criação de relatórios e alertas e produzir classificações de Benchmarking interno (dentro da própria infraestrutura aeroportuárias) e Benchmarking externo

(comparando com outras infraestruturas aeroportuárias). Estas ações devem ser baseadas em modelos matemáticos adequados e o acesso à informação deve ser facultado de forma ubíqua e amigável a todos os intervenientes.

O trabalho de investigação necessário para cumprir com o objetivo proposto anteriormente levou à estruturação dos seguintes objetivos secundários:

1. Compreender as soluções existentes relacionadas com os sistemas de apoio à decisão usadas para a avaliação de infraestruturas aeroportuárias, descrevendo as diferentes abordagens e apresentando as suas limitações e vantagens de modo que, no estado da arte, estejam representados os diferentes métodos de decisão e respetiva caracterização em termos de políticas, áreas e indicadores chave, gestão, apoio à decisão, ubiquidade e acessibilidade da informação.
2. Compreender as soluções existentes relacionadas com a avaliação de infraestruturas aeroportuárias no que diz respeito à sua avaliação de desempenho e eficiência das mesmas destacando-se as metodologias aplicadas para a obtenção de dados entre o decisor e os setores avaliados.
3. Comprovar a aplicabilidade holística e a exequibilidade do sistema de monitorização e classificação proposto envolvendo as áreas chave da infraestrutura e os decisores associados, aplicado a uma infraestrutura aeroportuária usando como referência o maior aeroporto português.
4. Apresentar um novo método capaz de apoiar os decisores com base nas condições e nos dados da infraestrutura em sintonia com os regulamentos, requisitos para sistemas de gestão, e políticas definidas. Este método será suportado por metodologias matemáticas e deverá ser desenvolvido tendo em conta os critérios de simplicidade, fiabilidade e precisão.

Argumento da Tese

Esta tese propõe uma abordagem inovadora para a monitorização e subsequente avaliação e classificação de infraestruturas aeroportuárias tendo como base a aplicação holística a qualquer infraestrutura aeroportuária promovendo assim uma classificação simplificada e de uso generalizado. O argumento desta tese é o seguinte:

O carácter multidimensional e subjetivo da avaliação de uma infraestrutura aeroportuária requer soluções que incluam todos os intervenientes para uma boa persecução da gestão e otimização da utilização destas infraestruturas. Em primeiro lugar, o decisor deve ser capaz de interagir com o sistema de uma forma amigável e simplificada usando ferramentas de uso generalizado. Em segundo lugar, os dados recolhidos devem ser armazenados numa plataforma que garanta a segurança, integridade e acessibilidade por parte dos decisores. Em terceiro lugar, o sistema da tomada de decisão tem que apoiar decisores envolvidos, através da apresentação de informação

baseada nos dados obtidos ou em previsões que devem originar ajustes nos indicadores destacados em cada área chave. Além disso, o sistema deve gerar etiquetas com as classificações de cada área chave apresentando o grau de desempenho e também a eficiência global da infraestrutura, utilizando a regulamentação de classificação promovida através do modelo proposto baseado na metodologia multicritério MACBETH.

A sustentação deste argumento, foi realizada segundo a seguinte abordagem:

O problema e a área de investigação foram estudados tendo em conta os estudos de avaliação de desempenho e eficiência de aeroportos, o benchmarking aeroportuário, os processos de tomada de decisão, e as metodologias aplicadas para essa avaliação, assim como, sistemas de monitorização ubíquos baseados na Internet ou em softwares de uso generalizado. A revisão da literatura, para estas temáticas, foi realizada de uma forma sistemática e apresentada de forma detalhada demonstrando as vantagens e limitações associadas.

A aplicabilidade holística e a exequibilidade do sistema de monitorização e classificação proposto foram comprovadas envolvendo todas as áreas de um aeroporto tendo por base o aeroporto português de Lisboa (Aeroporto Humberto Delgado usando um período de análise de 11 anos desde 2003 a 2013). Durante este período foram recolhidos dados referentes aos 42 indicadores chave distribuídos em 6 áreas chaves de modo a construir a base de dados em conformidade com o estipulado pela ACI e adotado neste sistema. Foi enviado e preenchido um questionário online por especialistas em infraestruturas aeroportuárias, desde gestores, engenheiros, controladores aéreos, académicos, militares, entre outros, permitindo recolher as opiniões baseadas na experiência profissional e pessoal de cada um.

Finalmente, o modelo de apoio à decisão, foi também criado baseado nos descritores de desempenho, definidos através das opiniões dos especialistas para cada um deles e um sistema de classificação de eficiência baseado nas classificações obtidas pelos aeroportos de teste. Foi também desenvolvida uma norma para a certificação de eficiência aeroportuária e desenvolvida uma etiqueta gráfica com 5 níveis de realização com a respetiva regulamentação e implementação. O modelo proposto inclui a análise multicritério MACBETH e a análise estatística que permite produzir alertas localizados, relatórios e sugestões para a melhoria do desempenho e da eficiência da infraestrutura aeroportuária.

Principais Contribuições

Esta tese tem como primeira contribuição o enquadramento do desempenho e eficiência de um aeroporto como um subsistema do transporte aéreo, usando para tal a descrição sistemática do transporte aéreo, caracterizando e esquematizando este sistema complexo.

O estado da arte e a revisão bibliográfica realizada no capítulo 3, é uma descrição detalhada dos estudos existentes em desempenho e eficiência aeroportuária, em processos de benchmarking em aeroportos, em processos e sistemas de apoio à decisão, e são a segunda contribuição desta tese.

A terceira contribuição é a proposta de um modelo matemático para determinar o desempenho e eficiência de uma infraestrutura aeroportuária, baseado em sistemas capazes de lidar com múltiplas fontes de dados e capaz de integrar a opinião de especialistas deste tipo de atividade. No capítulo 4 é proposto um modelo qualitativo com base no modelo de análise multicritério de apoio à decisão MACBETH combinado com um modelo quantitativo baseado nos descritores de desempenho obtidos através da consulta de opinião de especialistas e na comparação entre os valores das expectativas matemáticas estabelecidas com os resultados obtidos. Este modelo está descrito de forma exaustiva neste capítulo e culminou na submissão de um artigo para publicação numa revista internacional com indexação ISI.

Como quarta contribuição desta tese, é proposta a monitorização do desempenho e eficiência baseado numa plataforma online e no software Excel da Microsoft o que permite a instalação em qualquer computador ou o acesso através da internet. O *Performance and Efficiency Support Analysis for Airport Global Benchmarking* PESA-AGB tem a capacidade de produzir relatórios em tempo real, alertas, bem como apoiar as decisões. Através deste sistema é possível implementar uma certificação de desempenho e eficiência com a atribuição de uma classificação qualitativa baseada na regulamentação proposta, o desenvolvimento da proposta de certificação está descrito no capítulo 5.

A quinta contribuição consiste na análise da adequação e precisão deste modelo quando aplicado a tomadas de decisão relacionadas com a melhoria e otimização do desempenho e eficiência das infraestruturas aeroportuárias estudadas através do caso de estudo que se encontra descrito em detalhe no capítulo 6.

A sexta contribuição é a proposta de um modelo global de avaliação aeroportuário de apoio à decisão, o GDA, com base na imputação de dados combinada com um modelo de análise multicritério de apoio à decisão MACBETH – PESA-AGB. Foi analisada a adequação e precisão deste modelo quando aplicado a tomadas de decisão relacionadas com as áreas em estudo, que tem como base um artigo submetido para publicação numa revista internacional com indexação ISI.

Principais Conclusões

Todas as premissas resultantes deste trabalho de investigação foram testadas no laboratório de investigação em transportes do Núcleo de Investigação em Transportes (NIT), de modo a produzirem evidências inequívocas dos conceitos e técnicas propostas. A análise das metodologias utilizadas pelos sistemas de apoio à decisão em infraestruturas aeroportuárias e a aplicação do modelo de apoio à decisão proposto a estas infraestruturas foi implementado de modo a validar a sua aplicação holística através da utilização do Microsoft Excel combinado com a metodologia multicritério MACBETH.

A realização do principal objetivo proposto referente ao desenvolvimento de um sistema holístico integrado para a monitorização de uma infraestrutura aeroportuária que ao mesmo tempo proporciona a integração da base de dados e o **sistema de apoio à decisão** e que permite obter

a classificação de desempenho e eficiência anual através de uma plataforma online e do Excel, utilizando uma base de dados segura e em complemento um sistema de apoio à decisão que pode gerar alertas em tempo real e mensagens para os gestores aeroportuários.

A inclusão efetiva de especialistas e decisores, a interoperabilidade e a aplicação holística para sistemas de monitorização de desempenho e eficiência aeroportuária levantam desafios e preocupações para sua aplicação, conceção e desenvolvimento. A interação amigável com o sistema permite potenciar as melhores decisões e acompanhamento baseados em sistemas de monitorização que visam resultados mais precisos e a otimização das decisões.

Assim, existem várias limitações às várias abordagens que têm sido propostas na literatura. Primeiro, grande parte dos sistemas de avaliação aeroportuária são projetados para interagir diretamente com os gestores sem ter em conta as linhas estratégicas de gestão. Em segundo lugar, a partilha e acesso à informação, é muitas vezes inexistente ou impraticável. Em terceiro lugar, estes sistemas são geralmente limitados em termos de integração de dados com todas as áreas de análise de uma infraestrutura aeroportuária. Em quarto lugar, a fiabilidade e a precisão desses sistemas são raramente demonstradas. Em quinto lugar, o estudo sobre a avaliação holística de infraestruturas aeroportuárias permanece escasso ou mesmo inexistente.

Deste modo, o objetivo principal foi propor uma alternativa que não esteja limitada pelas restrições mencionadas acima. Os objetivos secundários foram estabelecidos por forma a repartir o trabalho de investigação numa componente teórica e prática, para atingir o objetivo principal. A componente teórica foi baseada no estudo das soluções existentes relacionadas com a metodologia multicritério MACBETH utilizada como apoio à decisão, além disso, questionários e pontuações foram as técnicas de gestão de conteúdos encontradas na literatura.

A componente prática consistia na implementação num aeroporto próprio do modelo GDA, não sendo possível adquirir todos os dados necessários do aeroporto de Lisboa, a avaliação aeroportuária foi realizada com 85% dos dados reais para o período de avaliação 2003-2013, sendo o restante recolhido em aeroportos brasileiro e americanos com características semelhantes ao aeroporto de Lisboa. No entanto, foi possível demonstrar e validar o modelo para aplicar o GDA a um conjunto real de dados contribuindo para uma compreensão mais amigável das melhorias e lacunas no desempenho e eficiência aeroportuária.

Perspetivas de Investigação Futuras

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

- I. As futuras versões, do modelo PESA-AGB, devem incluir novos KPAs, como no caso da área de influência do aeroporto (Hinterland), introduzindo os respectivos KPIs de tráfego, socioeconómicos e de turismo.

- II. Estabelecer cooperação formal com gestores de aeroportos para aplicar o GDA a novos aeroportos em cenários de casos reais.
- III. Um dos fatores que deve ser analisado em estudos futuros é a sazonalidade das operações em alguns aeroportos. Outro fator é estudar a sensibilidade das pontuações KPA em relação aos pesos dos especialistas para cada KPI e KPA.
- IV. Alargar os estudos de caso para os outros níveis do processo ascendente, subestimando KPAs de aeroporto e cada um dos 42 KPIs e um grupo de aeroportos ao longo de todas as pontuações de desempenho de aeroportos com características diferentes, como aeroportos de carga insular, remota e LCC.
- V. O desenvolvimento de uma base de dados na web possibilitando a consulta livre de dados agregados centralmente com a chancela da ICAO, ACI ou EUROCONTROL que permitiria classificar todos os aeroportos de acordo com os mesmos padrões.
- VI. Investigação futura poderá correlacionar a interação da etiqueta APE-Label com a sensibilidade dos KPIs e KPA às opiniões de especialistas e possibilitar a aplicação desta APE-Label a um vasto conjunto de aeroportos.

Abstract

Since the beginning of aviation, airports have played a pivotal role in Aeronautical Engineering. The airport concept has changed a lot over the past century from small airfields to international hubs. These airport infrastructures have played a significant role in the economic development of the regions they operate. The emergence of the airport city concept as a new successful organisational model suggests that any infrastructure of this kind to be competitive should adopt it. With all its inputs and outputs, the airport industry significantly influences the global economy. The balance between the public interest in general, shareholders, and airport operators must seek to be reconciled.

I was investigated how it would be possible to determine whether an airport would have the expected impact on the economy at different scales. Those scales could be that of a continent, a country, a region, or even a city and establish the decision criteria for building (or not) new airport infrastructures and making improvements (or not) in them. Searching for tools that would allow an appropriate evaluation of the management processes of an airport, the measurement of the position of the airport compared to its counterparts (benchmarking) is essential. However, the complexity of the models used makes this tool unfriendly for airport administration. Apart from that, the essential focus of this type of study is the land side of the airport. Nevertheless, there are other types of studies for evaluating the performance of airport processes. Still, these are also complex and do not involve all operational, financial and agent components near the airport.

The studies review reinforces the idea that a global analytical tool is essential to find the global perspective (airside, landside, and agents) of any airport's performance beyond the challenges that will be put to them soon and a complete benchmark of direct competitors. The construction of a new methodology requires that airport, land, and airside infrastructures be considered, and agents near the airport, customers, shareholders and airport operators. Thus, a well-founded analysis for a Global Decision Analysis (GDA) incorporates all the infrastructure stakeholders' interconnections in a single tool. GDA is, therefore, friendlier to stakeholders given the management and optimization of decisions based on an analysis system based on the MACBETH multi-criteria methodology, the PESA-AGB. This tool was built and applied to an airport with dimensions identical to Lisbon airport, demonstrating and comparing the evolution of performance and efficiency over 11 years from 2003 to 2013 by six key performance areas of the airport and the respective key performance indicators.

The development of an airport efficiency tag for each year of assessment was implemented. An APE-Label implementation, applied to any airport, is presented, and discussed in this study regardless of its size and location. The main obstacle to implementing this APE-Label is the heterogeneity of the airport infrastructure since it differs in the number of runways for public, private or even public-private property, among others. However, with the PESA-AGB methodology, it was possible to mitigate this factor. The main proposal is to provide a graphical APE-Label that informs all interested parties which infrastructure assessment is analysed across

the six key performance areas each year that will help to maximize performance and efficiency standards.

For the airport case study, a self-benchmarking analysis was carried out for the airport's study with distinctive characteristics representing the central Portuguese air infrastructure. The airport in study is considered the largest in terms of passengers, movements and cargo and is associated with Lisbon airport. Finally, the results of PESA-AGB and GDA have been presented in two visual analysis panels. The dashboards and the GDA report and recommendation are prepared.

Keywords

Air Transport; Global Decision Analysis; Airport Performance; Airport Efficiency; MCDA-PESA-AGB

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List of Acronyms

A-CDM	Airport Collaborative Decision Making
ACRP	Airport Cooperative Research Program
ACI	Airports Council International
AHP	Analytic Hierarchy Process
ATARD	Air Transportation and Regional Development
ATC	Air Traffic Control
ATEM	Air Transport Economy and Management
CDM	Collaborative Decision Making
DEA	Data Envelopment Analysis
DSS	Decision Support System
EASA	European Aviation Safety Agency
ELECTRE	ELimination Et Choix Traduisant la Realité that is, Elimination and Choice Expressing Reality
FAA	Federal Aviation Administration
GDA	Global Decision Analysis
GDA - MRR	Global Decision Analysis - Model Report and Recommendations
GDP	Gross Domestic Product
IATA	International Air Transport Association
ICAO	International Civil Aviation Organization
KPA	Key Performance Area
KPI	Key Performance Indicator
LPPs	Linear Programming Problems
MACBETH	Measuring Attractiveness by a Categorical Based Evaluation Technique
MCDA	Multi-Criteria Decision Analysis
NextGen	Next Generation Air Transportation System
PESA	Performance and Efficiency Support Analysis
PESA – AGB	Performance and Efficiency Support Analysis for Airport Global Benchmarking
PESA-GB	Performance and Efficiency Support Analysis for Global Benchmarking
PROMETHEE	Preference Ranking Organization Method for Enrichment of Evaluations

SESAR	Single European Sky ATM Research
SFA	Stochastic Frontier Analysis
SFPM	Single-Factor Productivity Measures
TOPSIS	Technique for Order Preference by Similarity to Ideal Solution
TRT	Transportation Research Team
TRB	Transportation Research Board
TFP	Total Factor Productivity
UBI	University of Beira Interior
US	United States
UK	United Kingdom
VFP	Variable Factor Productivity
WLU	Work Load Unit
WSM	Weighted Sum Methods

Chapter 1

Introduction

1.1 Thesis Focus and Scope

1.2 Problem Definition and Research Objectives

1.3 Thesis Statement and Main Contributions

1.4 Thesis Organization

1. Introduction

This thesis addresses the subject of Air Transport Economy and Management (ATEM) for airport efficiency and performance assessment and management. This chapter describes the focus and thesis scope further, with the problem definition and objectives, the thesis statement, main contributions, and thesis organisation.

1.1 Thesis Focus and Scope

Air transportation can be observed as a very complex system. This system perspective focuses on operations and physical elements working together for the system to be effective. Still, it also highlights the vital impact air transportation has on economic development, environmental quality, and national security.

Ever since the 18th century, when the first balloons astonished Europe, air transportation has figured prominently in the visions of inventors and military strategists. At the beginning of the 20th century, heavier than air machines began to show the capabilities that in later years would transform long-distance. At Present, the world's air transportation system is a crucial element of the world economy, and it is growing [8]. The increased from 9 million in 1945 to over 1.6 billion airline passenger trips worldwide suggests that the travelling public has adopted air travel as an essential means of long-distance transportation.

According to International Civil Aviation Organization (ICAO), an aerodrome is a defined area on land or water (including any buildings, installations and equipment) intended to be used either wholly or in part for the arrival, departure and surface movement of challenges faced by airlines and the aviation industry [8]. Over the past few years, it was compelled to rethink how they do business both at the financial and operational levels. To fully leverage the airport's new role as multimodal commercial centres and attracting companies, planners and developers have a meaningful and challenging position since airports are no longer just airports. These platforms have become nodes of a new intermodal transport system for both people and goods and unique cities in an enormous worldwide competition [9].

Another critical aspect, as Oum *et al.*[10] presented is the liberalisation of the airline industry worldwide. It has boosted the demand for more efficient and faster processing of aircraft, passengers, cargo and baggage. Air carriers choose the most efficient airports to allocate and expand operations, improve service quality, and reduce their costs. Airport managers are being faced with new questions every day in an era of growing commercial pressures. Thus, airports need to provide the services most efficiently, applying the best practices over airport operations within the industry practices.

With all its inputs and outputs, the airport industry has a substantial influence on the global economy. It must find an optimal level for balancing the interests of the public in general, the

stakeholders, and all the airport operators. The benchmarking of airports is essential to give all stakeholders the appropriate tools to participate in the management process of such infrastructures. The use of benchmarking benefits is a straightforward means to identify performance deficiencies or exceptional performance without detailed and complex examination of processes.

There has been an increased interest in utilising benchmarking to assess and improve performance, as many airports have transformed from government-operated public utilities to privately operated commercial enterprises. Some different aspects of the airport business were examined through Benchmarking [11],[12]:

- Pricing - the cost to the airline of flying to the airport regarding landing fees and terminal charges [13], [14],
- Service quality: customer satisfaction levels, average queue times, incidences of delays [15], [16],
- Cost - unit cost, such as operating or total cost per Work Load Unit¹ (WLU) [17],
- Productivity or efficiency - Total Factor Productivity (TFP), Variable Factor Productivity (VFP), or single-factor productivity measures [10], [17]–[20].

The results of these benchmarking studies are often used to highlight some positive or negative aspects of an airport – highest customer satisfaction in Asia, the most efficient airport in North America[21], [22], most costly airport in the world. Nevertheless, it is essential to understand how these statistics are produced and how different approaches and data quality can affect the results.

A revision of airport benchmarking studies made by Liebert and Niemeier [23] and [24] refers to different methodologies applied to a wide variety of airport areas and activities. The most frequently used methods are Data Envelopment Analysis (DEA), parametric stochastic frontier analysis and the price index total factor productivity [25]–[31]. The performance of airports using DEA was used to benchmark national infrastructures, including Portugal, Spain, Australia, U.S, U.K., Taiwan, and airports worldwide [29], [32].

1.2 Problem Definition and Research Objectives

1.2.1 Problem Definition

The problem addressed in this doctoral thesis is how to make the holistic diagnosis of an airport infrastructure using a multicriteria decision support tools-based monitoring system that, in this

¹ Work Load Unit (WLU) - Defined generally as one passenger or 100 kilograms of cargo

way, guarantees a precise evaluation and that contributes to an improvement in the perception of the decisions needed by professionals involved in airport management.

This study initially aimed to characterise airport decision support systems and their existing databases, considering the impact of this type of system. The existing databases, such as the Security Management System (SMS), which is composed of a proactive, systematic and prescriptive set of guidelines, policies and practices, thus enabling the management of the safety of an operation related to the airport, airline or general aviation. The US Federal Aviation Administration (FAA) defines SMS as a low-cost, industry-like methodology to safety risk management. It incorporates systematic practices, procedures, and policies for security risk management, security policies, security assurance and security promotion [33].

Airport infrastructures are multidimensional, requiring follow-up by several professionals in different specialities. Aviation organisations must comply with regulations and requirements for management systems, e.g. safety quality, environment, and safety at work. The standards for quality, environment and occupational safety and health [1], [2] have been integrated to allow airports to align or integrate the various management systems if they wish [3]. Standard requirements for air navigation service providers enable organisations to combine different management systems into a global management system. Thus, it is imperative to understand how systems interact. It will be desirable for information to be made available quickly and secure, thus avoiding redundancy of data, quickly obtaining the airport's history in the different dimensions, and still allowing data stored safely permanently.

Complex infrastructures such as airports provide a challenge in establishing an appropriate performance measurement system. Performance measurement is a critical management activity, both at the operational level of an airport and a broader system level. The advent of the commercialisation and privatisation of airports and related services requires a correct assessment to efficiently provide quality services in all airport operational dimensions [4]. Also, connectivity between software and hardware, network topology complexity, implementation, maintenance, and costs are additional limitations to using a performance measurement system for monitoring airport infrastructures.

Decision making in airport infrastructures faces a new approach called Collaborative Decision Making. The FAA defined this concept as a collaborative endeavour between the various elements of air transport, both government and business, to trade information for better decision making. It is considered by the FAA a key concept in the future of air transport systems [5].

In Europe, there are already a set of 28 European airports that comply with the collaborative airport decision making (A-CDM) such as Amsterdam, Barcelona, Berlin Schönefeld, Brussels, Copenhagen, Düsseldorf, Frankfurt, Geneva, Hamburg, Helsinki, London Gatwick (exchange of messages between Gatwick airport and NMOC is temporarily suspended), London Heathrow, Lyon-Saint Exupéry, Madrid, Milan Malpensa, Milan Linate, Munich, Naples, Paris CDG, Paris Orly, Oslo, Palma de Mallorca, Prague, Rome Fiumicino, Stockholm Arlanda, Stuttgart, Venice,

Zurich [6]. A-CDM has several objectives, such as reducing delays, improving the predictability of the existing system and optimising resources, and reducing environmental impacts by implementing it [7].

In the literature, the decision support systems proposed presents limitations concerning ubiquity and accessibility. The complexity of the airport context raises several challenges for designing, developing, and applying airport decision support systems, mainly due to modelling problems involving many variables. This difficulty usually results in inaccurate systems due to the requirement in the specialisation or the lack of data, and consequently in incorrect and inadequate evaluations.

1.2.2 Research Objectives

The main objective of this thesis is to present an integrated, holistic system for airport infrastructure monitoring that provides the integration of the database and the decision support system and allows obtaining the classification of annual performance and efficiency. The system will have to monitor the airport in its key areas that will enable the creation of reports and alerts and produce internal benchmarking ratings (within the airport infrastructure itself) and external Benchmarking (comparing with other airport infrastructures). These actions are based on appropriate mathematical models, and access to information is being provided in a ubiquitous and user-friendly manner. The research work required to meet the previously proposed objective led to the structuring of the following secondary objectives:

1. Understand the existing solutions related to the decision support systems used for the evaluation of airport infrastructures. Describing the different approaches and presenting their limitations and advantages so that, in state of the art, the different decision methods and their respective methods are represented characterisation regarding key policies, areas and indicators, management, decision support, ubiquity and information accessibility.
2. To understand the existing solutions related to evaluating airport infrastructures concerning their evaluation of their performance and efficiency, highlighting the methodologies applied to obtain data between the decision-maker and the sectors evaluated.
3. To prove the holistic applicability and feasibility of the proposed monitoring and classification model involving key infrastructure areas and associated decision-makers, applied to airport infrastructure using as reference the largest Portuguese airport.
4. Present a new method to support decision-makers based on infrastructure conditions and data in line with regulations, requirements for management systems, defined policies. This method will be supported by analytical methodologies and should be developed considering criteria simplicity, reliability and precision.

1.3 Thesis Statement and Main Contributions

The challenge of creating a system to apply a measurement model that included all airports worldwide in distinct environments and cultures and its efficiency certification is the motivational research work developed and described in this thesis. The research activities were performed in academic and enterprise environments. Although all diligence was made, it was impossible to work directly with the Portuguese airport's managers. Moreover, this unique experience was very fruitful, allowing the engagement in a European program, a COST action related to air transportation and regional development (ATARD). There were published articles in several international journals, conference proceedings and a book chapter, thus establishing permanent challenges that enhanced own research capabilities and skills. Also, the research work was based on international standards and guidelines by the International Civil Aviation Organization (ICAO), International Air Transport Association (IATA), Airports Council International (ACI), and European Aviation Safety Agency (EASA).

1.3.1 Thesis Statement

This thesis proposes an innovative approach for the monitoring and subsequent evaluation and classification of airport infrastructures based on the holistic application to any airport infrastructure, thus promoting a simplified and widely used classification. The argument of this thesis is as follows.

An airport infrastructure evaluation's multidimensional and subjective character requires solutions that include all the actors on great management persecution and optimisation of these infrastructures. First, the decision-maker should interact with the system user-friendly and simplified using commonly used tools. Secondly, decision-makers must store the data collected on a platform that guarantees security, integrity, and accessibility. Third, the decision-making system must support decision-makers involved by presenting information based on the data obtained or in forecasts that should lead to adjustments in the indicators highlighted in each key area. Also, the system should generate classifications labels of each key area showing the degree of performance and the overall efficiency of the infrastructure, using the classification regulation promoted through the proposed model based on the multicriteria methodology MACBETH.

The support of this argument was made according to the following approach.

The problem and the research area were studied, considering airport performance, efficiency evaluation studies, airport benchmarking, decision-making processes, and the methodologies applied for this evaluation and ubiquitous monitoring systems based on the Internet or widely used software. The literature review for these themes was carried out systematically and presented in detail, demonstrating the associated advantages and limitations.

The holistic applicability and feasibility of the proposed monitoring and rating system were proven, involving a test airport based on the Portuguese airport of Lisbon (Humberto Delgado

Airport and using an analysis interval of 11 years from 2003 to 2013. Data were collected on the 42 key indicators distributed in 6 key areas during this period, constructing the database as stipulated by the ACI and adopted in this system. An online questionnaire was sent to experts in airport infrastructures, from managers, engineers, air traffic controllers, academics, militaries, among others, allowing to collect the opinions based on professional and personal experience.

Finally, the decision support model was also created based on the performance descriptors, defined through the experts' opinions for each of them, and an efficiency classification system based on the ratings obtained by the test airport. A standard for the certification of airport efficiency was also developed, and a graphic label was created with five levels of accomplishment with the respective regulation and implementation. The proposed model includes the MACBETH multicriteria analysis and the statistical analysis that allows producing localised alerts, reports and suggestions for improving the performance and efficiency of the airport infrastructure.

1.3.2 Main Contributions

This thesis has its first contribution to the airport performance and efficiency framework as an air transport subsystem. The systematic description of air transport, characterising and schematizing this complex system.

State of the art and the literature review carried out in chapter 3 is a detailed description of existing studies on airport performance and efficiency, airport benchmarking processes, decision support processes and systems, which are the second contribution of this thesis.

The third contribution is the proposal of a mathematical model to determine the performance and efficiency of airport infrastructure, based on systems capable of handling multiple data sources and integrating the opinion of specialists of this type of activity. In Chapter 4, a qualitative model is proposed based on the multicriteria analysis model of decision support MACBETH combined a quantitative model based on the performance descriptors obtained through the specialists' opinion consultation and in the comparison between the values established mathematical expectations with the obtained results. This model is described exhaustively in this chapter, culminating in submitting an article for publication in an international journal with ISI indexing.

As the fourth contribution of this thesis, performance and efficiency monitoring based on dashboards and Microsoft Excel software are proposed, allowing installation on any computer. The Global Decision Analysis (GDA) model based on Performance and Efficiency Support Analysis (PESA) can produce real-time reports, alerts, and support decisions. Through this model, it is possible to implement performance, and efficiency certification labels, APE-Label, with the attribution of a qualitative classification based on the proposed regulation, the development of the certification proposal, and PESA-AGB scores described in chapter 5.

The fifth contribution consists of analysing the adequacy and precision of this model when applied to decision making related to the improvement and optimisation of the performance and efficiency of the airport infrastructure studied through a case study.

The sixth contribution is the proposed airport decision support system based on the data imputation combined with the multicriteria analysis model to support MACBETH – PESA – AGB. The adequacy and precision of decision-making related to an airport system with the Global Decision Analysis – Model Report and Recommendation (GDA – MRR) are described in detail in chapter 6.

1.4 Thesis Organization

This thesis is organised into seven core chapters. The subjects and organisation of these thesis chapters can be summarised as follows.

Chapter 1 describes the thesis context explaining the scope and focus of the research work and presenting the problem addressed by the thesis and the objectives to be accomplished and the thesis statement and the adopted approach for solving the problem. A thesis main contributions summary is included, followed by the description of the organisation and structure of the thesis.

Chapter 2 provides a theoretical framework for air transportation, presenting the motivation and background for airport performance and efficiency assessment and monitoring. It is described the air transportation system and subsystems, and it is provided with its schematic characterisation.

Chapter 3 provides a systematic review of the published work on airport performance and efficiency studies, airport benchmarking, the decision-making process in airports, and the different methodologies to assess airport performance and efficiency.

Chapter 4 focuses on the definition of a new model to assess the performance efficiency based on the multicriteria decision methodologies MACBETH – PESA as part of the Global Decision Analysis GDA described for airport evaluation. The survey preparation and characterisation, GDA indicators and possible scenarios are explained in detail.

Chapter 5 introduces the topic of airport labelling, presenting its basic concepts, regulation and implementation are proposed and described in detail: example, advantages, and promising improvements when applied to assess airport performance and efficiency. Moreover, the workflow of the proposed assessment system is explained in detail.

Chapter 6 provides the case study conducted in this research work. The primary purpose is to evaluate the feasibility of a global decision analysis model for assessing airport performance and efficiency. The proposed system in self-benchmarking is implemented and explained in is detailed, and further explanations are provided. Also, observed the airport in study feedback and recommendation are presented.

Chapter 7 presents this thesis's most important conclusions and contributions and discusses other directions for future research work.

Chapter 2

Air Transportation Theoretical Framework

2.1 Introduction

2.2 Air Transportation System

2.3 Airport as a Subsystem of Air Transportation

2.4 Airports Performance and Efficiency

2.5 Conclusion

2. Air Transportation Theoretical Framework

2.1 Introduction

Air Transportation is a complex system that focuses not only on physical and operations components that must be effective but also on its economic, safety, and environmental quality impacts in its geographical region. This chapter discusses the air transportation system from the airports perspective, considering the aircraft, airlines, and air traffic control system. Moreover, it describes passengers, airport management, and other stakeholders of the airport. Furthermore, this chapter emphasises the airport performance and efficiency as part of the air transportation system and possible future developments. Thus, the focus must be on the infrastructure, technology, airport, and airline operators as they most likely will be a catalytic factor for change.

2.2 Air Transportation System

The first balloons astonished Europe in the 18th century. Still, it was not until the beginning of the 20th century that machines heavier than air transformed long-distance travel and military strategists in the following years. Air transportation turned to a global travel and commerce primary driver since the first solo non-stop flight across the Atlantic Ocean in 1927 by Charles Lindbergh. Initially, with the focus on transportation of passengers and airmail, the connections of major cities were made by scarce pioneering airlines. Gradually, with jet aircraft launch, specifically, the Boeing 707 (Figure 2. 1), air transportation has expanded rapidly. Worldwide airline passengers thrive from 9 million (1945) to over 3.7 billion (2016), and it is expectable to double in the next 20 years [34]. Thus this suggests that travellers have adopted air travel as a primary means of long-distance transportation.

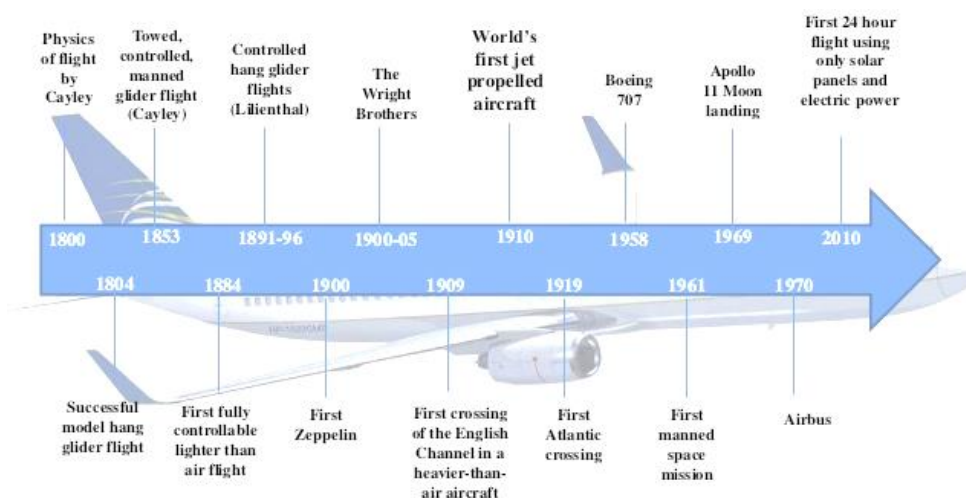


Figure 2. 1 - Aviation history timeline after 18th Century
Source: [35]

As an enabler for the carriage and hence the global exchange of people and goods, air transport plays a fundamental role in increasing connectivity and international economic and business development. It is one of the major forces behind the globalisation of production and distribution systems and is set to continue this role. In the European Union, air transport contributes 2.4% to the Gross Domestic Product (GDP) and generates 5.1 million jobs in more than 4,000 companies [36]. Air transport is also an essential enabler for tourism and business in regions difficult to reach by other transportation modes. Against this background, there is no surprise that air transportation demand has been growing regarding passengers and cargo [37].

Currently, the world's air transportation system is a growing critical component of the world economy. For example, even with September 11, 2001, terrorist attacks in the USA that caused fluctuations in the revenue passenger-kilometres (RTK), RTK is expected to increase by 5 per cent per year [38]. Economic prosperity can increase the demand for mobility and sequentially increase the use of air transport. Many studies conclude that a 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 [39].

Contrary to commonly considered, the air transportation business is a highly heterogeneous sector with a significant group of actors. What makes this a heterogeneous group is that while some airports remain subject to state control, others are fully privatised or even under a mixed regime. The privatised actors focus their business on profit maximisation. In contrast, the state-controlled ones aim to maximise socio-economic surplus, such as value-added and employment maximisation [40].

As depicted in Figure 2. 2 for the EU and Figure 2. 3 for the USA, the air transportation system complies with several actors, making this complex. All these systems pretend to deliver tangible benefits to operators and the flying public. The benefits and modernisation are intended to:

- pilots access to more information in the cockpit,
- air traffic controller has better tools that help to track and separate more efficiently and safely the aircraft,
- allowing airlines to fly in more efficient routes getting passengers faster to their destination, saving fuel and thus producing fewer exhaust emissions, and
- allowing the regulator more proximity to the aviation industry for a comprehensive initiative that integrates new and existing policies, procedures, and technologies.

It is widely accepted that to increase performance, ATM modernisation should focus on the flight's need as a whole and not in segmented portions, as is the case today [41].

With this expansion, however, have come several systems engineering challenges, all requiring further research and development of advanced methods:

- Constraints in Capacity,
- Safety and Security,
- Environmental Impacts of Aviation,
- Economics and Evolution of Airlines.

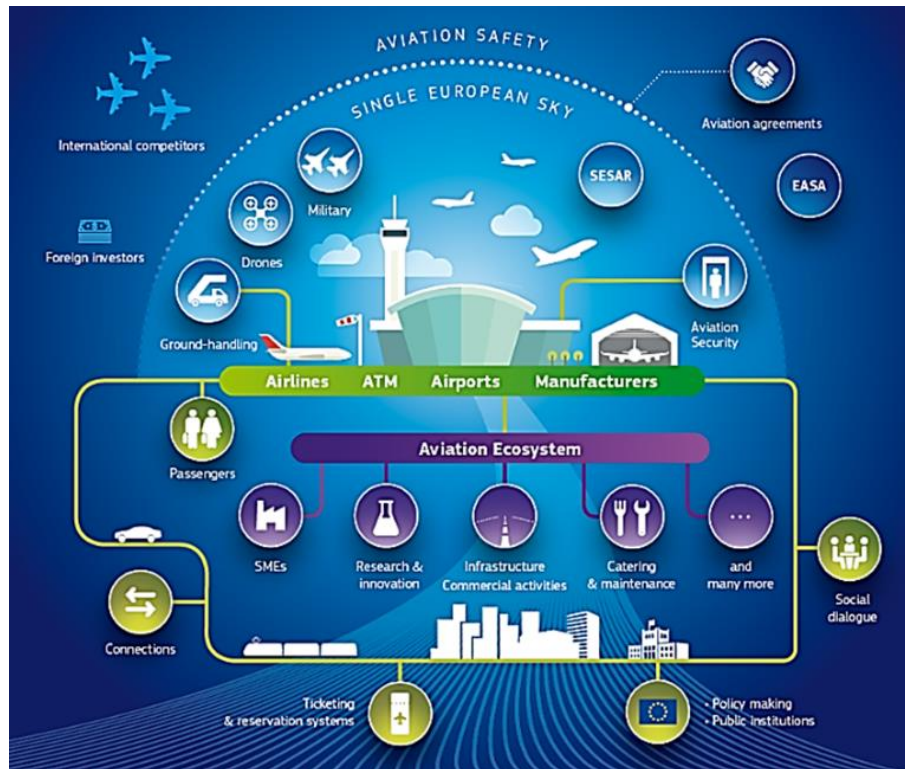


Figure 2. 2 – How air transport works in Europe
 Source: [42]

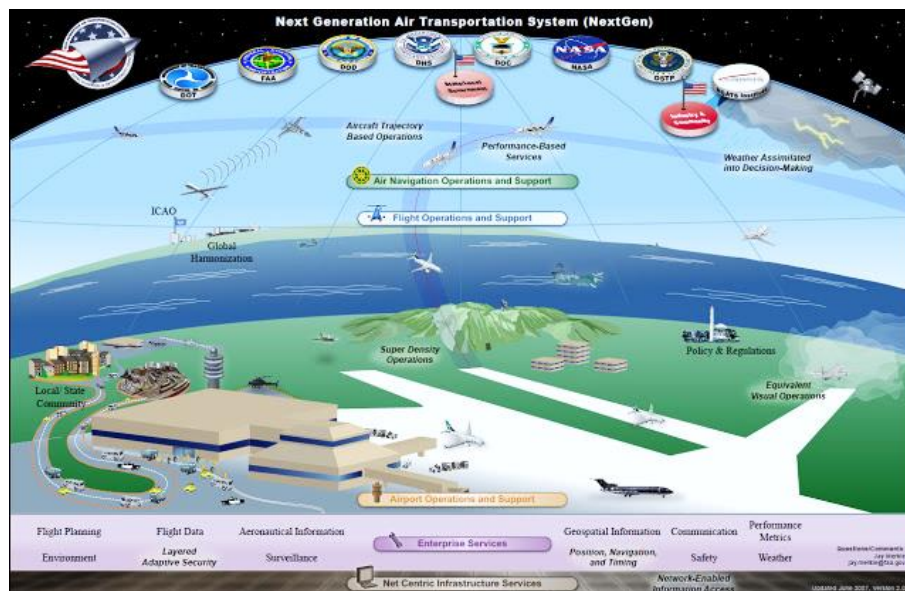


Figure 2. 3 – Next Generation Air Transportation System (NextGen)
 Source: [43]

Table 2. 1 depicts the cooperation between the different actors in the air transport industry. Considering the relationships among all actors will allow a better understanding of the air transport sector evolution.

Table 2. 1 - Control and cooperation between subsectors in the air transportation industry
Source: Adapted from [40].

Market actors	Airlines	Handling Companies	Airport Operators	Authorities
Airlines	Mergers and acquisitions (e.g. Air France and KLM; Air Berlin and Condor); Alliances (e.g. STAR); Code-share agreements; Joint ventures (e.g. Lufthansa Cargo and DHL Express); Participations (e.g. Thomas Cook in Air Berlin).	-	-	-
Handling Companies	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 three years).	Concentration by take-overs (e.g. Aviapartner, Menzie).	-	-
Airport Operators	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).	-
Authorities	Participation government in Flag Carriers (e.g. Olympic, TAP...).	Monopoly by airport authority or its sole concessionaire; Concession assignment control.	Participation in government in airports, including (partial) privatisation.	Participation in governments in airlines (e.g. French and Italian State in Alitalia).

2.3 Airport as a Subsystem of the Air Transportation System

International Civil Aviation Organization (ICAO) defines aerodromes as a designated 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 [44].

Airports are aerodromes dedicated to serving regular air transportation. They can be characterised as a system of infrastructures that complement each other to allow the movement of aircraft, people and goods [45]; and they can be divided into three types according to airports activity [46]:

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

The necessary infrastructure consists of runways, taxiways, apron areas, 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 [47]. These services can be divided into aeronautical and non-aeronautical services, as summarised in Table 2. 2.

Table 2. 2 Classification of airport activities.
Source: Adapted from [48].

Aeronautical and Airside Services		Non-Aeronautical and Landside Services
Operational	Handling	Commercial
Air Traffic Control;	Aircraft Cleaning;	Duty-Free Shops;
Meteorological Services;	Provision of Power and Fuel;	Other Retailing Shopping;
Telecommunications;	Luggage and Freight Loading and Unloading;	Restaurants and Bars;
Police and Security;	Processing of Passengers,	Leisure Services;
Fire, Ambulance and First Aid;	Baggage and Freight.	Hotel Accommodations;
Services;		Banks;
Runway, Apron and Taxiway;		Car Rental and Parking;
Maintenance.		Conference and Communications Facilities.

Initially, airports were publicly owned and controlled based on public service obligations. Though in the last decades, airports management and business model have suffered some transformations, mainly due to social, political, legal, technological and environmental changes [45], which led to the necessity of new management practices more focus on the “commercialisation” of the airport [47], [49].

The privatisation of airports increased airport competitiveness and created performance indicators to gain insight into their performance to maximise their efficiency [50].

Airports are a crucial element of the air transportation system. They provide the essential infrastructure – a place for switching from between air and ground modes or within the air transport sector. Notwithstanding, airports are more than just transportation infrastructures. They provide several jobs and support an area more extensive than the airport limits in social and economic terms but have undergone multiple structural changes during the last decades [51].

Airports started as public services protected and provided by the central government. In the aftermath of 1944, Chicago Convention emerged a controlled environment characterised by extensive regulation. During the following decades, the air transport sector benefited from a genuinely protected context and steady growth. Airports were mere public providers of transportation infrastructure. However, nowadays, they are becoming privately owned or commercialised entities [52]. First starting in the US in the late 1970s, a liberalisation wave swept the globe ever since [53]. The previous orderly environment has been shattered: unpredictable demand, growing financial constraints, new social trends or successive technological leaps [54]. The new context of the airport industry is increasingly dominated by less air transport market

regulation, both within and across borders. In this context, airports become commercially-oriented firms that compete for various customers with multiple services, and business viability is increasingly uncertain [52]. New opportunities appeared for competition among airports and the development of business perspectives and specific business models for these infrastructures [55]. Airports embrace the business competition spirit and are focused on becoming profitable and efficient and being a relevant development factor for the regions where implemented.

Airports are an essential part of the air transportation system, providing infrastructures to enable the transfer of passengers and freight between the landside and air vehicles, store and maintain aircraft, and have the capacity for other service providers requiring air transportation. Furthermore, airports have strategic importance to the regions they serve as they bring wealth, employment prospects, stimulate regional tourism and promote economic growth. Over the years, air traffic has grown exponentially without a corresponding investment in airport infrastructures. It is now reaching a stage where airports may face congestion due to lack of capacity. Due to this, there is growing strain to manage the air transport system more efficiently. Therefore, it is essential to analyse airport performance and efficiency and predict the factors that may affect it.

In the very beginning, airports served a utilitarian and military purpose purely. Thus, a traditional airport model started to emerge, that besides the objectives of safety and efficiency, had a convenient yet limited infrastructure. Nowadays, this primary standard still exists and includes essential operational spots such as check-in gates, a boarding area, and a limited amount of food vendors and shopping areas. Although this arrangement is efficient and fulfils its business function, it does not grant any additional elements of a unique character that could benefit the customer. That could serve as a market differentiator much needed in the era of the highly competitive airport business. Thus, due to a naturally appearing market demand, a scheme of an advanced airport has developed with the mission to enhance the passenger experience by providing an overabundance of added services and facilitation.

The airport system is an essential part of the air transportation system because it is the physical site where a modal transfer is made from the air mode to the land modes or vice versa (Figure 2.4).

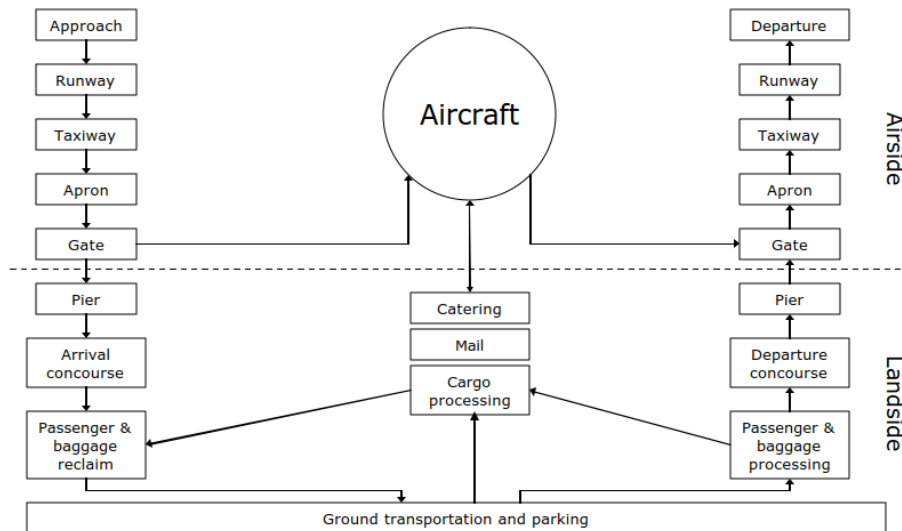


Figure 2. 4 – The airport system
Source: [56]

2.4 Airports Performance and Efficiency

Analysis of airport performance and efficiency has become one of the most important 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 of airport management, it is essential to have a well-structured system to assess airport performance efficiency and competitiveness [24].

The structure of 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, considering the price and environmental impact. However, it is necessary to consider the relations with and between third parties, such as airlines, external outputs, regulatory environment, geography and others. Figure 2. 5 outlines a generic structure for performance analysis [57].

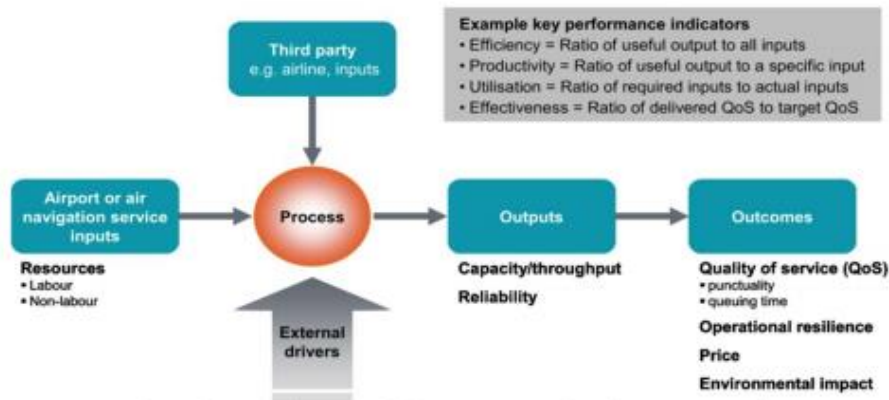


Figure 2. 5 – Generic framework for operational performance analysis.
Source: [57].

Measuring airport performance enables airport managers and the government to measure efficiency from an operational and financial perspective to alternative investments and supervise

airport safety and environmental impacts. By analysing the airport performance, the management can identify the performance areas 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 and efficiency analysis are fundamental for several different interested parties [58]:

- 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 business performance and to return their investment.

2.5 Conclusion

The emphasis on airport performance and efficiency as part of the air transportation system and possible future developments focusing on the infrastructure, technology, airport, and airline operators were depicted. SESAR and NEXTGEN show that managing airspace more dynamically can increase capacity while reducing delays and emissions. Moreover, obtain new optimized configurations, more suited to the demand structure and balancing controller workload.

The characterisation of the airport as a complex infrastructure with a large variety of stakeholders and the growth of sector privatisation led to more significant airport competitiveness. Moreover, it creates the need to benchmark the infrastructure 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.

Chapter 3

State of the art and literature review

3.1 Introduction

3.2 Studies on Airport Performance and Efficiency

3.3 Airport Benchmarking

3.4 Decision-Making Processes

3.5 Airport Performance and Efficiency Assessment

3.6 Conclusion

State of the art and literature review

3.1 Introduction

This chapter provides the literature review and state of art on airport performance and efficiency studies, airport benchmarking, decision-making processes and different methodologies to assess airport performance and efficiency.

The liberation of the air transport industry led to the growth of air traffic and consequently increased airports congestion. Airports need to expand their capacity and improve runway and terminal systems efficiency to face this problem. However, until the beginning of airport privatisation, slot demand was somewhat inefficient and needed improvements to face all air transport restructuring processes. All of this created the need for airports to start benchmarking themselves and compare them with other airports [59].

3.2 Airport Performance and Efficiency Studies

Based on the literature reviewed, the evolution of airport performance measurement may be explained in three stages. The first stage comprises the 1970s and 1980s. The 1990s and the early 2000s comprises the second stage. The third stage includes the period from the early 2000s until the present day. Figure 3.1 illustrates this evolution, along with information regarding the airport business environment and the extensive literature on performance measurement (PM) [60].

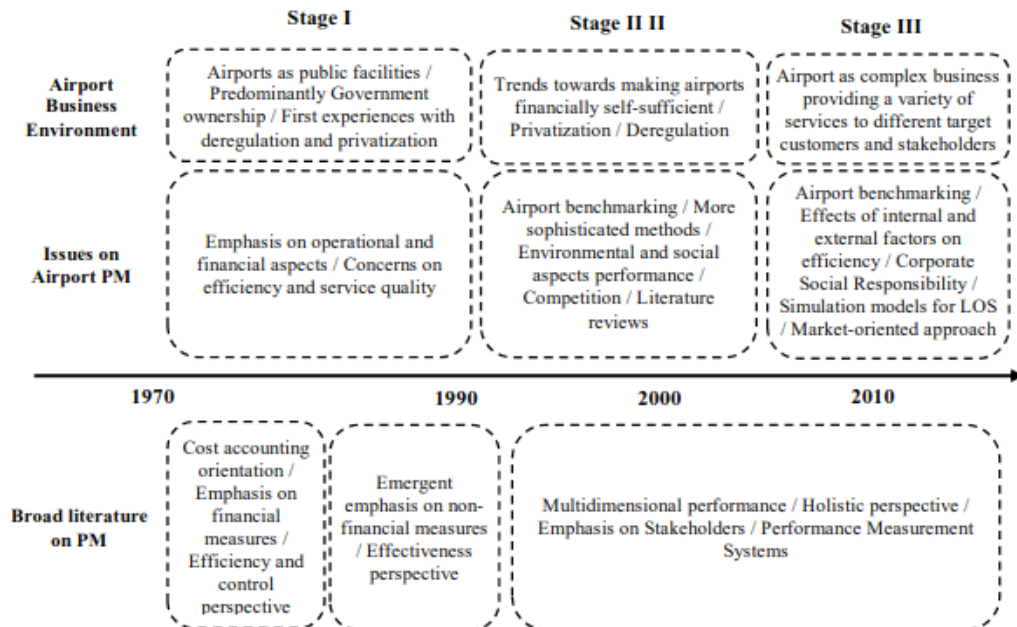


Figure 3.1 - Evolution of the literature on airport performance measurement
Source: [60]

Stage I airport performance studies were scarce in the literature. Few studies have been identified, mainly focusing on the operational, efficiency and financial aspects of airport performance separately. Thus, this scarce literature is associated with weak business pressure on airports once these infrastructures were mostly under government ownership. Focusing on the European context, Doganis and Graham [61] concluded that a few airports had implemented comprehensive and systematic performance practices, mainly stressing the use of financial and operational indicators.

Stage II, making airports financially self-sufficient, has been progressively motivated to adopt a different approach regarding performance measurement [50], [62]. During this stage, airports without government support were recognised to stand alone and operate established firms. Airport benchmarking arose as the main topic to improve the methods for efficiency/productivity assessment. Within the airport industry, organisations such as Air Transport Research Society, for example, performed regular studies on the airport infrastructures. At the beginning of the 2000's some empirical studies and literature reviews on actual practices on airport performance were published [12], [58]. A review on the evaluation of the airport level of service was provided by Correia and Wirasinghe [63]. There were also reviews of previous benchmarking studies focusing on airport efficiency [50], [63]–[65]. The literature on airport performance measurement at this stage is more systematic than in stage I. The critical analysis may represent a significant milestone since they reveal a maturing of the research on airport performance measurement.

Stage III, covering the last two decades, seems to reveal an increasing interest in approaches and methods currently used in other service settings. The following issues represent the more recent literature on airport performance measurement (see Table 3.1).

Table 3.1- Airport performance dimensions
Source: [60]

Dimension	Scope	Example of measures
Efficiency/ Productivity	Related to how well the airport uses the available resources in processing aircraft, passengers, cargo and mail (may comprise an economic and a technological perspective).	Several physical and financial inputs and outputs are used as ratios or parametric or non-parametric models: Air traffic movements; Passengers; Cargo; Work Load Unit; Aeronautical revenue; Operating revenue; Number of employees; Labour cost; Operating cost; Etc.
Service Quality	It is related to a broad concept of quality, including customer perception and objective performance indicators (comprises aspects of service quality and service level (LOS)).	Subjective measures related to customers' perception of infrastructure and service attributes. Quantitative measures regarding the availability of area per passenger; availability of equipment; waiting times; processing times; delays; Etc.
Safety	The state in which risks associated with aviation activities related to, or direct support of aircraft operation, are reduced and controlled to an acceptable level [66].	Outcomes: Accidents; Incidents; Other safety-related occurrences. Drivers: Runway conditions; Number of safety training courses conducted; Number of attendees at safety

Dimension	Scope	Example of measures
		training courses; Number of warning citations issued; Etc.
Security	The state in which people and properties within the airport's boundaries are protected from potential injury/loss caused by deliberate illicit actions performed by people.	The number of reported security breaches; Number of security inspections conducted; Destructive or criminal behaviour within the airport; Time it takes to resume regular service after security incidences; Security screening process; Etc.
Commercial	It is related to the broad notion of airport business, in which the airport is seen as a firm providing a variety of services and products with a focus on different customers and stakeholders (comprises ancillary services such as terminal retail, food and beverage, parking, hospitality, Etc.).	Non-aeronautical revenue; Commercial area leased; Number of parking spaces per passenger; Parking turnover rate, Duty and Tax-free income per passenger; Concession revenue per m2; Average ticket; Sales by type of retail; Branding; Market value; Etc.
Economic/ financial	It is related to the economic outcomes resulting from the interplay among an organisation's attributes, actions, and environment, including financial and economic performance concepts.	Revenues, Expenditures; Cash flow; Profit/Loss; Return on Sales; Return on Assets; Internal Rate of Return; Economic Value Added; Return on Investment; Debt Service; Investment growth rate; EBITDA; Etc.
Environmental	It is related to the externalities. It was generated by aeronautical and airport activities that impact the local environmental sustainability (noise, air quality, water quality, energy conservation and ecology).	Energy consumption; Water consumption; Gaseous pollutants (ambient concentrations of contaminants); Waste; Aircraft noise emissions; Number of complaints regarding noise; the number of homes or people subjected to noise within a particular noise contour; Etc.
Social	They are related to the impacts of airport activities on the interests of the local community (comprises relationship with the local community, job creation, investments attraction, effects on housing prices; Etc.).	Number of jobs created; % women, minorities, and people with disabilities of the total workforce; Social programs; Sporting/social/cultural sponsorship; The number of activities focused on the community; Media contact indicators; Impact on real state pricing; Etc.
Competitiveness	It is related to offering a range of products and services that meet its market quality standards at reasonable prices.	Market share for airports; Airline competition at the airport; Number of destinations (non-stop); Airline operating expenses per passenger at the airport; Etc.

Despite the introduction of relevant issues, airport benchmarking remains the main topic of interest. Benchmarking practices are paramount for improving performance; however, while airports are required to identify the organisational practices that might be related to superior performance [29], it seems that the airport-related literature mainly adopts an efficiency-based perspective for benchmarking [65]–[67]. About performance measurement practices, Graham [68] observed the adoption of performance measurement frameworks by some airports, namely the Balanced Scorecard.

Some critical articles discussed the practical implications and the methods used for airport efficiency/productivity assessment and benchmarking [23], [24], [68]–[71]. Regarding the related professional literature, there are efforts to provide more comprehensive frameworks for

airport performance measurement [72]–[75]. It is noteworthy that these industry best practices comprise a wide range of performance aspects that have not been commonly present within research studies. The second more frequent topic in Service quality, the interest in understanding airport service quality multidimensionality, emphasising passengers’ perspective, is increasing [16].

Based on the literature reviewed, the following dimensions may represent the diversity of airport performance aspects alleged by external stakeholders: Efficiency/productivity, Service Quality, Safety, Security, Commercial, Economic/financial, Environmental, Social, and Competitiveness. These nine distinct dimensions may be grouped within organisational and operational performance (Figure 3. 2).

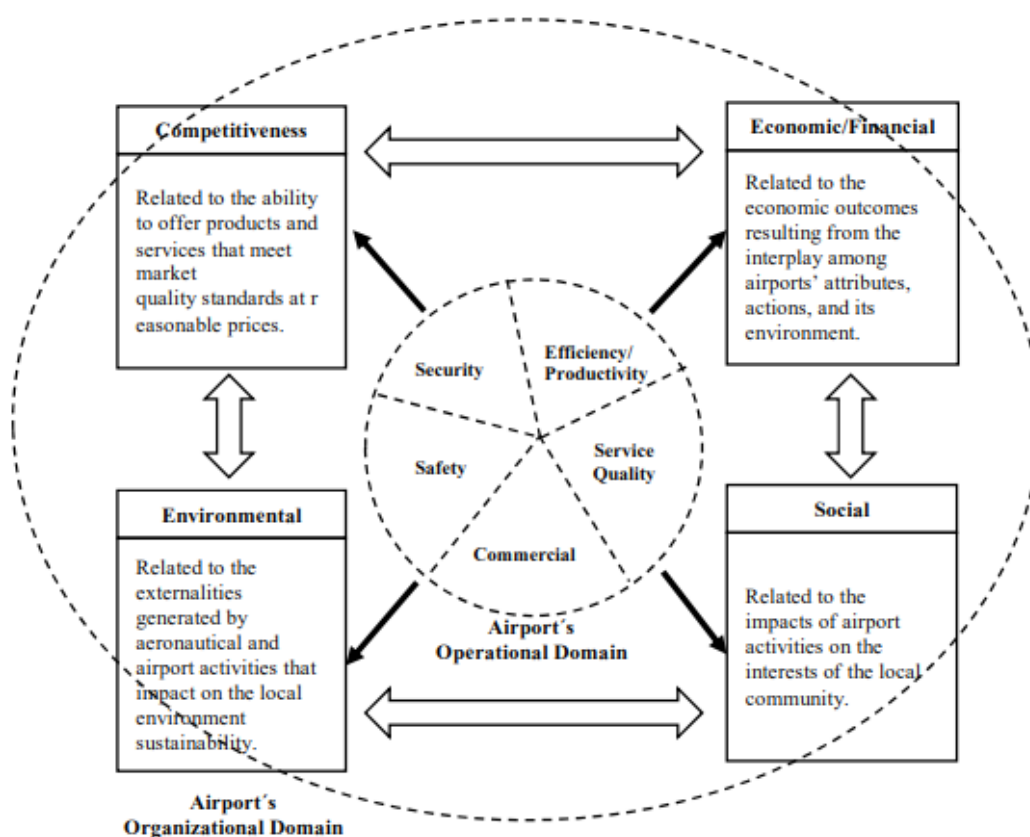


Figure 3. 2 - Airport performance dimensions
Source: [60]

The domain of organizational performance refers to an extended concept of airport effectiveness. This domain has four dimensions: Economic-financial, Environmental, Social, and Competitiveness) are interrelated. Therefore, an integrated assessment of airport performance regarding these dimensions should provide meaningful information on airport sustainability according to the perspective of different stakeholders.

Considering operational performance facilitates the relationship between the internal airport activities and the organizational performance domain. This operational domain characterizes the outcomes of the airport internal activities and capabilities that the external stakeholders may adequately perceive. For instance, excellent performance regarding human resources or

information technology is not directly perceived by the passengers, but only their effects on the service quality dimension.

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 determining the overall business performance. Thus, airport benchmarking is a component of airports strategic planning process and a tool to monitor and compare airport, economic, operational and service performance. Benchmark measures the performance of discrete airport functions. By identifying and adopting the best practices, the airport can increase its efficiency, quality and customer satisfaction, thus assessing the implementation of the airport strategic planning. In other words, airport benchmarking links day-to-day operations and management strategies with the airports short and long-term actions plans and initiatives [76].

There are two main categories of benchmarking [77]:

- Partial – Compares and Assesses 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 organisation's relative performance.

Within partial and holistic categories, there are two prevalent types of benchmarking. Firstly, Internal benchmarking, also known as Self-benchmarking, within the organisation, compares the internal performance of processes, functions and services over a time series. Secondly, external benchmarking, also known as Peer-benchmarking, compares the organisation's performance with peers or other organisations in the same sector of activity at a precise point in time or through a time series [76].

There are five stages of the benchmarking process of an organisation [76], [78]:

- Decision stage, where it is decided what to benchmark and chose the indicator for the benchmarking process, considering that they should be quantifiable,
- The 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 applied best practices increase the performance and efficiency of the organisation by continuously monitoring the progress and communicating the results to the decision-makers.

3.4 Decision-Making in Airport Infrastructures

A decision is a response to a situation with 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 [79].

There are many different definitions of decision making, but they all revolve around the same principles [80]:

- Decision making is the analysis of finding and choosing alternatives based on the principles and preferences of the decision-maker,
- Decision making is the process of adequately reducing ambiguity and doubt about options to accept a realistic choice to be made from among them.

Therefore, there is something to be decided, and there are always alternatives that must be considered. The result is usually a decision based on what needs to be solved, and it is never a given fact that the decision is the correct one. Although there is not a single definition for decision making, its process can be defined in five steps [81]:

1. 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 the following steps. 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;
2. Identify the alternatives - Brainstorm as many alternatives as possible without excluding any alternatives, consider all 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;
3. 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, a manager needs to evaluate each alternative feasibility, effectiveness and consequences;
4. 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 straightforward, such as the other option with the most pros and fewest cons. Other times, the optimal solution is a combination of several alternatives;
5. 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 intended results when the solution

was chosen. 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. Thus, this means that they usually will try to reach a consensus. Even though not all of them agree that they can adapt and accept the chosen one, decision making in airport infrastructures faces a new approach called Collaborative Decision Making (CDM). This concept has been defined as a collaborative endeavour between the various elements of aviation transportation, both government and industry, to trade information for better decision making by the Federal Aviation Administration (FAA) [82]. 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: [83].

A-CDM has a series of objectives like reducing delays, improving the existing system's predictability and optimising resources, and reducing environmental impacts while doing so [7]. According to EUROCONTROL, A-CDM carries several objectives [83]:

- For the Airport Operator, enhanced 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 Aircraft Operator, they will have enhanced awareness of the status and location of aircraft, as will receive more accurate aircraft arrival times and 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 the 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 and knowing the exact time that has been given start-up clearance for the departing aircraft. Thus, this makes for more accurate planning and 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 turn-around planning, to name but two. The A-CDM is divided into the following elements: (i) Information Sharing, (ii) Milestone Approach, (iii) Variable Taxi Time, (iv) Pre-departure Sequencing, (v) Adverse Conditions, and (vi) Collaborative Management of Flight Updates. An Airport CDM partner is a stakeholder airport, who participates in the CDM process. The main Airport CDM partners are (i) Airport Operator, (ii) Aircraft Operators, (iii) Ground Handlers, (iv) De-icing companies, (v) Air Navigation Service Provider (ATC), (vi) Network Operations, and (vii) Support services (Police, Customs and Immigration) [83].

Effective performance often requires interaction amongst several individuals who must work as a team. A critical feature of teams is that individuals must coordinate their decisions and activities by sharing information and resources to attain shared goals. Attempts to improve team performance must focus awareness on the performance of individuals. However, individuals are depending on other team members to provide information and for the coordination of activities. Communication, team training, team leadership, monitoring, feedback, backup and coordination are critical CDM components. Figure 3.4 depicts the organisational issue: Cross Organisations Teams and Decision-Making Optimisation of Airport Resources.

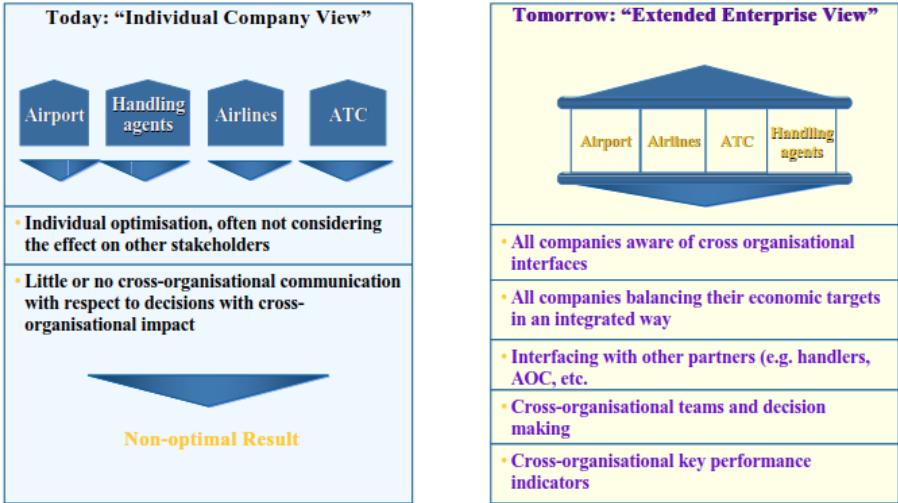


Figure 3.4 - Airport partners – Extended enterprise view
 Source: [84]

Today common objectives are often specified between two airport partners through existing Service Level Agreement(s) (SLAs), for instance, between an airline(s) and handler(s) regarding turn-round operations or provision of information and messages between an airline(s) and the CFMU. CDM specifies collaborative procedures between three or more partners to obtain better efficiency in the current management of the resources.

CDM requires airport partners to have positive attitudes towards each other (team behaviour), receive adequate direction and support to accomplish common goals, understand other airport partners' tasks with whom they interact, and share good and bad experiences.

Common objectives will help partners to co-ordinate their activities by:

- Sharing experience,
- Monitoring the coordination,
- Synchronising operations,
- Communicating and providing feedback and backup assistance when needed.

The difficult challenge is to move from individual partners with specific role assignments and specific tasks to a team where interaction, coordination and collaborative procedures and decisions are required to achieve common goals and outcomes.

Consistent, collaborative airport data and CFMU data will be linked and shared with the new Air Traffic Flow Management (ATFM) messages to greatly enhance traffic predictability and global efficiency by developing a "Network Real-Time Monitoring System". Moreover, CDM has local and regional and worldwide applications in all phases of the gate-to-gate concept, from pre-flight planning to "on-blocks" at the arrival stand.

Accuracy, the quality of information, makes partners confident in the data and enables them to make the right decisions. A funnel rule defines the expected accuracy amongst the milestones: more accurate data is needed as the event becomes imminent.

Data, the data linked to events show, more than the status of a process, the result of a decision or the confirmation of estimation. This concept defines clearly the owner of the data and the responsibility of each user.

Monitoring the events and their related data allow monitoring and control of the progress of the turn-round process. The milestones allow the results for timeliness, accuracy, reliability and predictability of the data to be checked. When an event occurs, it is time to set or update the related data and raise alarms in case of disruptions. On any inconsistency, an alarm will be raised. A post-analysis shall determine when a process turned out unsuccessful, point the reason, and allow a proposed solution.

Post Data Analysis, providing information, and better quality induces costs that higher benefits should balance. Giving access to expected quality information would benefit the addressee and be reflected through quantitative, measurable enhancement for the entity providing the information (return on investments). Consequently, it is essential to obtain an agreement on KPIs and recorded data to quantify the results. A post-analysis can evaluate quantifiable benefits amongst the milestones for each partner who shares CDM information and improves his quality of service. The milestones should help identify potential deviation plans, trigger re-planning, and allow collaborative decisions.

3.5 Airport Performance and Efficiency Analysis

3.5.1 Airport Benchmarking Methodologies

There are many methods to benchmark, which allows the work to choose the most appropriate methodology to achieve its objectives.

Since airports consisting of a multi processes system, a group of quantitative methodologies have been developed to assess productivity and efficiency of airports performance [59]. The difference between these two approaches of airports performance consists of maximum achievable outputs since efficiency considers the maximum potential outputs that the available inputs can create. In contrast, productivity considers the accurate outputs created [24]. Throughout the years, a variety of methodologies appeared to assess productivity and efficiency. Von Hirschhausen and Cullmann [85] organised these methodologies by type of approach as represented in Figure 3. 5

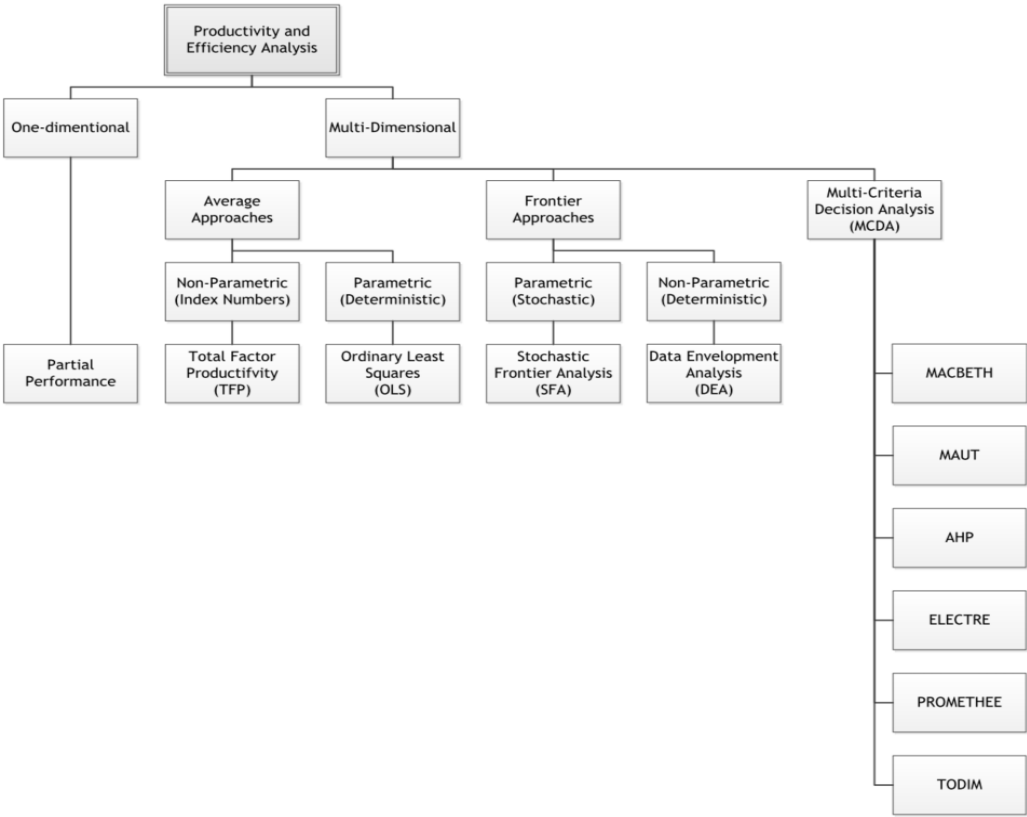


Figure 3. 5 – Quantitative methodologies to assess productivity and efficiency.
Source: Adapted from [85], [86].

The one-directional approach, particularly partial measures, consists of dividing one output by one input, making this approach the simplest to assess productivity. However, its results have to be taken with caution because they fail to capture the effects of different inputs. For this reason, to access airports performance, it is recommended to use multi-dimensional approaches.

Table 3.2 describes the different types of significant methodologies used in airport performance assessment with the main weakness of each one [24].

Table 3.2 - Main methodologies used in airport performance assessment.
Source: [24].

Methodology		Weakness
Partial Measure	This method uses partial ratio data to compare the target sample's performance comparison in a single dimension, such as an airport's financial and cost performance.	This method only focuses on specific fields of airport performance. The evaluation result of this method would not provide a more comprehensive evaluation of an airport's performance.
Multi-Criteria Decision Analysis (MCDA)	<p>It is 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 surveys or interviews and chooses optimal solutions based on those selected indicators.</p>	Because selecting indicators is based on the expert's experience and judgment, the result may be affected by subjective factors.
Total Factor Productivity (TFP)	In economies, TFP is a variable that accounts for effects in total output not caused by inputs. TFP allows for measuring cost efficiency and effectiveness and for distinguishing productivity differences in airport performance. This technique can also be used for investigating the impact of variations of input and output price on an airport's performance.	TFP requires an aggregation of all outputs into a weighted output index and all inputs into a weighted input index using pre-defined weights, which can be biased.
Stochastic Frontier Analysis (SFA)	SFA sometimes referred to as the econometric frontier approach, is one of the main parametric approaches used by researchers to evaluate efficiency.	Although the parametric approaches consider the effect error, which is not considered in a non-parametric approach, the parametric methods still face challenges in separating random error from efficiency.
Data Envelopment Analysis (DEA)	DEA is a non-parametric approach, which requires no assumptions about the functional form and calculates a maximal performance measure for each airport relative to all other airports.	The critical 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.

After carefully analysing this group of methods to assess performance and efficiency, and every one of its advantages and disadvantages, MCDA was chosen as the best one to apply in this study.

Complementing previous studies done by José Braz [86] and João Jardim [87] study the MCDA tool for airport benchmarking.

3.6 Conclusion

Airport performance measurement has been the subject of increasing interest since the beginning of the 1990s. The evolution of the literature may comprise three distinct stages: what appears to have followed changes occurring at the industry level and the developments of the broad literature on performance measurement, although the latter with a significant lag. The first stage is characterized by the emphasis on operational and financial aspects. In the second stage, efficiency/productivity benchmarking became the main topic of interest; nonetheless, a broader perspective for the airport performance measurement was introduced. Finally, the third stage seems to stress a more market-oriented approach for performance measurement. Since ever more airports worldwide are operated as business organizations, airport managers are challenged to effectively identify and meet their stakeholders' needs. Therefore, airport performance must be measured according to a broader perspective in which measures should be derived from the stakeholders' needs, more than a prescriptive exercise.

The characterisation of the airport as a complex infrastructure with a large variety of stakeholders and the growth of sector privatisation led to bigger airport competitiveness. Thus, this creates the need to benchmark this infrastructure 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 the pros and cons of each method typically used in airport benchmarks, MCDA better fits this work's needs. MCDA helps to integrate a broad set of key performance areas with experts' experience and their judgment, although the result may be affected by subjective factors.

Regarding airports and air transportation decision-making, the CDM approach poses very interesting solutions to long-time existing problems. With this concept involving ground handling, air and ground operations, ATC, every operational area of the airport, the decision-making can be simplified and enhanced.

Chapter 4

Global Decision Analysis (GDA)

4.1 Introduction

4.2 GDA KPA and KPI Assessment and Database Creation

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

4.4 GDA Model Report and Recommendations (GDA-MRR)

4.5 Conclusion

4. Global Decision Analysis (GDA)

4.1 Introduction

This chapter introduces the database construction with GDA KPA and KPI assessment and database creation. This chapter continues with a brief MCDA methodology description used in the study, and the mathematical explanation can be found in annexe 1. Moreover, Measuring Attractiveness by a Categorical Based Evaluation Technique (MACBETH) is used to analyse the case studies. The Performance and Efficiency Support Analysis (PESA) and in particular for Airport Global Benchmarking (PESA – AGB) and then finally the GDA Model Report and Recommendations (GDA-MRR) to aid airport manager. Figure 4. 1 describes the tool steps to conclude the evaluation process.

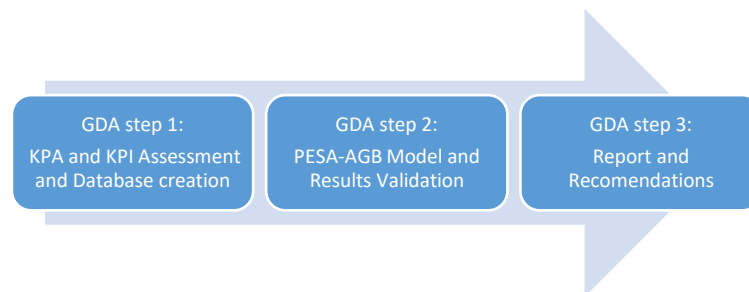


Figure 4. 1 – GDA tool steps
Source: Own elaboration

4.2 GDA Step 1 - KPA and KPI Assessment and Database Creation

The primary goal is to construct a database that uses a list of airport performance indicators characterised and identifies the KPI in each category and the data sources. A detailed review of academic and professional literature was done to cover all bases. Several sources that provided helpful information like the Developing an Airport Performance-Measurement System by Airport Cooperative Research Program (ACRP) from Transportation Research Board (TRB) [73], and Guide to Airport Performance Measures by ACI - Airport Council International [72], among others [12],[88],[89].

KPIs represent a set of measures concentrating on those aspects of organizational performance that are the most critical for the existing and future success of the organization. They are used to measure the most critical aspects of the airport. KPIs may have different structures and units, sometimes do not say anything by themselves and are helpful compared to historical data or equivalent measures for other airports.

The package includes 42 detailed statistical tables that provide measurable barometers of industry activity for airport managers, specialists, investors and other aviation stakeholders. The resulting

indicators are based on an annual survey, the airport is divided into different activity areas KPAs, and airport KPIs are developed for each of them. KPIs are selected for each area based on ACI Guide to Airport Performance Measures [73]. There has been some previous work where Airport KPIs are developed by [17], [59], [90]. [91], [92], and more recently, ACI Airport Key Performance Indicators provide insight into areas such as financial and employee performance, fixed-asset productivity and airport operations.

4.2.1 KPA and KPI Assessment

GDA model uses a set of pre-defined KPAs, and KPIs recommended by [72], who elaborated a guide to measuring airport performance leading to six KPAs: 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 [90]. A more broad description can be found in appendix 1:

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 essential indicators of overall airport activity and important drivers and components of other indicators [72]. Five KPIs describe this KPA.

Safety and Security – These are critical airport functions that sometimes overlap. Safety indicators are used to track airfield safety issues and 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 [72]. Six KPIs describe this KPA.

Service Quality – Focused on how passengers perceive service level provided by the airport and service delivery objective measures [72]. Eight KPIs describe this KPA.

Productivity/Cost-Efficiency - Airports often combine productivity and cost-effectiveness in a single KPA. As used by ICAO, productivity refers to the output to input relationship, while cost-effectiveness refers to the financial input or cost required to produce a non-financial output [72]. Nine KPIs describe this KPA.

Financial / Commercial – Covers a wide range of measures that analyse an airport's financial performance, including airport charges, airport financial strength and sustainability, and individual commercial functions performance [72]. Eight KPIs describe this KPA.

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 [72]. Six KPIs describe this KPA.

Table 4.1 presents the six KPAs and their respective KPIs of the PESA-AGB value tree based on [91] and [92] adapted from [72].

Table 4.1 - Scope of each key performance area (KPA) and key performance indicator (KPI) of PESA-AGB.**Source: Based on [91] and [92] adapted from [72].**

Key Performance Area (KPA) Criteria	Area	Key Performance Indicator (KPI) – Sub Criteria	Definition [Measuring Units]
Core: measures used to characterise and categorise airports	Passengers		Passengers, including enplaning and deplaning, measured over a year. [n° pax]
	Origin and Destination Passengers		Passengers whose air travel begins or ends at the airport, measured over a year. [n° pax O&D]
	Aircraft Movements		The aircraft take-offs or landings at an airport measured over a year. One arrival and one departure are counted as one movement. [n° movs]
	Freight or Loaded/Unloaded	Mail	Freight or mail loaded or unloaded at the airport, measured in metric tonnes over a year. [metric tonnes]
	Destinations–Nonstop		The number of airports with nonstop service, including destinations with only seasonal service, measured over a year. [n° airp non-stop]
Safety and characterises airport responsibilities	Runway Accidents		Aircraft accidents involving a runway per thousand aircraft movements (take-offs and landings are counted separately), measured over a year. [accidents/1000movs]
	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, measured over a year. [incursions/1000movs]
	Bird Strikes		The number of incidents per thousand movements involving bird strikes, collisions of airborne animals (usually birds, but also including bats) with aircraft, measured over a year. [bs / 1000movs]
	Public Injuries		The number of public injuries per thousand passengers, measured over a year. [pinj/1000movs]
	Occupational Injuries		Occupational injuries to airport authority employees per thousand hours worked. [ocpinj/1000hoursworked]
	Lost Work Time from Employee Accidents and Injuries		Lost time due to employee accidents and injuries, measured per thousand hours worked. [lwt/1000hoursworked]
Service Quality: reflects the evolution of airport	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. [maxmovs/hour]
	Gate Departure Delay		Average gate departure delay per flight in minutes - measured from scheduled departure time at average and peak times. [$\sum \delta_{gtj} / n_{flights}$]
	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. [$\sum \delta_{ttj} / n_{flights}$]
	Customer Satisfaction		The overall level of passenger satisfaction as measured by survey responses. [0-100%]
	Baggage Delivery Time		The average time for delivery of the first bag and last bag was measured over a year. [$\sum \delta_{bdjt} / n_{flights}$]
	Security Clearing Time		Average security clearing time from entering the queue to completion of processing - measured at average and peak times. [$\sum \delta_{sctj} / n_{pax}$]
	Border Control Clearing Time		Average border control clearing time from entering the queue to completion of processing - measured at average and peak times. [$\sum \delta_{bcctj} / n_{pax}$]
	Check-in to Gate Time		Average time from entering the check-in queue to arrive at the boarding gate - measured at average and peak times. [$\sum (\delta_{tj} \times pax_j) / \sum n_{pax}$]
Productivity/Cost Effectiveness: measures related/overlapping	Passengers per Employee		Total passengers per employee, expressed as full-time equivalents (FTEs), measured over a year. [pax/emp]

Air Transport Performance and Global Decision Analysis

Key Performance Area (KPA) Criteria	Key Performance Indicator (KPI) – Sub Criteria	Definition [Measuring Units]
measures of an airport's performance	Aircraft Movements per Employee	Aircraft movements per employee, expressed as full-time equivalents (FTEs), measured over a year. [movs/emp]
	Aircraft Movements per Gate	Aircraft movements per gate, measured over a year. [movs/gate]
	Total Cost per Passenger	Airport total costs per passenger, i.e., operating costs plus non-operating costs, divided by passengers, measured over a year. [tcost /pax]
	Total Cost per Movement	Airport total costs per movement, i.e., operating cost plus non-operating cost divided by movements, measured over a year. [tcost /movs]
	Total Cost per workload units-WLU	Airport total costs per Work Load Unit, i.e., operating costs plus non-operating costs divided by Work Load Units. [tcost/wlu]
	Operating Cost per Passenger	Airport operating costs per passenger, divided by passengers, measured over a year. [opcost/pax]
	Operating Cost per movement	Airport operating cost per movement, measured over a year. [opcost/movs]
	Operating Cost per WLU	Airport operating costs per WorkLoad Unit, measured over a year. [opcost/wlu]
Financial/Commercial: measures relating to airport charges, airport financial strength and sustainability	Aeronautical Passenger Revenue	Aeronautical charges per passenger, measured over a year. Average of aeronautical revenues collected per passenger for airfield use (landing fees, ramp/apron fees), gate charges, terminal space, passenger-related charges, and ground-handling user fees. [rev/pax]
	Aeronautical Movement Revenue	Aeronautical charges per movement, measured over a year. Average of aeronautical revenues collected per movement for airfield use (landing fees, ramp/apron fees), gate charges, terminal space, passenger-related charges, and ground-handling revenue. [rev/movs]
	Non-Aeronautical Operating Revenue as Percent of Total Operating Revenue	Total non-aeronautical operating revenue as a percentage of total operating revenue, measured over a year. [nonaerooprev/totalop rev (%)]
	Non-Aeronautical Operating Revenue per Passenger	Total non-aeronautical operating revenue per passenger, measured over a year. [nonaerooprev/pax]
	Debt Service as a Percentage of Operating Revenue	Debt service (principal plus interest) as a per cent of operating revenue, measured over a year. [debt/oprev (%)]
	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 measured at the end of the year. [lt debt/pax]
	Debt to EBITDA Ratio	Debt-to-EBITDA (earnings before interest, taxes, depreciation, and amortisation) is measured at the end of the year. [debt/ebita]
	EBITDA per Passenger	EBITDA (or earnings before interest taxes, depreciation and amortisation) per Passenger, measured over a year. [EBITDA/pax]
Environmental: measure to assess environmental impacts	Carbon Footprint	The carbon footprint is the total set of greenhouse gas (GHG) emissions caused by activities at the airport within the airport's control, expressed regarding the amount of carbon dioxide or its equivalent in other GHG emitted. It excludes emissions caused by airline/tenant operations and the public. [GHG/PAX]
	Waste Recycling	The percentage of solid waste that is recycled/reused/composted, including pre-consumer organics and post-consumer compostable, as well as airfield trash, measured over a year. It does not include construction waste. [% water recycled]
	Waste Reduction Percentage	The percentage reduction over the previous year in tonnes of solid waste, including pre-consumer organics and post-consumer compostable, and airfield trash. It does not include construction waste. [Waste red (%)]
	Renewable Energy Purchased by the Airport (Percent)	The amount of renewable energy purchased by the airport, as a percentage of total energy

Key Performance (KPA) Criteria	Area	Key Performance Indicator (KPI) – Sub Criteria	Definition [Measuring Units]
	Utilities/Energy Square Meter of Terminal	Usage Per	consumed by the airport. It excludes energy purchases by tenants. [REP (%)] Utilities and energy used per square meter of the terminal building (conditioned space), measured in kilowatt-hours and over a year. [KWh/m ²]
	Water Passenger	Consumption Per	Water consumption in the terminal complex divided by the number of passengers, measured over a year. [H ₂ O (Lit)/PAX]

All KPIs are dimensionless to make it possible to use them in any airport type, size and location, making them ubiquitous and user friendly. Moreover, it provides directions on developing and implementing an active performance/efficiency-measurement system for airports, which will be of interest to several airport stakeholders.

4.2.2 GDA Database creation

The KPI set spans the airport holistic characterization. The indicators use is intuitive, easy to understand, and a small number of indicators for each KPA, for it to be possible to monitor information rapidly. A questionnaire-based survey study is performed to sort the relevance (first to more minor relevant) of each KPI within the KPAs [93]. The data gathering to use with these KPIs can be obtained by pre-agreements with airport management CEOs or administrators. Despite several diligences, it was not possible to establish this kind of pre-agreement to this study. It is also possible to aggregate the needed data by using the airport reports and national statistical information provided by government institutions on air transportation, thus constructing the database to use the GDA model. Having the data in the right database platform is very important. Figure 4. 2 Depicts the GDA database construction phases.

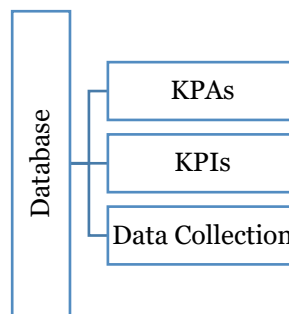


Figure 4. 2 – Database Construction Phases for GDA
Source: Own elaboration

The database used in this study is a Microsoft Excel™ spreadsheet database vertical-style (Appendix 1) created to make the use of this GDA model more user-friendly and guarantee the ubiquity of use as it is. Also, possible to create a professional excel reporting system with this software.

4.3 GDA Step 2 - Performance and Efficiency Support Analysis for Airport Global Benchmarking (PESA – AGB) and Outputs

Airport board members, directors, department leaders, and other employees and aviation regulatory agencies, industry associations, and airport planning professionals and advisors will benefit from a holistic framework to assess airport performance and efficiency.

A brand-new approach to assess airport performance and efficiency based on MCDA-MACBETH allows a smooth engagement of all shareholders in such complex processes and within a global perspective: from air and land sides of the airports and its catchment area.

In general, airport performance depends on a significant number of interrelated indicators or characteristics. This new GDA benchmarking model for airport performance assessment is an additive model, which means the difference in attractiveness between performance levels (the added value of an improvement) on one criterion (KPI) does not depend on other KPIs and can be measured independently.

4.3.1 MCDA Methodologies

MCDA methods have been built to improve decision quality involving multiple criteria by making choices more explicit, rational and efficient [94].

Lai, Potter and Beynon [24] state that the main method in MCDA is the Analytical Hierarchy Process (AHP), which uses procedures for deriving the weights and the scores archived by alternatives 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,
- ELECTRE II, III and IV remaining subsets are the most satisfying alternative for choosing with rankings by eliminating many alternatives,
- 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) uses ideal and non-ideal solutions to find the best alternative but assumes that each indicator takes monotonic function utility.

Given the advanced designs of alternatives (MCDA) available, preference was given to MACBETH's multi-criteria evaluation method. The method chosen was due to the simple

application of the model. In general, the technique helps to reduce the subjectivism of alternatives through its programming. Table 4. 2 presents positive and negative points of the multicriteria analysis models, based on [95], [96], and [97], that compete with Macbeth [98].

Table 4. 2 - Models of multicriteria analysis positive and negative points
Source: Own Elaboration

<p>AHP - Analytic Hierarchy Process [95] (+) Process based on the hierarchy of the tree decision problem and the qualitative format facilitates the relationship with the process participants. (-) The conversion from verbal to numerical scale and how to define the criteria weights.</p>
<p>ELECTRE - Electre I [96] (+) Use preference modeling based on overclassification relationships between pairs of shares. (-) It involves complex concepts and a large number of parameters.</p>
<p>PROMÉTHÉE - [97] (+) It is anchored in robust mathematical modeling and is able to process like those involving stochastic elements. (-) The model is difficult to work with subjective premises.</p>
<p>MACBETH - [98] (+) Simplicity of the method, which requires only qualitative judgments about differences in attractiveness between elements to generate scores; qualitative application and great interactivity. (-) Subjectivity.</p>

The Weighted Sum Methods (WSM) are the most commonly used [99]. The most significant problem of these methods in determining 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 [100], Analytic Hierarchy Process (AHP) [101] and MACBETH [98], [102] 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 judgment revision and 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.

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

MACBETH is a decision-making method that allows options evaluation in a multiple criteria scenario. Its main difference among other MCDA methods is that it only needs qualitative

judgements about attractiveness difference between two elements to generate criteria's weight and in each criteria options numerical scores [32].

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 the 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, considering all the criteria to calculate the overall value scores, reflecting their attractiveness [103].

This MCDA problem is necessary to determine a scale of values for each criterion and assign ranks to each alternative. There is a common way of doing this assignment in some cases, 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) [104].

Unlike the AHP method that compares the importance of the criteria directly, MACBETH makes the comparison indirectly by comparing the dummy alternatives that represent each one of the criteria. To not 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 fictitious choice represents the criterion when it has the highest attractiveness criteria and the worst in the other criteria. The inclusion of this alternative avoids zero weight being attributed to any criterion, which violates Roy's axiom of exhaustion [101].

With these judgments established, the MACBETH method is implemented first to verify any semantic and cardinal inconsistencies and, later, to determine a cardinal value scale representing the decision-makers value judgments.

PESA-AGB model is derived based on PESA-GB (Performance and Efficiency Support Analysis for Global Benchmarking) model [105]. PESA-AGB was built to assess airport performance and efficiency using the pre-defined KPAs and KPIs defined in the previous subchapter. This model is based on the MACBETH mathematical foundations described in Annexe 1 and supported by the work of Bana e Costa et al. [106]. It is structured in a six steps arrangement (Figure 4.3): Structuring (Step 1); Survey (Step 2); Meeting (Step 3); Evaluation (Step 4); Classification (Step 5); and Outputs (Step 6). Although the task sequence is as shown, it is possible to redefine or adjust any task at any time. Complete visualisation of the PESA-AGB model is shown in Appendix 2.

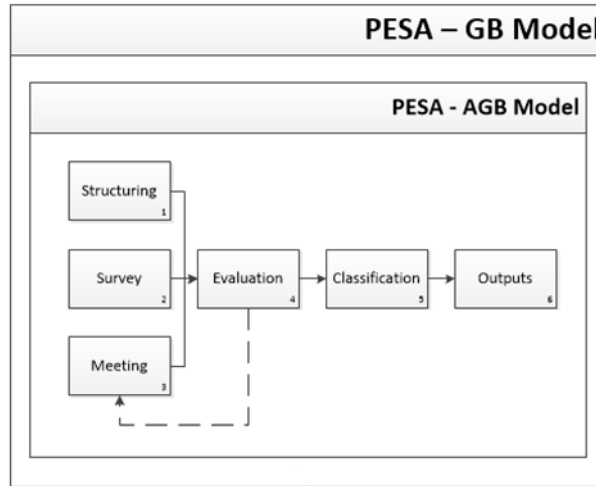


Figure 4.3 – PESA-AGB Model building tasks.
Source: Own elaboration.

4.3.3 Structuring

Structuring (Step 1) consists of 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 4.4.

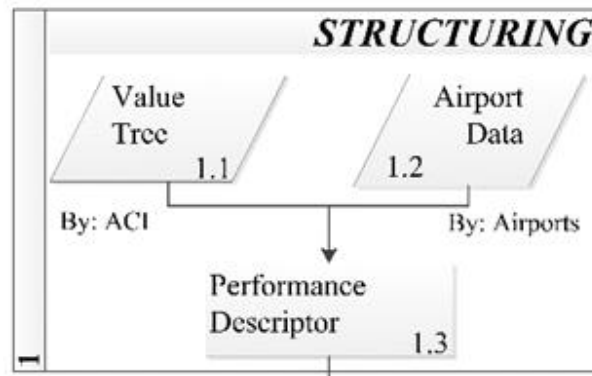


Figure 4.4 - Structuring step of PESA-AGB model.
Source: Own elaboration.

Value Tree (1.1)

There are many different circumstances related to airport operations (aviation activities, commercial activities, location constraints, among others). It is crucial to find different key performance areas and indicators to be the most accurate for the analysis [87]. A crucial step is the choice of KPIs to structure the decision tree (1.1), 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 ten criteria within each KPA.

The **value tree (1.1)** constructed from ACI Guide to Airport Performance Measures [72] can be depicted in Figure 4. 5.

Airport Data (1.2)

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 specific KPIs.

Step 1.2 consists of a vast amount of collected airport data from known airports, with ANA airports reports (traffic, sustainability, accounting) [99], [100], [101]–[108], [109]–[123], it was possible to create an excel database for all the KPI of PESA-AGB value tree in the period considered, 2003 to 2013.

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

Descriptors are performance scales, illustrated in Table 4.3, formed by four reference levels of accomplishment that permit performance assessment on each KPI included in the PESA-AGB model and trace each area's performance profile. For all descriptors, it is established two reference levels – “target” and “neutral” levels (which have essential meaning for managers). The target is the best level of performance of airport data collected in the defined period indicating that no improvement is required in the respective criterion. Neutral is the worst level of performance of airport data collected in the specified period. It is neutral in terms of the need for improvement (because it ensures stable working conditions). Still, below this level, action is recommended to improve airport performance until the “neutral” level is achieved.

Table 4.3 – KPIs’ performance descriptor structure.
Source: Own elaboration.

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

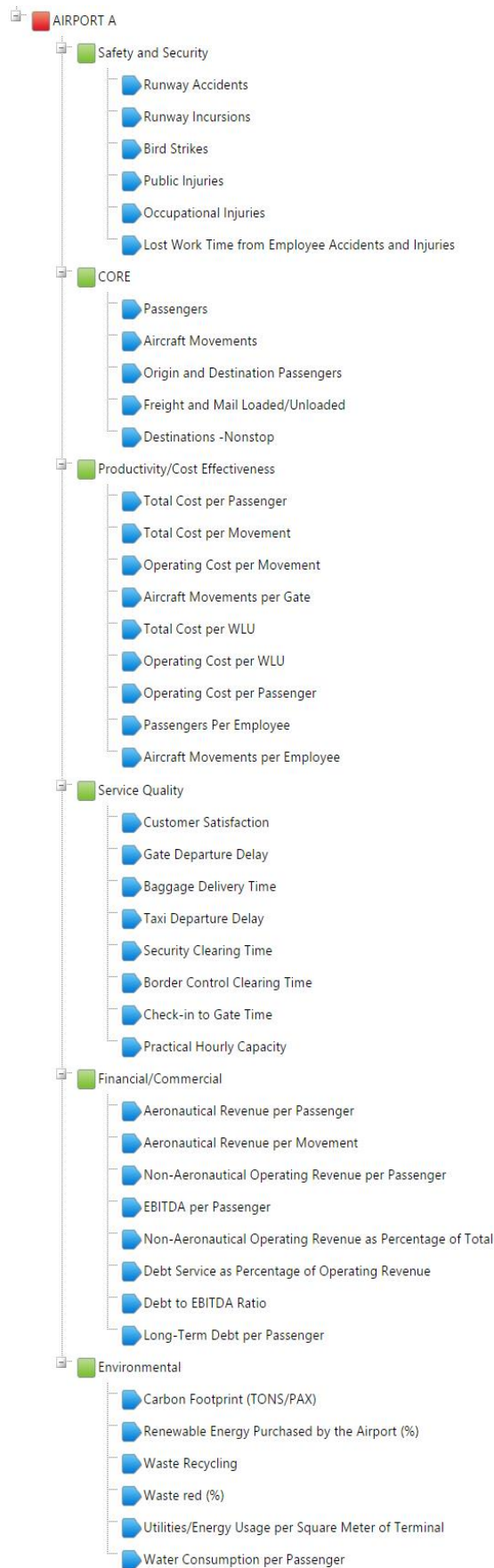
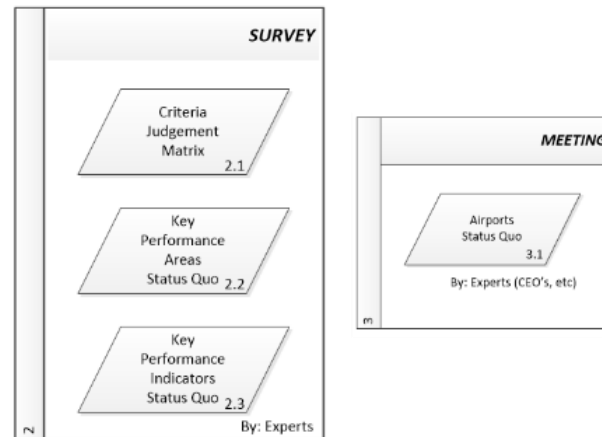


Figure 4. 5 – PESA-AGB Value Tree.
Source: Own elaboration.

4.3.4 Survey and Meetings

Survey (Step 2) and meetings (Step 3) represent collected expert's judgments through surveys and/or meetings (Figure 4.6). Using expert's answers statistical averaging, a status quo scale (ordinal value scale) is created.



**Figure 4.6 – Survey and meeting steps from the PESA-AGB model.
Source: Own elaboration.**

Survey (Step 2)

The survey (appendix 3 explains in detail all steps) consisted of the following six steps [93]:

- (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 KPIs experts' opinions. KPAs' and KPIs' status quo (2.2 and 2.3 of step 2), which follows mathematical foundations in appendix 3 using experts' answers from survey steps (iii) and (v). Criteria judgment matrix (2.1) follows mathematical foundations in annexe 1 using experts' answers from the survey step (vi). Figure 4.7 depicts an example of a criteria judgment matrix, which combines the performance descriptor (1.3) with the expert's judgements.

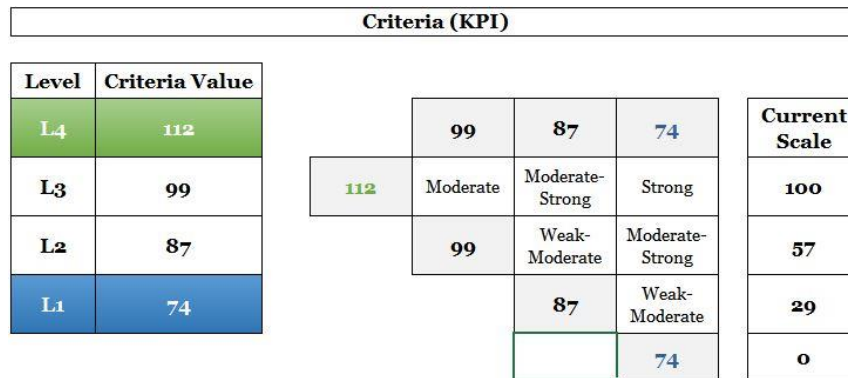


Figure 4.7 – Example of a criteria judgement matrix.
Source: Own elaboration.

Meetings (Step 3)

The meeting (Step 3), or decision conference, gathers the key player who wishes to benchmark their airport performance and efficiency, assisted by an impartial facilitator. This facilitator is a specialist in decision analysis and works as a process adviser, 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 4.8 shows the building process of a decision conference [90].

Airports status quo (3.1) follows mathematical foundations in Annexe 1 using experts' shared opinions, where airports status quo allows to perform a global peer benchmarking between different airports.

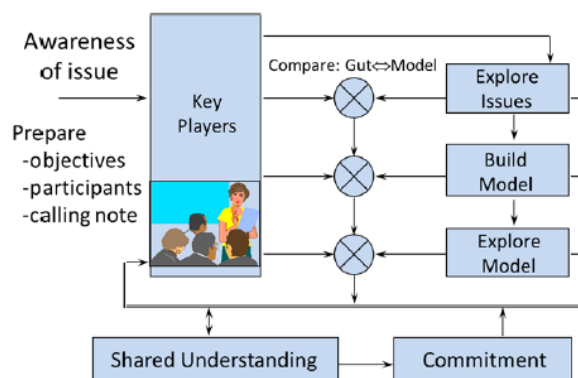


Figure 4.8 - Building process of a decision conference.
Source: [127].

4.3.5 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 4.3.3, respectively (Figure 4.9).

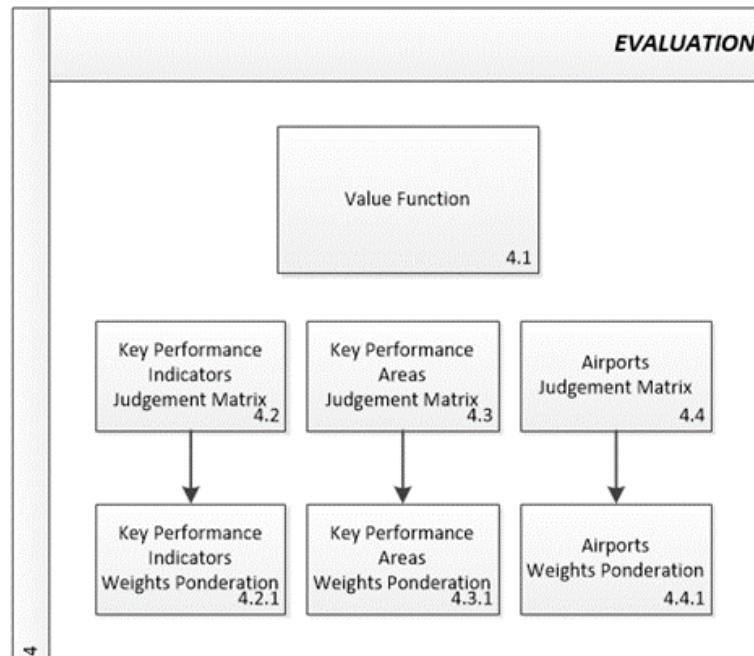


Figure 4.9 - Evaluation step from PESA-AGB model.
Source: Own elaboration.

Value function (4.1) consist of 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 determined by the criteria judgment matrix in Step 2. The PESA-AGB model can assign scores to each criteria value with these functions, following the experts’ judgments.

Figure 4.10 depicts an example of a criteria value function, obtain with the criteria judgment matrix of Figure 4.7.

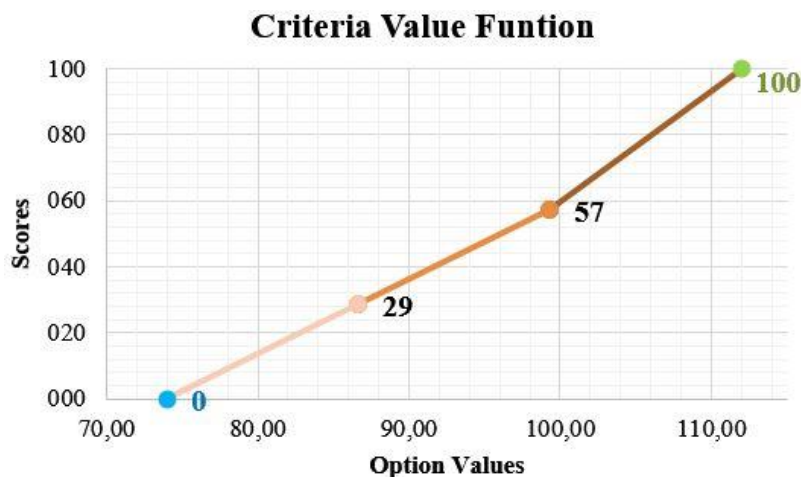


Figure 4.10 – Example of a criteria value function from the PESA-AGB model.
Source: Own elaboration.

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 Step 2. Firstly, the 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-GDA-PESA-AGB: a comparison using the difference between the ordinal values given by the experts.

Figure 4.11 represents an example of a judgement matrix and respective weight ponderation using the status quo scale.

KPA						
	KPI 2	KPI 3	KPI 4	KPI 5	Status Quo	KPI's Weights
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 4.11 – Example of a judgement matrix and respective weight ponderation. Source: Own elaboration.

4.3.6 Classification

Classification (Step 5) uses the value functions and weight ponderations from step 4 to obtain each KPI, KPA and airport score for each option (Figure 4.12).

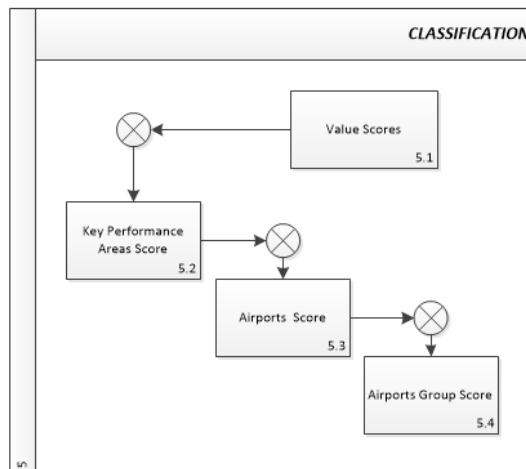


Figure 4.12 - Classification step from PESA-AGB model. Source: Own elaboration.

Value Scores (5.1)

Value Scores (5.1) is a simple step that assigns scores to each criteria value. The scores (y) are determined using the linear equations ($y = mx + b$) from value functions defined in section 4.3.5.

KPAs scores (5.2)

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. The following scores determination follow a bottom-up arrangement. Table 4.4 depicts an example of a KPA scores table.

Table 4.4 – Example of KPA scores table example
Source: Own elaboration

Year	KPA 1					KPA Score
	KPI 1.1	KPI 1.2	KPI 1.3	KPI 1.4	KPI 1.5	
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
Weights	25,71%	22,86%	20,00%	17,14%	14,29%	

Airports scores (5.3)

Airports scores (5.3) are obtained by multiplying each KPA score (5.2) with its weight ponderation determined in step 4.3.1. Table 4.5 depicts an example of an airport scores table with six KPA.

Table 4.5 – Example of an airport scores table example
Source: Own elaboration

Year	Airport						Airport Score
	KPA 2.1	KPA 2.2	KPA 2.3	KPI KPA 2.4	KPA 2.5	KPA 2.6	
2003	64,59	1,14	9,36	28,24	59,19	17,03	30,95
2007	78,61	46,16	58,51	68,28	62,05	41,06	60,33
2013	71,35	80,99	52,56	66,73	63,44	90,58	70,54
Weights	21,95%	19,51%	17,07%	14,63%	14,63%	12,20%	

Airports group scores (5.4)

Airports group scores (5.4) are calculated by multiplying each airport score (5.3) with its weight ponderation determined in step 4.4.1. Step 5 (Classification) uses each option (year) score of each KPI (defined in the previous step) and the weights ponderation to obtain each KPA score for each option. The final step, Step 6 (Outputs), assembles a large variety of outputs which allows monitoring performance over time, consisting of performance profiles, and options and difference profiles value by KPI, KPA, airports (internal benchmarking) and airport groups (external benchmarking).

Table 4.6 depicts an example of an airport scores table with six KPA.

A six categories' scales were associated with the score ranges of each KPA and each airport (Table 4. 7) to make the options score more operational to the decision-makers.

Table 4.6 – Example of an airport group scores table
Source: Own elaboration

Year	Airport Group			KPA Score
	Airport 1	Airport 2	Airport 3	
2003	39,50	30,35	38,18	36,77
2007	72,10	60,33	65,35	67,29
2013	72,69	70,54	68,97	71,28
Weights	50,00%	28,57%	21,43%	

Table 4. 7 - Levels, scores and category thresholds with six levels and 11 categories scales
Source: Own elaboration

Levels	Lo	]Lo,L1[	L1	]L1,L2[	L2	]L2,L3[	L3	]L3,L4[	L4	]L4,L5[	L5
Scores	0	10	20	30	40	50	60	70	80	90	100
Category Thresholds	Catastrophic	Alert-Catastrophic	Alert	Alert Poor	Poor	Poor Satisfactory	Satisfactory	Satisfactory Good	Good	Good Excellent	Excellent

Figure 4. 13 shows an example of core KPA category thresholds profile for the KPI scores on an airport where the 2003 option has the lowest scores while 2013 archives the highest scores.

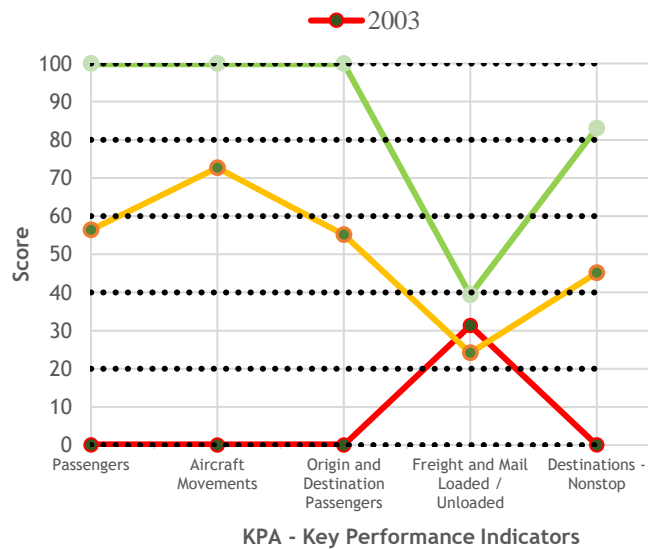


Figure 4. 13 - Example of core KPA category thresholds profile for the KPI scores of an airport
Source: Own elaboration

In Table 4. 8, it is feasible to find the information on core KPA category thresholds and scores for 2003, 2007 and 2013 options on the airport and conclude that the categories scales for the core KPA are positive and no action is necessary.

Table 4. 8 - Airport Core KPA category thresholds and scores for 2003, 2007 and 2013 options.**Source: Own elaboration based on the expert's meetings.**

Options	Scores	Category Thresholds
2003	6,2	Alert-Catastrophic
2007	50,6	Poor-Satisfactory
2013	84,6	Good-Excellent

4.3.7 Outputs

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

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

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

PESA-GBA model also produces graphics that depict KPI, KPA, airport, and airport group value scores. Moreover, to better understand the PESA-AGB model process, a step-by-step example of obtaining the final airport score can be depicted in Appendix 2.

4.4 GDA Step 3 - Report and Recommendations

4.4.1 GDA Report

The Benchmarking Report is part of the GDA model. It aims to contribute to the airport performance and efficiency assessment objectives, but it aims to identify, recognise, and promote good practice management and promotion. It is also intended as an exchange instrument for innovative ideas between airports or inspiration for those who plan to use GDA in the future. The report is targeted mainly at the Airport community but can be adapted for passengers or air cargo airlines. These include international airport experts and other local stakeholders. A certain level of knowledge of airports is assumed, but the exceedingly technical language has been dodged wherever possible. It should be accepted that this report is based on the 11 years (2003 to 2013) period only and can be updated to include information on future data.

4.4.2 Structure and methodology

The core part of the Benchmarking Report on airport performance and efficiency assessment is a catalogue element of good practice. These were derived from a stepwise analysis of the ACI scheme's factors during the evaluation process. The GDA methodology was used.

All the airports are similar to those of ANA, SA that holds a concession to run public airport service supporting civil aviation in Portugal with a share capital of 200.000.000,00 euros, owned 100% by VINCI Airports International, SA [128]. One of the main challenges in benchmarking airport performance is obtaining valuable data. The accessibility and quality of data on airport activities and finance vary considerably worldwide, subject to the ownership structure of the airports, bookkeeping practices in each country, and the data collected by government statistical agencies. Therefore the airport is chosen to be similar to those of ANA SA. The available airport data was collected, and the missing data was fulfilled by the similar USA and Brazilian airports with one runway and similar passenger flow. Experts' answers were collected, clustered and categorised, in order of relevance about KPA and KPI, and the KPI fill all KPIs judgement matrix giving rise to a first step to the list of elements of good practice. PESA-AGB methodology based on MACBETH methodology was applied to the airport in the study and plotted the outputs graphics and scores.

The 2003-2013 elements of good practice discussed in chapter 6 are the KPAs and KPIs of Table 4.1.

The analysis of the data collected is the next step in the report. The results are analysed, insights on the gaps between results and the KPA and KPI performance descriptors and value functions are identified. The report and recommendation structure are depicted in Figure 4. 14.

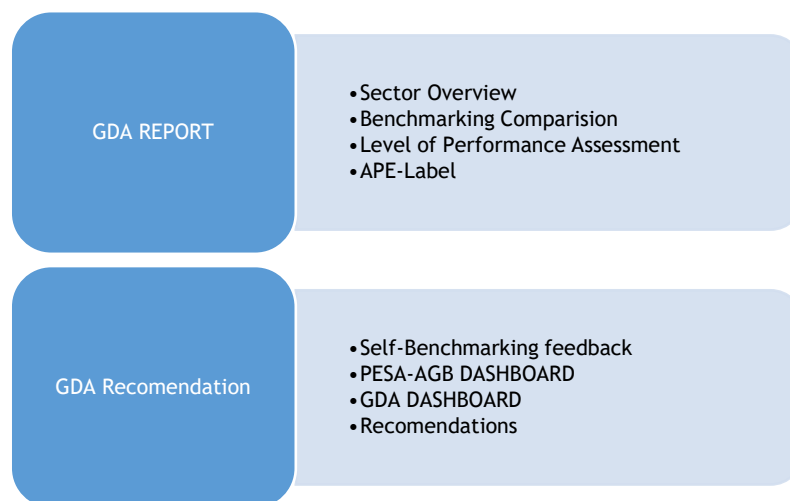


Figure 4. 14 – GDA Report and Recommendation Structure
Source: Own Elaboration

4.4.3 Report Model

A. Sector Overview

There are 10 Portuguese airports. ANA is responsible for managing all airports in mainland Portugal (Lisbon, Oporto, Faro and Beja Civilian Terminal) in the Azores (Ponta Delgada, Horta, Santa Maria and Flores) and Madeira (Madeira e Porto Santo), Figure 4. 15.

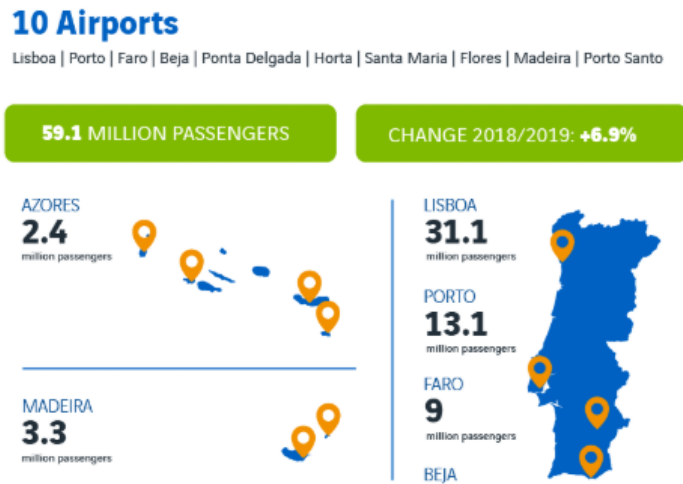


Figure 4. 15 – Portuguese Airport Overview 2019
Source: [128]

The analysis in this report refers to the 2003-2013 period; the remaining data from 2014 to 2019 is not available in this report. Nevertheless, it is possible to observe that the airports in Portugal have been growing in the passengers KPI. The Lisbon airport is the base of the Airport in the study in the analysis of this report.

B. Airport Benchmarking Comparison

Radar Charts

A report with the analysis of the KPA ad KPI is obtained by using radar score graphics, statistics and quadrant distribution based on the traditional grading scale to perform a high-level assessment of how the airport in the study performs. It is paid special attention to weak spots and recommends it to making the airport stronger.

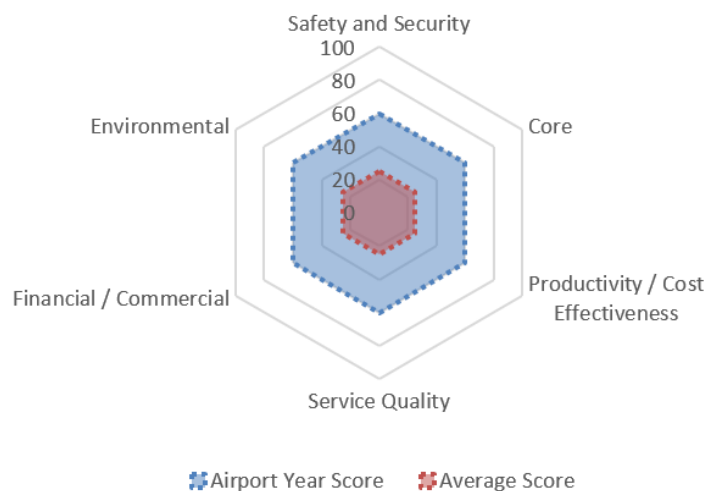


Figure 4. 16 – Radar Chart with Airport Year Score vs Average Score
Source: Own Elaboration

A radar chart (Figure 4. 16) represents multivariate data in the form of a two-dimensional chart of 6 quantitative variables (KPA). It compares the values of the 6 KPAs relatives to a central point. It helps rate the 6 KPA for 11 years period. The airport benchmarking comparison is made with the KPA scores compared with the KPA average score, and it is identified if the KPA Score is above or below the KPA average score. The analysis focuses on visible strengths and deficiencies, displays the critical KPA, completes each KPA, makes data-driven decisions quickly, and offers a vivid and visual description.

Quadrant Chart

Technically, a quadrant chart is a scatter chart divided into four sections (quadrants) to make the visualization more readable. This chart type is used when data can be grouped into quadrants, such as SWOT (strengths, weaknesses, opportunities, and threats) analysis.

For the airport quadrant chart, it is GEPP (Good, Excellent, Performing, and Poor):

Q(1)-Good stands for Airport High Performance and KPA Low Potential. The airport score performs above the average but below average in the KPA Score. This is often due to excellent scores in other KPA that indicates that the actual KPA is not critical to the high-performance airport score.

Q(2)-Excellent, Airport High Performance and KPA High Potential. The airport score performs above the average and has a strong KPA Score potential, and this is often due to the actual KPA being key to the high-performance airport score.

Q(3)-Performing, Airport Low Performance and KPA High Potential. The airport score performs below the average and has a strong KPA Score, and this quadrant reflects the best opportunity for improving the KPA Score potential in the airport.

Q(4)-Poor, Airport Low Performance and KPA Low Potential. The airport score performs below the average and below average in the KPA Score. This quadrant reflects the poor options (years) scores that need immediate analysis on the KPA performance and how to increase its performance potential.

The GEPP quadrant chart includes a uniform set of evaluation criteria KPA that can easily compare options (years). Key findings outline each KPA and each year in a GEPP quadrant distribution as depicted in Figure 4. 17.



Figure 4. 17 - KPA and year quadrant distribution
Source: Own Elaboration

C. Airport KPA 2003-2013 Graphs

A KPI Feedback is a business-performance tool that effectively visualises Key Performance Indicators. Airports use this feedbacks to track progress against targets and goals to improve performance. The KPI Feedback contains a mixture of Charts, Graphs and Tabular information. A KPI Feedback is not only a more refined way to collate data, and it is designed to visualise KPIs and metrics that specifically target performance against objectives. They are the pinnacle of a structured performance monitoring or improvement process. It tracks how effectively an organisation is performing against that objective, target, or goal. Airports can use KPIs to bring about performance improvements that drive growth. The goal for each KPI is established throughout the PESA-AGB value function KPA, KPI and Airport Scores. The target is to be above the best airport score (good mark) and never be below worst (neutral mark) airport scores with the weight’s application, GDA Recommendations.

D. APE-Label

In chapter 5 is depicted how an Airport Performance and Efficiency – Label (APE-Label) development could be applied to any airport and function as a potential driver for guiding air travellers in their airport choices. APE-Label, is build and applied to the airport in the study.

4.4.4 GDA Recommendations

In the GDA Recommendations, Gaps and extreme variations are pointed, and the corrective recommendation is stated. This GDA Recommendation is built with Airport Self-benchmarking feedback, PESA-AGB DASHBOARD, GDA DASHBOARD and Recommendations.

A. Airport Self-Benchmarking KPA and KPI Feedback

A KPI Feedback is a business-performance tool that effectively visualises Key Performance Indicators. Airports use these feedbacks to track progress against targets and goals to improve performance. The KPI Feedback contains a mixture of Charts, Graphs and Tabular information. A KPI Feedback is not only a more refined way to collate data, and they are designed to visualise KPIs and Metrics that specifically target performance against objectives. They are the pinnacle of a structured performance monitoring or improvement process. It tracks how effectively an organisation is performing against that objective, target or goal. Airports can use KPIs to bring about performance improvements that drive growth. The goal for each KPI is established throughout the PESA-AGB value function KPA, KPI and Airport Scores and a score of the best and worst airport scores of the final scores with the weights are depicted in Table 4. 9.

Table 4. 9 – Airport Score Goal and KPA target performance
Source: Own Elaboration

	Safety and Security	Core	Productivity / Cost Effectiveness	Service Quality	Financial / Commercial	Environmental	Airport Score
Good	Best Airport Score	Best Airport Score	Best Airport Score	Best Airport Score	Best Airport Score	Best Airport Score	Airport Score
2003	KPA Score	KPA Score	KPA Score	KPA Score	KPA Score	KPA Score	KPA Score x KPA Weight
(...)	(...)	(...)	(...)	(...)	(...)	(...)	(...)
2013	KPA Score	KPA Score	KPA Score	KPA Score	KPA Score	KPA Score	KPA Score x KPA Weight
Neutral	Worst Airport Score	Worst Airport Score	Worst Airport Score	Worst Airport Score	Worst Airport Score	Worst Airport Score	
Weights	KPA Weight	KPA Weight	KPA Weight	KPA Weight	KPA Weight	KPA Weight	

Calculation of the scoring results are performed in the following four steps:

1. Assess the superior (bigger) and bottom (lower) level of performance of Airport Score to establish the performance intervals and refer to a 3-colour correlation: Excellent is Green, Fair is Yellow and Poor is Red (Figure 4. 18).

Scoring Results	
>=Higher Airport Score	Excellent
Lower to Higher Airport Score	Fair - some improvement needed
<= Lower Airport Score	Poor - Needs significant improvement

Figure 4. 18 – Levels of performance intervals
Source: Own Elaboration

2. Scoring the KPA in 3 levels punctuation, if KPA score is between 0 points and the lower airport score it has 0 points of 2 possible. If it is between the lower airport score and the major airport score, it has 1 point of 2 possible, and lastly, if it is between the major airport score and the 100 points score, it has 2 points of 2 possible (Figure 4. 19).

Scoring		
0 point	1 point	2 points
0-Lower	Lower-Major	Major-100

Figure 4. 19 – Three Levels punctuation KPA Scoring
Source: Own Elaboration

- 3. Assessing KPA Score for all options (Years 2003-2013), it is applied the three levels of points KPA Scoring, it is possible to assess the level of performance and efficiency of the KPA in the 11 years of study as depicted in Figure 4. 20.

<i>Airport</i>	KPA Score (calculated)	Possible
KPA		
2003		2
(...)		2
2013		2
	0	6
	<i>Total score</i>	<i>Total Possible Score</i>

Figure 4. 20 – Level of performance KPA assessment table
Source: Own Elaboration

- 4. The Self-Benchmarking of the Airport KPA is now plotted in a table as depicted in Table 4. 10.

Table 4. 10 - Self-Benchmarking of the Airport KPA per year
Source: Own Elaboration

KPA	KPA Score	Feedback
		If KPA scores under lower airport score - Red area - Poor - Needs significant improvement.
		If KPA scores between lower and major airport score - Yellow area - Fair - some improvement needed
		IF KPA scores above major airport score - Green area - Excellent

The structure report and recommendations apply to the KPI analysis for each KPA and the analysis of the airport group Peer-Benchmark with the necessary adjustments. All these benchmarks are analysed with the GDA - PESA-AGB KPI, KPA and Airports Scores.

B. PESA – AGB DASHBOARD

The PESA-AGB DASHBOARD is built in Microsoft Excel, linking to the PESA-AGB model with seven highlighted areas. Airport KPA profile, airport KPI profile, airport options ranking, airport KPA value profile, airport KPA ranking, airport options (years) profile, and KPA options (years) and differences profiles, allowing airport managers to visualise all the areas and indicators scores and alerts.

C. PESA – AGB DASHBOARD

The GDA DASHBOARD is built with six highlighted areas in Microsoft Excel linking airport options (2003-2013) final score, airport KPA self-benchmarking, airport and KPA-KPI cumulative points, airport APE-Label, airport KPA quadrant chart, and airport KPA radar chart, helping airport managers to visualise all the self-benchmarking results and alerts.

D. Recommendations

All these benchmarks are analysed with the GDA - PESA-AGB KPI, KPA and Airport Scores. In the GDA Recommendations, Gaps and extreme variations are pointed, and the corrective recommendation is stated. The structure report and recommendations apply to the KPI analysis for each KPA and airport in study with the necessary adjustments.

The recommendations for the airport in study using KPA ranking and Category Thresholds are used to suggest the improvement in the scores:

Recommendation: improve practice addressing the KPIs with more relevance.

Recommendation: maintain good practice.

4.5 Conclusion

Analysis of airport performance has become one of the most important topics for civil aviation authorities, even more in the economically fast-growing regions that faced a significant increase in passengers and cargo transport. With the intensification of market competition and privatization of airport management, it is essential to have a well-structured system to assess airport performance efficiency and competitiveness [24]. Airport benchmarking depends on airport performance and efficiency indicators, and it is an essential issue for business, operational management, regulatory agencies, airlines, and passengers. Using the PESA-AGB based on MACBETH (Measuring Attractiveness by a Categorical Based Evaluation Technique) approach, a hierarchical additive value model was constructed with criteria weights and value scales derived from expert's judgments (obtained by an online survey [129]) and by comparison of different reference levels and profiles of performance. GDA 3 steps model measures airport performance and efficiency, and peer benchmarks it within a set of direct competitors or self-benchmarks itself during a specified period. GDA (Global Decision Support) model report and recommendations, integrated into a management system, identify deficiencies requiring urgent intervention and corrective measures to improve its continuous improvement [130].

It was developed a manageable set of KPIs used to monitor the airport and quickly retrieve information when some process or area fails the target to the desired standard, by comparison with other airports (peer-benchmarking) and analysing the development of the airport over time

Air Transport Performance and Global Decision Analysis

(self-benchmarking). This set has not yet been tested operationally so, and the next step would be the implementation and test for at least two airports.

Chapter 5

GDA APE-Label

5.1 Introduction

5.2 Implementation

5.3 Layout of Classification

5.4 APE-Label

5.5 Conclusions

5. GDA APE-Label

5.1 Introduction

This chapter explores how an Airport Performance and Efficiency – Label (APE-Label) development could be applied to any airport and function as a potential driver for guiding air travellers in their airport choices.

The proposed APE-Label resulted from Performance and Efficiency Analysis – Airport Global Benchmark (PESA-AGB) model outputs. The use of the Airport Council International (ACI) guide, which divided the airport into six Key Performance Areas (KPA) associated with several Key Performance Indicators (KPIs) each, was depicted in chapter 4. These are integrated into the multi-criteria decision analysis MACBETH-PESA-AGB model and was applied to 1 airport to self-benchmark them in 11 years' time period. Empirical results were combined within the PESA-AGB model. The six KPA essential for developing an APE-label were classified: core, safety and security, service quality, productivity/cost-effectiveness, financial and environmental. The comparison of pre-set data allows the airport management to establish new performance goals with new standards and measures.

This chapter highlights the significant APE-label role in increasing the air traveller perceived airport choice to travellers. With all its inputs and outputs, the airport industry has a substantial impact on the worldwide economy. It must find an optimal level for evaluating the interests of the public in general, the stakeholders, and all the airport operators. Thus, this APE-Label has a practical implication in developing business strategies to a more transparent, more competitive, green, better quality, and more safe and secure airport.

5.2 Implementation

The need for airport infrastructure improvement due to the global air traffic increase expected as annual growth of 5.2% until 2029 [131] drives the airports to monitor their performance as a requirement to be successful in this competitive market. In recent years the performance measurement interest has been increasing, recognising the importance this fact has for private and public infrastructures with a volatile business environment [60]. Since then, airports have been pressured to adapt their operations and reduce the charges to meet the air carriers business model operational requirements [59].

The evolution of air transportation has shown several trends, mainly caused by social, technological, economic and political drivers [39]. Airlines have a strong influence on 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 [132]. Thus, this demand adds pressure on airport management to sell off limited capacity cheaply, forcing airports to reconsider their

relationship with airlines [47]. Airports need to expand their capacity and improve runway and terminal systems efficiency to face this problem. However, until the beginning of airport privatization, slot demand was inefficient and needed improvements to meet all air transport restructuring processes. All of this created the need for airports to start benchmarking themselves and compare them with other airports [59].

An airport is an excellent example of a complex system. It includes aircraft, fuel trucks, support vehicles such as baggage trolleys, passenger buses, follow-me, catering, cleaning, security vehicles in addition to baggage-handling equipment, flight, and resources planning, and several other systems that can and do operate autonomously of each other. For the airport to work correctly, it needs to have optimal independent systems, and these systems need to collaborate, merging information from various sources. A sophisticated infrastructure such as airports entails a proper arrangement of all the intervenient systems and resources to assist decision-makers in managing daily operations accurately. Thus, this suggests that airport stakeholders face challenging decision-making questions with strong interdependencies and conflicting objectives in the areas of safety, security, and efficiency of services. The process of decision-making that assesses these questions requires the arrangement of solutions capable to uninterruptedly monitor and accurately understand operational events within each organizational context [133]. The privatization of airports increased airport competitiveness and created performance indicators to gain insight into their performance to maximize their efficiency [134]. The growth of airport capacity also became a major priority that leads, for example, to a reduction of turnaround time.

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 determining the overall business performance. Benchmark measures the performance of discrete airport functions assessing the implementation of the airport's strategic planning. Identifying and accepting the best practices of the airport can increase its efficiency, quality and customer satisfaction. In other words, airport benchmarking links day-to-day operations and management strategies with the airports short and long-term actions plans and initiatives [77]. Thus, this makes the airport benchmarking a component for airports strategic planning process and a tool to monitor and compare airport, economic, operational and service performance.

This study presents and discussed an APE-Label implementation applied to any airport despite its size and location. The main obstacle to implementing this APE-Label is the heterogeneity of the airport infrastructure, as it differs from the number of runways to the ownership. The primary purpose is to provide a graphic APE-Label that informs all the stakeholders what the evaluation of the infrastructure analysed through six key performance areas each year may help maximise efficiency standards.

Other types of labels have been implemented with high success; new tires sold in the EU after November 2012 come with a standard label. It classifies the tire into three categories – fuel efficiency, wet grip and external noise – with a rating for each area. The EU Commission requires

tire manufacturers to comply with new labelling regulation (EC) no. 1222/2009 to unify and clarify the safety requirements and efficiency of tires [135]. Another commonly used label is the Energy one that helps consumers to choose energy-efficient products [136]. In the European Union, many everyday products (Figure 5.1) such as washing machines, refrigerators, and cooking appliances contain energy labels and have been designed to meet minimum energy efficiency standards [137]. This study presents and examines the idea of introducing an air transport eco-label that could help build awareness among air travellers by providing them with environmental information during booking, thereby making flights environmentally comparable. Thus, this would also stimulate more competition between airlines, motivating them to improve their environmental performance and creating a competitive advantage for those performing better [138].

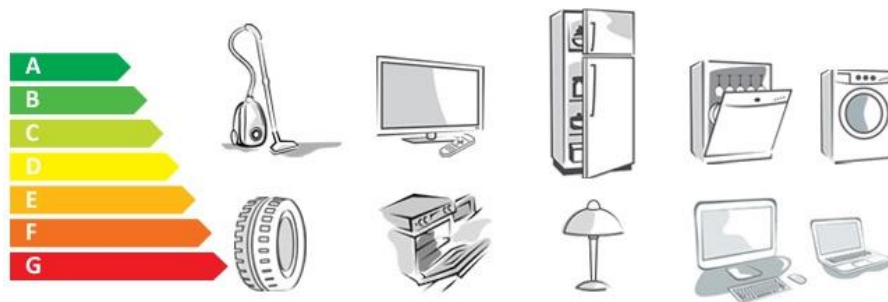


Figure 5.1 - Everyday products with Energy labels

Source: [137]

Considering that a computer is not a refrigerator or a tire and, it is possible to have an efficiency label applied to all, the discussion to have an APE-Label despite the airport heterogeneity is challenging and not consensual.

With APE-Label, the aim is to deepen the current understanding of the effects of an APE-Label on the decision making by airport stakeholders. This research provides an approach to implement this label based on the GDA airports efficiency supported by their performance data constructed with PESA-AGB based on the online survey answers provided by air transport experts. A generic and all proposed APE-Label regulation can be implemented if an international bill is supported by the International Civil Aviation Organization (ICAO) or by the European Commission.

The APE-Label construction into an airport intends to educate all stakeholders on how this infrastructure has been efficient throughout the year of operation analysed. First, it is necessary to acquire existing data of all KPI - key performance indicators for each KPA - key performance areas described by Baltazar *et al.* [130] and suggested in the previous chapter. Secondly, the use of the PESA-AGB (Performance Efficiency Support Analysis – Airport Global Benchmarking) model is explained in detail in chapter 4.

5.3 Layout of Classification

The lack of reliable and comparable information on the airport's performance and efficiency makes it difficult for the stakeholders to take these elements into account, especially when choosing one airport. All performances data and efficiencies scores can be displayed at the airport and on all technical, promotional literature such as catalogues, leaflets, and web-based marketing.

5.3.1 Grading and measurement of Airport Performance and Efficiency

The KPA definition can be found in the previous chapter in Table 4.1 - Scope of each key performance area (KPA) and key performance indicator (KPI) of PESA-AGB. KPA efficiency class shall be determined and illustrated on the APE-Label, based on measurement and scores of the category thresholds obtained in the PESA-AGB of the GDA, according to the 'A' to 'F' scale specified in Table 5. 1.

Table 5. 1 KPA levels class and efficiency scores.
Source: Own elaboration based on the expert's meetings.

<i>Efficiency Class</i>	<i>KPA - Efficiency Score</i>
	<i>[Six levels (classes) from F (least efficient) to A (most efficient)]</i>
A	80 ≤ Efficiency Score ≤ 100
B	60 ≤ Efficiency Score < 80
C	50 ≤ Efficiency Score < 60
D	40 ≤ Efficiency Score < 50
E	20 ≤ Efficiency Score < 40
F	00 ≤ Efficiency Score < 20

The KPA efficiency score is obtained by multiplying the one-year KPA score by the KPA weight calculated with the airport experts' opinions in the online survey and is depicted in Equation 5. 1 and

Table 5. 2

$$\text{Airport efficiency score} = \sum_{i=1}^6 \text{KPA Year Score}_i \times \text{Weight}_i \quad \text{Equation 5. 1}$$

Table 5. 2 Airport score by KPA efficiency scores and weights.
Source: Own elaboration based on the expert's meetings.

	Safety and Security	Core	Productivity / Cost Effectiveness	Service Quality	Financial / Commercial	Environmental	Airport Score
Year Score	0-100	0-100	0-100	0-100	0-100	0-100	0-100
Weights	21,95%	19,51%	17,07%	14,63%	14,63%	12,20%	100%

5.4 APE-Label Content and Format

5.4.1 APE-Label Content

The APE-Label template design is focused on six KPA and the final efficiency score for the airport using the KPA levels class depicted in Figure 5. 2

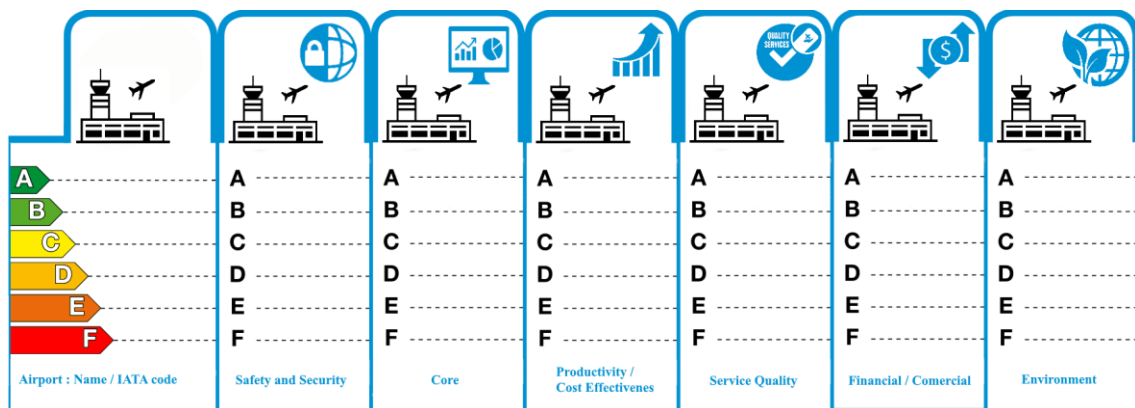


Figure 5. 2 - APE-Label template.
Source: Own elaboration.

The information included in the upper part of the APE-Label is the pictogram, scale and level class, with a colour code associated with the letter (from A to F) that gives an idea of the airport efficiency KPA specified by Table 5. 1. Information to be include in the bottom part of the APE-Label is the airport name and IATA code² in the first column and the KPA name in the following columns.

5.4.2 APE-Label Format

The APE-Label is a rectangle with the minimum size of 220 mm comprehensive and 80 mm high, divided into three parts, the airport pictogram and KPA pictogram part is 35 mm wide and 25 mm high. The second part is the scale and airport class 40 mm wide and 40 high, and KPA efficiency class 30 mm wide and 40 high, and the third part is airport name and IATA code with 40mm wide and 10mm high, and KPA name with 30mm wide and 10 mm high. The background of the APE-Label is 100% white, and the typefaces (A-F) are in Arial 10pt, and the colours, using RGB

² An **IATA airport code**, also known as an **IATA location identifier**, **IATA station code**, or simply a **location identifier**, is a three-letter geocode designating many airports and metropolitan areas around the world, defined by the International Air Transport Association (IATA). The characters prominently displayed on baggage tags attached at airport check-in desks are an example of a way these codes are used.

(Red, Green and Blue) and hexadecimal nomenclature, and shall fulfil all the following requirements:

- Upper part blue colour and KPA pictogram: 0, 145, 210 – Hex: 0091D2 and right justified in the column,
- Upper airport pictogram: 0, 0, 0 – Hex: 000000 and bottom left-justified in the top of the column,
- Label Class A: 0, 144, 54 – Hex: 009036 and right justified in the arrow,
- Label Class B: 87, 171, 39 – Hex: 57AB27 and right justified in the arrow,
- Label Class C: 255, 237, 0 – Hex: FFED00 and right justified in the arrow,
- Label Class D: 250, 187, 0 – Hex: FABB00 and right justified in the arrow,
- Label Class E: 235, 105, 11 – Hex: EB690B and right justified in the arrow,
- Label Class F: 255, 0, 0 – Hex: FF0000 and right justified in the arrow,
- Airport name and IATA and KPA name: 19, 151, 212 – Hex: 1397D4 and Arial Bold 6 pt and centred in the column.

The APE label is printed in a larger format. Its content shall nevertheless remain proportionate to the specifications above.

5.5 Conclusion

This chapter aims to design and analyse the effects of using an APE-Label aggregating the airport's areas structure as defined by ACI and how it will affect stakeholders' decisions. Thus, the six KPA essential for the development of an APE-label were classified: core, safety and security, service quality, productivity/cost-effectiveness, financial and environmental using empirical results within the PESA-AGB model, the comparison of a pre-set data allowed the airport management to establish new performance/efficiency goals with new standards, becomes a GDA output. Given that the decision-making processes in large companies and infrastructures are gaining more importance every day and are considered crucial to their success, this study revised some concepts and processes directly adapted to the airport's case. This way, it is possible to build a framework for the future in decision making regarding airports.

The study proposes that the use of APE-Label is demonstrative that a visual and complete label helps guide all airport stakeholders in their decision-making for an optimal balance of their interests. APE-label is a tool to increase the air traveller perceived airport choice to travellers. Thus, this APE-Label has a practical implication in developing business strategies to a more transparent, more competitive, environmental conscience, better services, and more safe and secure airports. The aim is to lead a market transformation towards a more efficient and low-emissions infrastructure beyond the standards already achieved. It will also pave the way for competition to have the best performance and price, which will, in turn, stimulate investment in research and development.

Chapter 6

Case Study

6.1 Introduction

6.2 Self-Benchmarking Airport Case Study

6.3 GDA Support System Outputs

6.4 Conclusions

6. Case Study

6.1 Introduction

This chapter describes the case study, where a self-benchmarking analysis was conducted for the airport in the study with distinctive characteristics, representing the main Portuguese air infrastructure. The airport in the study is considered the largest one in terms of passengers, movements, and cargo and is associated with Lisbon airport. Finally, is presented the GDA support system results with dashboards for PESA-AGB outputs and GDA outputs.

Airport benchmarking depends on airport performance and efficiency indicators, and it is an essential issue for business, operational management, regulatory agencies, airlines, and passengers. Using the PESA-AGB, this model measures airports performance and efficiency and can peer-benchmarks within a set of direct competitors or self-benchmarks itself during a specified period from 2003 to 2013. PESA-AGB model outputs, integrated into the management system GDA-MRR, allow identifying deficiencies requiring urgent intervention and corrective measures for continuous improvement. This chapter evaluated the GDA-MRR feasibility for the airport performance, efficiency assessment, and the dashboard construction for self-benchmarking is explained in detail.

The *cliché* “You cannot manage what you do not measure” applies to airport’s, an attainable scope for the benchmarking is the definition of the metrics and data requirements for these metrics. In this study, the metrics, data requirements and PESA-AGB Outputs are explained in detail in appendix 2 of this document. Also, the KPAs and KPIs are typically addressed in this airport self-benchmarking study (and where significant comparison data is available).

6.2 Self-Benchmarking Airport Case Study

The first step in benchmarking an airport is determining the benchmarking project's scope and overall business objectives. In this case, it is established a baseline performance and efficiency as a diagnostic tool using the GDA-MRR model, described in chapter 4, to compare trend data over time to baseline performance can help predict and avoid failure, improving long-term reliability. Efficiency can also benefit by identifying and therefore allowing the correction of typical performance decay during an extended business period. GDA model is applied to the airport in the study, and GDA-3 steps are described in the following sections of this chapter.

The airport in the study, associated with Lisbon Airport, also known as Lisbon Portela Airport (IATA: LIS, ICAO: LPPT), is an international airport located 7 km north of Lisbon city centre, the capital of Portugal. As visible in Figure 6. 1, the airport is surrounded by urban development, is one of the few airports in Europe located inside a major city. It is operated by VINCI Airports and ANA – Aeroportos de Portugal.



Figure 6. 1 – Lisbon Airport Aerial Photo.
Source: [139].

Data for each option (2003-2013) collected for this airport is depicted in Table 6. 1., to better view the data, please look into appendix 2.

Table 6. 1 - Airport in study Data
Source: [99], [100], [101]–[108], [109]–[123]

KPA (Criteria)	KPI (Sub Criteria)	Ano											Metric	
		2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013		
Safety and Security	Runway Accidents	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	Accidents / 1000MOVs
	Runway Incursions	0,0592	0,0628	0,0556	0,0768	0,0624	0,0619	0,0618	0,0758	0,0606	0,0798	0,0600	0,0600	Incursions / 1000MOVs
	Bird Strikes	0,4100	0,7600	0,8130	0,4440	0,3720	0,2640	0,6900	0,5610	0,7120	0,6570	0,6900	0,6900	BS / 1000MOVs
	Public Injuries	0,4889	0,5319	0,5399	0,1132	0,1021	0,3928	0,3324	0,2172	0,1004	0,2484	0,0984	0,0984	Pinj / 1000MOVs
	Occupational Injuries*100	0,5330	1,0205	0,8590	0,5447	0,6353	0,5596	1,5080	1,3503	0,9223	0,7551	0,7541	0,7541	Ocpinj / 1000HoursWorked
	Lost Work Time From Employee Accidents and Injuries	7,7397	9,6380	4,1339	2,5163	3,4327	2,9101	1,8895	5,9443	4,1639	2,4670	5,9443	5,9443	LWT / 1000HoursWorked
Core	Passengers	9636257	10731861	11236476	12314917	13393182	13603616	13265268	14049808	14806537	15314800	16025510	16025510	nPAX
	Origination and Destination Passengers	9414564	10510168	11015669	12130014	13240879	13532558	13245926	14026154	14790440	15294210	16009049	16009049	nP PAX O&D
	Aircraft Movements	112500	122200	124187	132458	144800	140016	136286	138147	139497	140909	142333	142333	nP MOVs
	Freight and Mail Loaded / Unloaded	95766	100075	100103	99556	82880	88832	83345	105304	94356	90282	97179	97179	Metric TONs
	Destinations--Nonstop	74	78	83	169	126	124	126	102	108	112	107	107	nP AIRP non-stop
Productivity/Cost Effectiveness	Passengers Per Employee	14757	16394	17205	18858	20275	20832	19473	20870	22543	22702	23776	23776	PAX / EMP
	Aircraft Movements per Employee	172	187	190	203	210	214	194	205	213	209	217	217	MOVs / EMP
	Aircraft Movements per Gate	5114	5555	4964	5298	5484	3784	3578	2763	2790	2818	2927	2927	MOVs / GATE
	Total Cost per Passenger	19,468	18,272	17,584	16,253	15,238	15,261	15,843	15,110	14,562	16,551	16,262	16,262	TCost / PAX
	Total Cost per Movement	1667,556	1600,655	1591,861	1511,068	1471,457	1482,688	1587,098	1538,578	1543,761	1797,259	1780,541	1780,541	TCost / MOVs
	Total Cost per WLU	18,474	19,288	18,866	17,274	16,635	11,415	14,774	14,946	15,143	17,808	18,325	18,325	TCost / WLU
	Operating Cost per Passenger	4,958	5,465	5,481	5,348	3,189	3,197	3,054	3,189	3,280	3,941	4,469	4,469	OP Cost / PAX
Operating Cost per Movement	424,667	478,718	496,230	497,198	307,578	310,582	305,926	324,677	347,749	427,912	488,638	488,638	OP Cost / MOVs	
Operating Cost per WLU	4,705	5,769	5,861	5,684	3,482	2,391	2,848	3,154	3,411	4,240	5,028	5,028	OP Cost / WLU	
Service Quality	Practical Hourly Capacity	39	41	38	42	43	39	37	38	44	42	45	45	MaxMOVs/hour
	Gate Departure Delay	12,30	14,40	13,20	10,10	9,90	11,50	10,10	9,80	10,50	14,00	12,20	12,20	ΣΔCTI / nFlights
	Taxi Departure Delay	3,20	3,50	2,10	2,90	2,00	1,40	1,90	2,50	1,70	1,50	2,00	2,00	ΣΔTTI / nFlights
	Customer Satisfaction	65,40	67,20	65,90	67,00	67,80	68,70	66,70	70,80	71,80	72,20	74,10	74,10	A-100-90 % B-90-70 % C-70-50 % D-50-30 % E-30-0 %
	Baggage Delivery Time	27,30	25,40	27,00	31,10	24,90	34,00	24,00	22,50	21,50	17,50	18,00	18,00	ΣΔBDTI / nFlights
	Security Clearing Time	25,60	26,40	24,30	26,60	24,30	25,70	25,00	20,50	22,70	26,30	25,10	25,10	ΣΔSCTI / nPAX
Financial/Commercial	Aeronautical Revenue per Passenger	9,599	8,734	8,411	7,755	7,232	7,075	7,239	6,859	6,780	6,593	6,295	6,295	REV / PAX
	Aeronautical Revenue per Movement	822,222	765,139	761,483	720,994	698,349	687,421	725,185	698,358	718,811	715,902	689,239	689,239	REV / MOVs
	Non-Aeronautical Operating Revenue as Percentage of Total Operating Revenue	0,322	0,328	0,340	0,344	0,349	0,348	0,351	0,350	0,347	0,355	0,358	0,358	NonAeroOp REV / TotalOp REV(%)
	Non-Aeronautical Operating Revenue per Passenger	4,216	3,980	4,061	3,876	3,746	3,685	3,878	3,689	3,611	3,621	3,573	3,573	NonAeroOp REV / PAX
	Debt Service as Percentage of Operating Revenue	0,331	0,367	0,358	0,327	0,286	0,299	0,330	0,313	0,234	0,293	0,324	0,324	Debt / OP REV (%)
Long-Term Debt per Passenger	9,020	12,787	17,982	18,445	18,023	20,643	20,691	19,964	19,219	13,606	52,845	52,845	LT Debt / PAX	
Debt to EBITDA Ratio	2,540	4,001	5,007	4,893	4,379	5,043	4,504	4,529	3,816	3,669	14,924	14,924	Debt/EBITDA	
EBITDA per Passenger	3,551	3,196	3,591	3,769	4,116	4,093	4,594	4,408	5,036	3,708	3,541	3,541	EBITAD/PAX	
Environmental	Carbon Footprint (TONS)	3334	3308	3282	3256	3230	3204	3025	3096	3235	3145	3050	3050	GHG
	Carbon Footprint (TONS/PAX)	0,0003	0,0003	0,0003	0,0003	0,0002	0,0002	0,0002	0,0002	0,0002	0,0002	0,0002	0,0002	GHG/1000 PAX
	Waste Recycling	5,78	7,57	10,17	9,39	11,48	14,56	19,46	23,95	30,84	19,11	13,33	13,33	%Waste recycled
	Waste Reduction Percentage	-3,31	-0,55	27,63	-14,53	8,69	-0,26	-3,95	-11,84	-2,68	6,17	9,78	9,78	Waste red (%)
	Renewable Energy Purchased by the Airport (%)	24,20	26,10	28,00	29,90	31,80	33,70	48,80	53,00	56,00	59,00	73,10	73,10	REP (%)
	Utilities/Energy Usage per Square Meter of Terminal	555,38	581,42	604,08	417,73	452,55	481,31	513,02	589,15	571,16	448,15	520,30	520,30	KWh/m²2
Water Consumption per Passenger	40,00	39,60	31,10	33,00	39,00	39,00	32,10	37,80	35,90	32,30	30,60	30,60	H2O (Lit)/PAX	

PESA-AGB model flowchart in appendix 1 is followed in the six steps. Results for each step are depicted in appendix 2.

Table 6. 2 - Airport in study Performance Descriptors
Source: Own elaboration.

		L4-Target	L3	L2	L1-Neutral
Safety and Security	Runway Accidents	0	0,002	0,004	0,006
	Runway Incursions	0,0556	0,0637	0,0717	0,0798
	Bird Strikes	0,2640	0,4470	0,6300	0,8130
	Public Injuries	0,0984	0,2455	0,3927	0,5399
	Occupational Injuries	0,5330	0,8580	1,1830	1,5080
	Lost Work Time from Employee Accidents and Injuries	1,8895	4,4723	7,0552	9,6380
Core	Passengers	16025510	13895759	11766008	9636257
	Origination and Destination Passengers	16009049	13810887,33	11612725,67	9414564
	Aircraft Movements	144800	134033,3333	123266,6667	112500
	Freight and Mail Loaded /Unloaded	105304	97829,33333	90354,66667	82880
	Destinations–Nonstop	169	137	106	74
Productivity / Cost Effectiveness	Passengers Per Employee	23775,890	20769,634	17763,377	14757,121
	Aircraft Movements per Employee	217,151	202,195	187,238	172,282
	Aircraft Movements per Gate	5554,545	4624,010	3693,475	2762,940
	Total Cost per Passenger	14,562	16,197	17,833	19,468
	Total Cost per Movement	1471,457	1580,058	1688,658	1797,259
	Total Cost per WLU	11,415	14,040	16,664	19,288
	Operating Cost per Passenger	3,054	3,863	4,672	5,481
	Operating Cost per Movement	305,926	369,684	433,441	497,198
Operating Cost per WLU	2,391	3,555	4,718	5,881	
Service Quality	Practical Hourly Capacity	45	42	40	37
	Gate Departure Delay	9,80	11,33	12,87	14,40
	Taxi Departure Delay	1,40	2,10	2,80	3,50
	Customer Satisfaction	74,10	71,20	68,30	65,40
	Baggage Delivery Time	17,50	23,00	28,50	34,00
	Security Clearing Time	20,50	22,53	24,57	26,60
	Border Control Clearing Time	6,70	8,60	10,50	12,40
Check-in to Gate Time	17,50	20,10	22,70	25,30	
Financial / Commercial	Aeronautical Revenue per Passenger	9,599	8,498	7,396	6,295
	Aeronautical Revenue per Movement	822,222	777,289	732,355	687,421
	Non-Aeronautical Operating Revenue as Percentage of Total Operating Revenue	0,358	0,346	0,334	0,322
	Non-Aeronautical Operating Revenue per Passenger	4,216	4,002	3,788	3,573
	Debt Service as Percentage of Operating Revenue	0,234	0,278	0,323	0,367
	Long-Term Debt per Passenger	9,020	23,628	38,236	52,845
	Debt to EBITDA Ratio	2,540	6,668	10,796	14,924
EBITDA per Passenger	5,036	4,423	3,810	3,196	
Environmental	Carbon Footprint (TONS/PAX)	3025	3128	3231	3334
	Waste Recycling	0,0002	0,0002	0,0003	0,0003
	Waste Reduction Percentage	30,84	22,49	14,13	5,78
	Renewable Energy Purchased by the Airport (%)	27,63	13,58	-0,48	-14,53
	Utilities/Energy Usage per Square Meter of Terminal	73,10	56,80	40,50	24,20
	Water Consumption per Passenger	417,73	479,85	541,96	604,08

The data collected and using the value tree in Figure 4. 5, building the airport in study performance descriptor structure depicted in Table 4.3 is presented in Table 6. 2.

After structuring the value tree and its data, and the performance descriptors for the airport in the study are constructed (Step 1), the PESA-AGB model compiles a survey and a meeting (Step 2 and Step 3) to be applied to groups of experts in the KPAs fields. With these structuring steps, it is now possible to start the PESA-AGB evaluation and classification process (Step 4 and Step 5), resulting in final scores. Subsequently, the GDA PESA-AGB model step 2 analyses these scores,

providing a categorical threshold and a wide range of outputs analysis (Step 6). All PESA-AGB outputs are depicted in appendix 2. With the scores obtained for the airport in the study, the GDA model step 3 Report and Recommendations is now possible to implement and the attribution of APE-Label.

6.2.1 The airport in study Report Sector Overview

There are 10 Portuguese airports. ANA is responsible for managing all airports in mainland Portugal (Lisbon, Oporto, Faro and Beja), in the Azores (Ponta Delgada, Horta, Santa Maria and Flores) and Madeira (Madeira e Porto Santo), the passenger's movements for the 2019 year are depicted in Figure 4. 15. The analysis of the airport in the study (similar to Lisbon airport) refers to the 2003-2013 period.

6.2.2 The airport in study Benchmarking Comparison

KPA scoring is obtained by giving zero points to year score below 32%, giving one point to year score below 67% and two points to year score above 67%. KPA score is obtained by dividing the total score by the total possible score. The Self-Benchmarking of the Airport KPA is now plotted in a table as depicted in Figure 6. 2.

The airport in study KPA comparison with the PESA-AGB Scores shows that the best KPA is Safety and Security with 77% score, in second place are CORE, and Productivity / Cost Effectiveness KPAs with 59%, in the third-place, are Financial / Commercial. Environmental KPA with 50% and last is Service Quality with 36% in the 11 years evaluation.

The airport in study final score ranking with the PESA-AGB Scores shows that the best year is 2011, the second is 2007, and the third is 2008, the last year 2013 comes in fourth place. The more relevant KPAs have a more substantial influence on the final airport score, so if one or more have a lousy score, the ranking position will suffer a descent. Year ranking positions are depicted in Figure 6. 3.

6.2.3 Airport KPA Level of Performance Assessment

KPA and airport in study score are depicted in Table 6. 3. The airport 1 KPA performance level is depicted in Figure 6. 2. The score for each KPA is obtained by dividing total score by total possible score and using levels of performance intervals in Figure 6. 4 derived from good and neutral values of Table 6. 3

Airport 1	KPA Score	Possible
Safety and Security	77%	
2003	2	2
2004	1	2
2005	1	2
2006	2	2
2007	2	2
2008	2	2
2009	1	2
2010	1	2
2011	2	2
2012	1	2
2013	2	2
Total score	17	22

Airport 1	KPA Score	Possible
Core	59%	
2003	0	2
2004	0	2
2005	1	2
2006	1	2
2007	1	2
2008	1	2
2009	1	2
2010	2	2
2011	2	2
2012	2	2
2013	2	2
Total score	13	22

Airport 1	KPA Score	Possible
Productivity / Cost Effectiveness	59%	
2003	0	2
2004	0	2
2005	0	2
2006	1	2
2007	2	2
2008	2	2
2009	2	2
2010	2	2
2011	2	2
2012	1	2
2013	1	2
Total score	13	22

Airport 1	KPA Score	Possible
Service Quality	36%	
2003	0	2
2004	0	2
2005	0	2
2006	1	2
2007	1	2
2008	1	2
2009	1	2
2010	1	2
2011	1	2
2012	1	2
2013	1	2
Total score	8	22

Airport 1	KPA Score	Possible
Financial / Commercial	50%	
2003	2	2
2004	1	2
2005	1	2
2006	1	2
2007	1	2
2008	1	2
2009	1	2
2010	1	2
2011	1	2
2012	1	2
2013	0	2
Total score	11	22

Airport 1	KPA Score	Possible
Environmental	50%	
2003	0	2
2004	0	2
2005	1	2
2006	1	2
2007	1	2
2008	1	2
2009	1	2
2010	1	2
2011	1	2
2012	2	2
2013	2	2
Total score	11	22

Figure 6. 2 – 2003-2013 KPA Level of performance assessment tables
Source: Own Elaboration

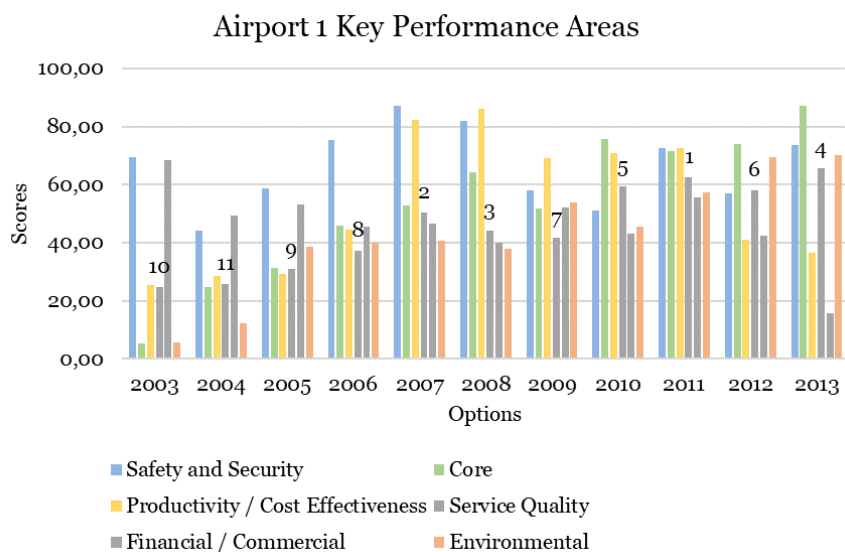


Figure 6. 3 – 2003-2013 KPA Ranking positions

Source: Own Elaboration
Table 6. 3 – Airport 1 score Goal and KPA target performance
Source: Own Elaboration

	Safety and Security	Core	Productivity / Cost Effectiveness	Service Quality	Financial / Commercial	Environmental	
Good	66,60	66,60	66,60	66,60	66,60	66,60	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
Neutral	31,92	31,92	31,92	31,92	31,92	31,92	

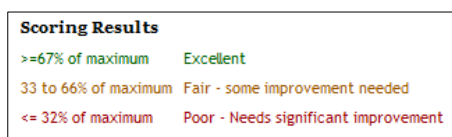


Figure 6. 4 - Levels of performance intervals
Source: Own Elaboration

A. The airport in study KPA 2003-2013 Graphics

Airport KPA 2003-2013 Graphics, all performance and efficiency graphics are plotted in this section and gives a visual understanding of the KPA behaviour in the 11 years study.

A.1 Radar Charts

A radar chart (Figure 6. 5) represents multivariate data in the form of a two-dimensional chart of 6 quantitative variables (KPA). It compares the values of the 6 KPAs relatives to a central point applied to the 2003-2013 period. The airport benchmarking comparison is made with the KPA scores compared with the KPA average score, and it is identified if the KPA Score is above or below the KPA average score.

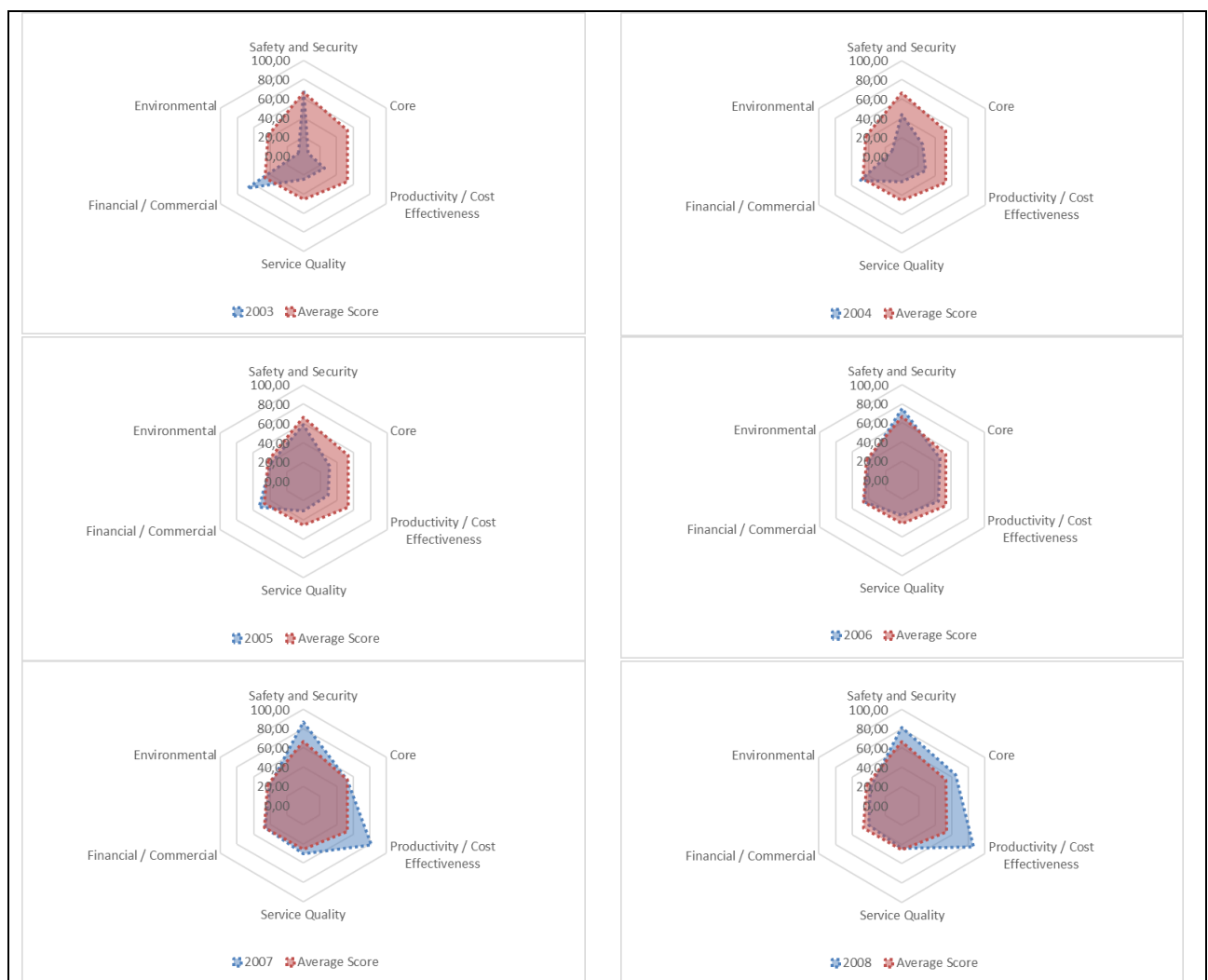
The airport in study radar analysis for the KPAs is depicted in Figure 6. 5. It is possible to observe that the KPA average score of the airport in study out of 100 points is: 66,21 points for Safety and Security KPA, 53,14 points for Core KPA, 53,26 points for Productivity / Cost Effectiveness KPA, 45,55 points for Service Quality KPA, 46,56 points for Financial / Commercial KPA, and 42,90 points for Environmental KPA.

The 2004 year is the only one with all KPA below average in all KPAs, and 2011 with all KPAs above average. With only one KPA above average 2003, 2005 KPA (Financial / Commercial), and 2006 Safety and Security KPA.

With 3 KPAs above average.

The highlight was in 2007 and 2008 with a solid Safety and Security, CORE, Productivity / Cost Effectiveness KPAs score, 2009 suffers a shift from Safety and Security and CORE KPAs lower scores to the Financial / Commercial and Environmental KPAs higher scores. 2010 CORE, Productivity / Cost Effectiveness and Service Quality KPAs scores, and CORE, Service Quality and Environmental KPAs scores. Within the eleven years, Safety and Security KPA are above average five times, two times in the last five years. CORE and Productivity / Cost Effectiveness and Service Quality KPAs are also five times above average, four, three and four times in the last five years, respectively. Financial / Commercial and Environmental KPAs are four times above average, two and four times in the last five years, respectively.

Generally, the airport in study scores in the radar graphics point to the investment in better environmental strategies allied to a better service quality granted a high search to the airport in study destination as possible to see in the CORE KPA scores of the last five years of analysis.



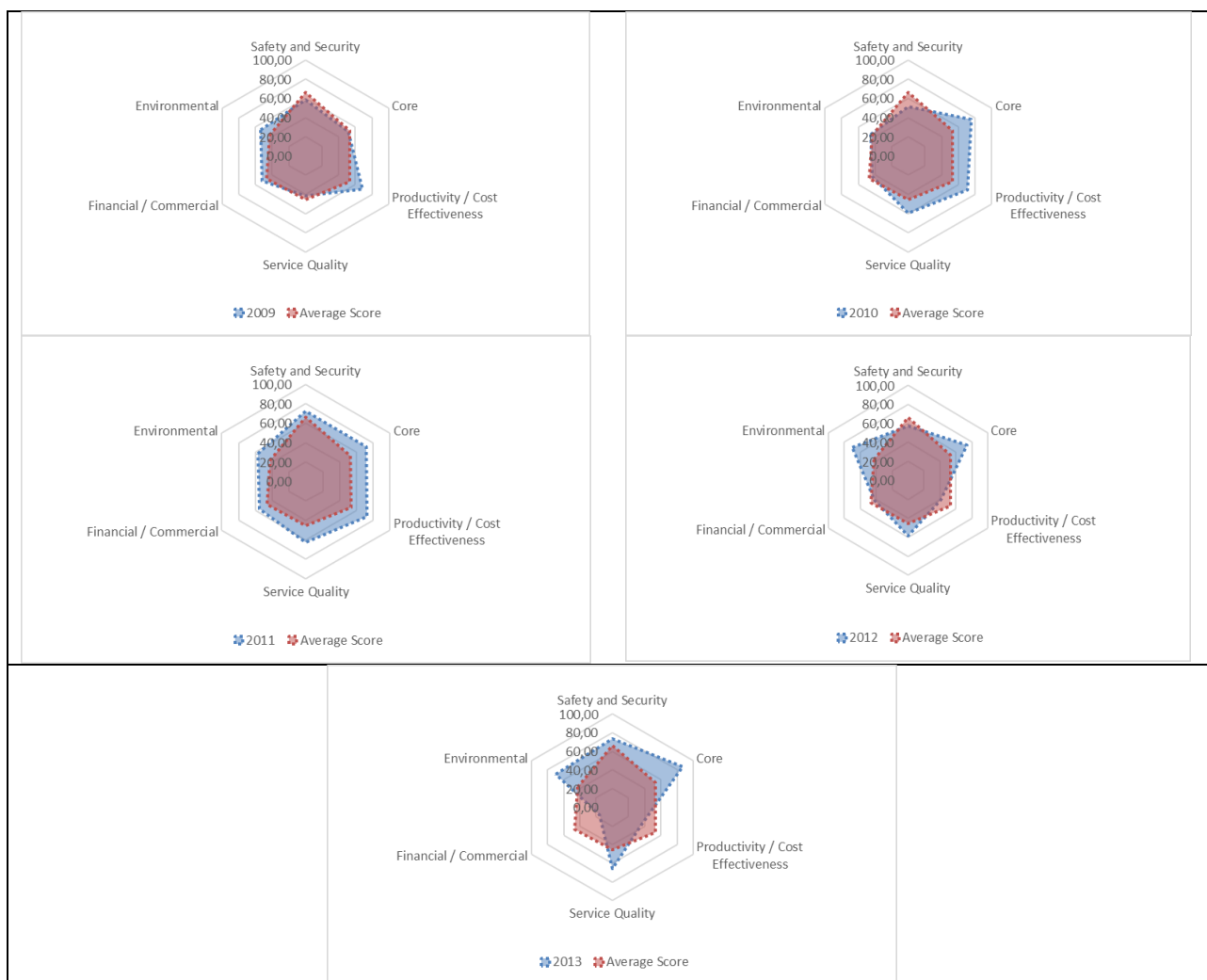


Figure 6. 5 – Radar Chart with Airport in study Year Score vs Average Score
Source: Own Elaboration

A.2 Quadrant Chart

Key findings outline each KPA and each year in a quadrant distribution as depicted in Figure 6.6.

Q(1)-Good stands for Airport High Performance and KPA Low Potential. The years 2006, 2012 and 2013 for the Productivity / Cost Effectiveness KPA, 2013 for the Financial / Commercial KPA, and 2008 for the Environmental KPA, these are areas of low impact in the overall score of the airport in study, that is why the airport score is high even this KPA have low scores.

Q(2)-Excellent, Airport High Performance and KPA High Potential. The years 2006-2013 for the Safety and Security KPA, 2007-2013 for the Core KPA, 2007-2011 for the Productivity / Cost Effectiveness KPA, 2007-2013 for the Service Quality KPA, 2007-2012 for the Financial / Commercial KPA, and 2007, 2009-2013 for the Environmental KPA make the airport score very high from 2007-2013.

Q(3)-Performing, Airport Low Performance and KPA High Potential. The years 2003, 2005-2006 Safety and Security KPA, 2003-2006 Financial / Commercial KPA, and 2006 Environmental KPA reflects the best opportunity for improving KPA Score potential in the airport as it was performed in the years later than 2006.

Q(4)-Poor, Airport Low Performance and KPA Low Potential. The years 2004 for the Safety and Security KPA, 2003-2005 for the Core KPA, 2003-2006 for the Productivity / Cost Effectiveness KPA, 2003-2005 for the Service Quality KPA, and 2007, 2003-2005 for the Environmental KPA make the airport score shallow from 2003-2006 and also below average in the KPA Score. It needs immediate analysis on the KPA performance and how to increase its performance potential, which was accomplished in the last six years of the analysis.

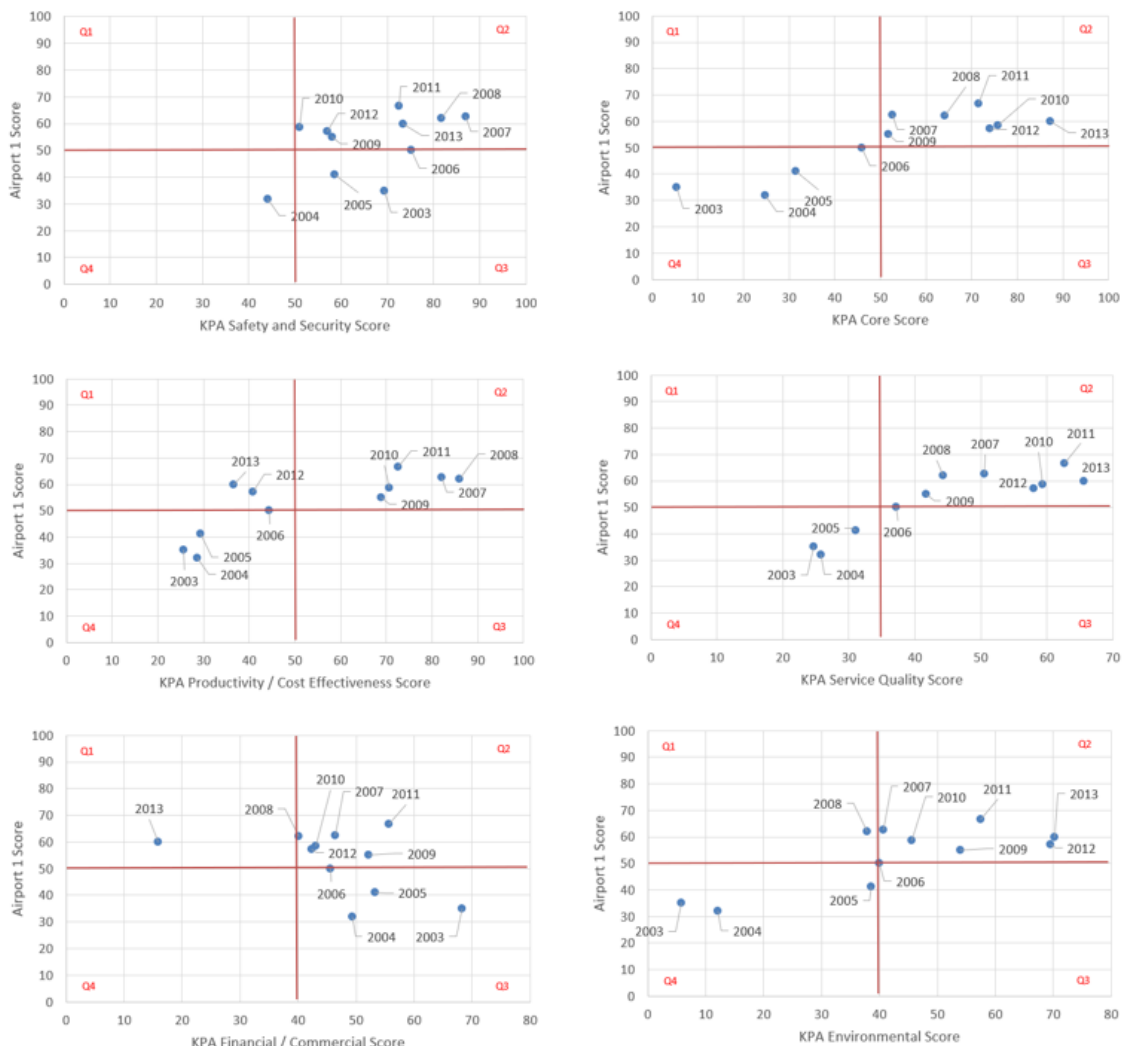


Figure 6. 6 - KPA and year quadrant distribution
Source: Own Elaboration

6.2.4 APE LABEL for Airport in study

Applying PESA-AGB to the airport in study, the resulting scores to elaborate APE-Label are depicted in Table 6. 4.

Table 6. 4 - Airport in study scores and associated performance level colour.
Source: Own elaboration

Year	Safety and Security	Core	Productivity and Cost Effectiveness	Service Quality	Financial and Commercial	Environmental	The airport in study 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

The resulting APE-Label airport in study with Table 6. 4 scores from 2003 to 2005, 2006 to 2010 and 2011 to 2013, are depicted in Figure 6. 7, Figure 6. 8, and Figure 6. 9.

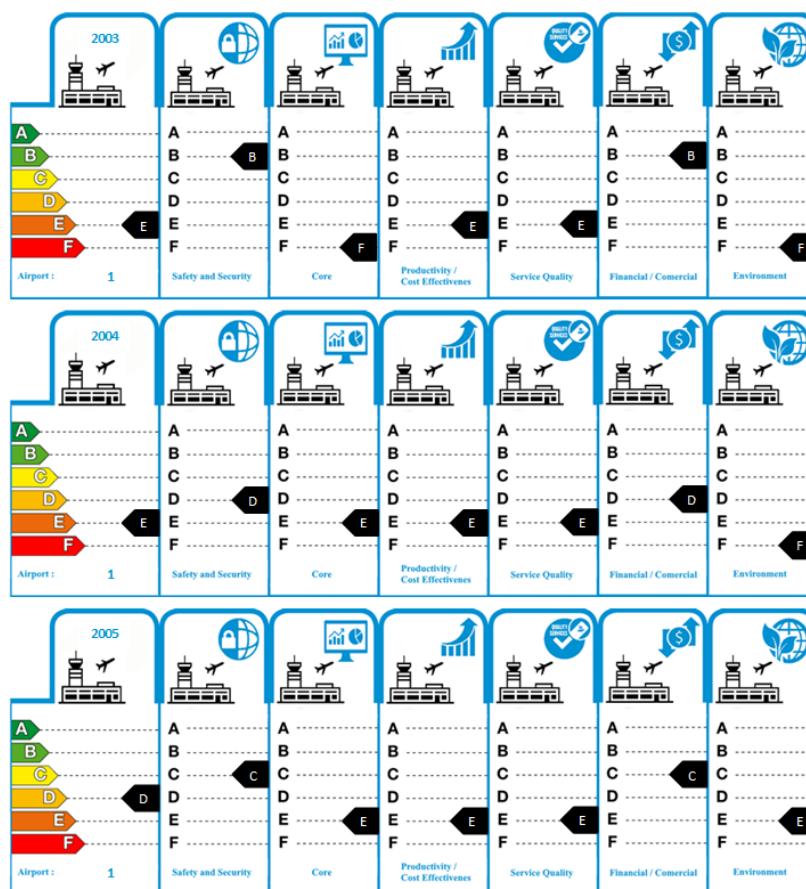


Figure 6. 7 - KPA airport in study APE-Label for the years 2003 to 2006
Source: Own Elaboration

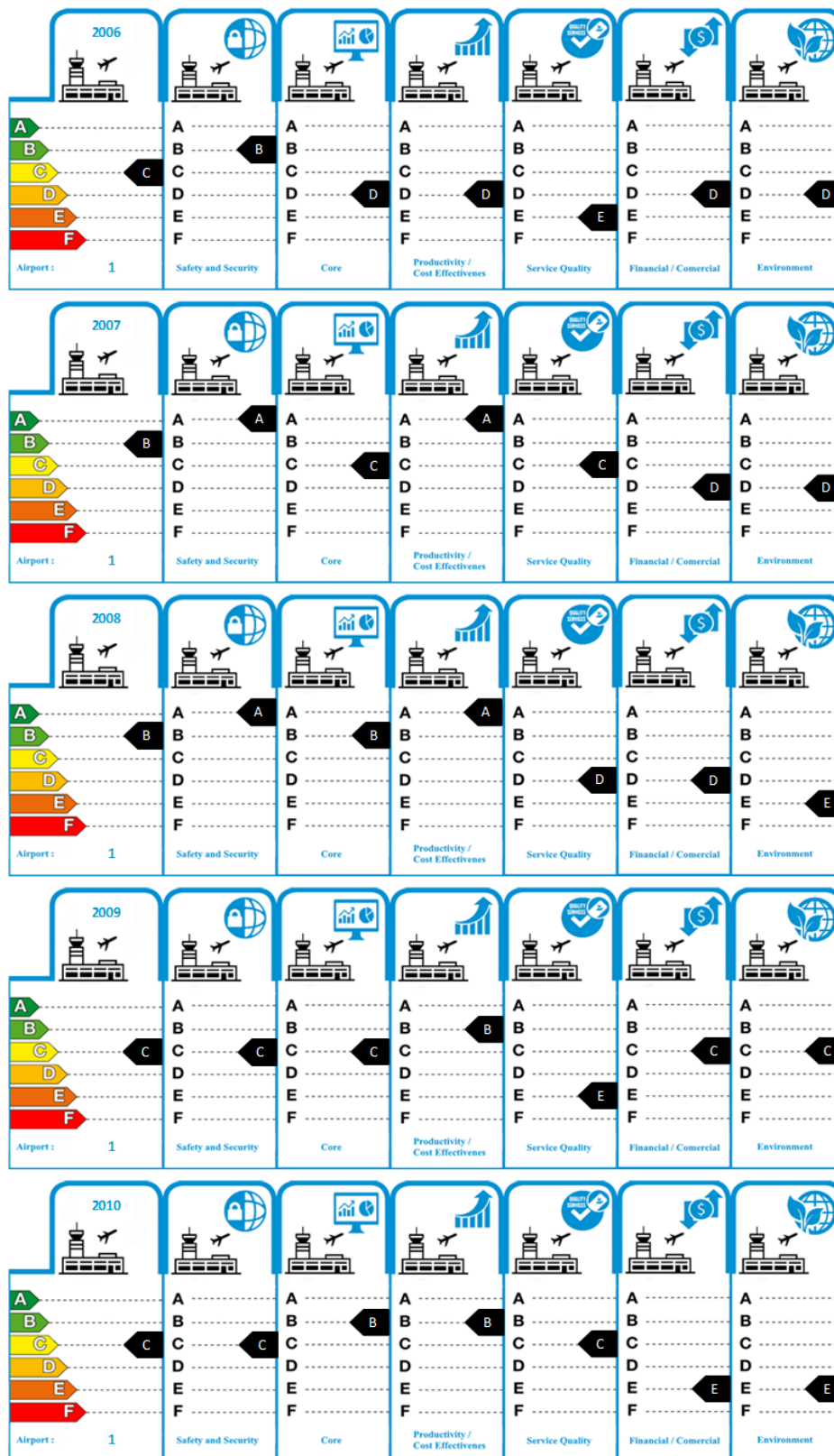


Figure 6. 8 - KPA airport in study APE-Label for the years 2007 to 2009
Source: Own Elaboration

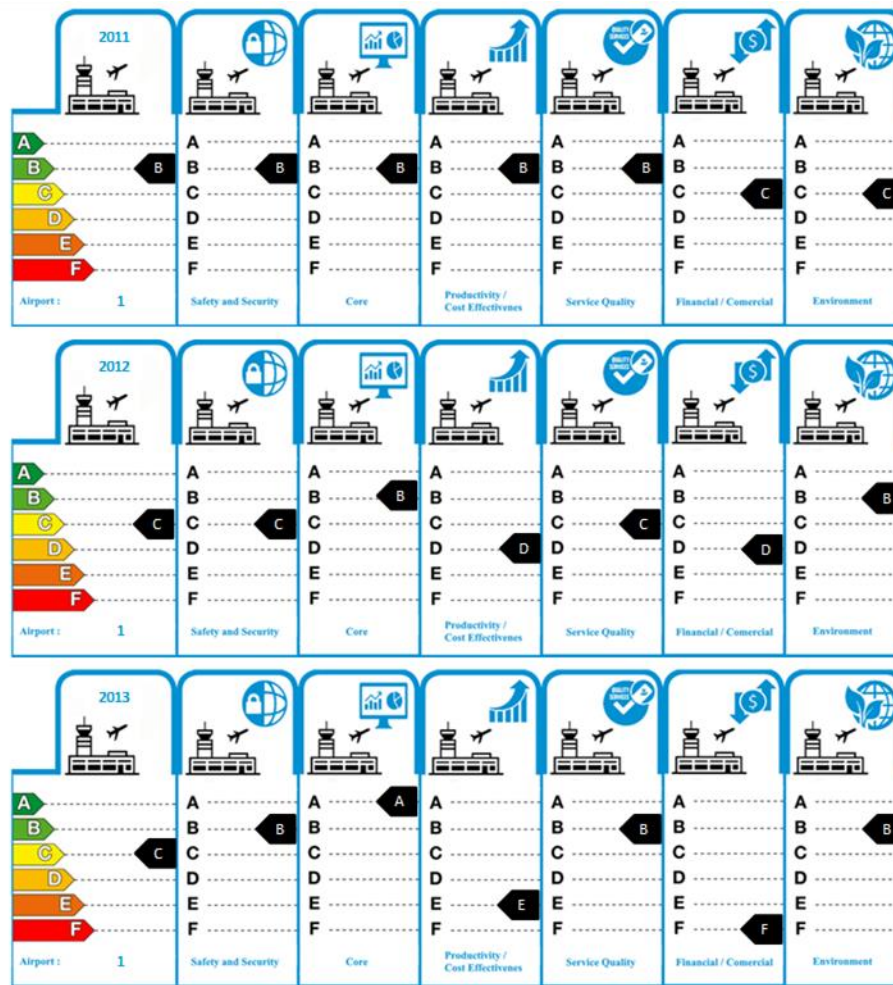


Figure 6.9 - KPA airport in study APE-Label for the years 2010 to 2013
Source: Own Elaboration

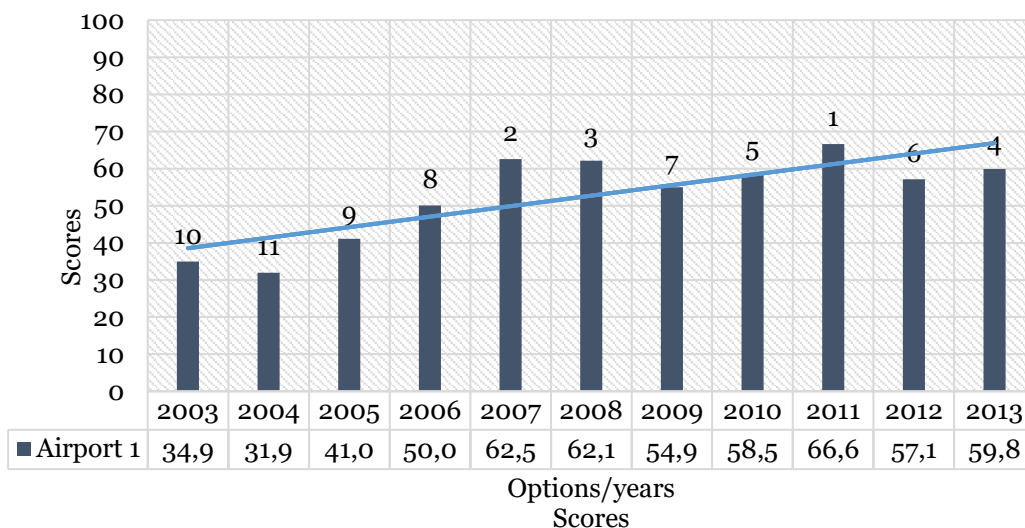


Figure 6.10 - Airport in study Ranking positions for the years 2003 to 2013
Source: Own Elaboration

The airport in study shows growth from 2003 to 2013, as depicted in Figure 6.10. Self-benchmark analysis of these eleven years from 2003 to 2013 shows three significant variations in the direction

of most efficient scores: Core KPA changed from F to A-class, Service quality KPA changed from E to B class and Environmental KPA from F to B class. Thus, the final airport efficient score changed from E to C class, depicting a more green, quality, and competitive airport. It lacks a better financial and commercial approach and productivity and cost-effectiveness enhancement making way for a better class in the airport efficiency score. The best year score is 2011, where every KPA are classified above C level, and the worst years were 2003 and 2004.

6.3.1 The airport in study Recommendations

A. Self-Benchmarking Feedback

The Self-Benchmarking feedback is built based on the traffic lights methodology that uses, from conditional formatting, three colours (green, yellow and red) to indicate whether the performance of the KPAs and KPIs, defined in Chapter 4, needs some or urgent intervention. KPA and KPI feedback per year are depicted in Table 6. 5, Table 6. 6, Table 6. 7, Table 6. 8, Table 6. 9, Table 6. 10, Table 6. 11, Table 6. 12, Table 6. 13, Table 6. 14 and Table 6. 15.

Table 6. 5 – Self-Benchmarking of the Airport KPI and KPA traffic lights methodology - 2003
Source: Own Elaboration

KPA	KPA Score	Feedback	
Safety and Security	69,37	This is an excellent result. However, this result is in the lower end of the higher level of performance limit, mainly due to low scores in Public Injuries, Lost Work Time from Employee Accidents and Injuries KPIs that needed some intervention to improve KPA score.	
Core	5,36	This result is poor. It is at the lower end of the Lower level of performance limit-not a good result. Very low scores indicate zero or near zero scores in Passengers, Aircraft Movements, OD-Passengers Freight and mail loaded/unloaded KPIs needed urgent intervention to improve KPA score.	
Productivity / Cost Effectiveness	25,59	This result is poor, it is at the lower end of the Lower level of performance limit-not a good result. Very low scores indicate that (zero or near zero) scores in almost every KPIs needed urgent intervention to improve KPA score, except for Aircraft Movements per Gate.	
Service Quality	24,64	This result is poor, it is at a lower level of performance. Very low scores indicate zero or near zero scores in almost every KPIs that needed urgent intervention to improve KPA score, except for Border Control Clearing Time.	
Financial / Commercial	68,27	This is an excellent result. However, this result is in the lower end of the higher level of performance limit, mainly due to low scores in EBITDA per Passenger, Non-Aeronautical Operating Revenue as Percentage of Total, and Debt Service as Percentage of Operating Revenue KPIs that needed some intervention to improve KPA score.	
Environmental	5,81	This result is poor, it is at the lower end of the Lower level of performance limit-not a good result. Very low scores indicate zero, or near zero scores in 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 KPIs needed urgent intervention to improve KPA score.	

Table 6. 6 – Self-Benchmarking of the Airport KPI and KPA traffic lights methodology - 2004
Source: Own Elaboration

KPA	KPA Score	Feedback	
Safety and Security	44,14	This is a fair result. However, this result is in the lower end of the middle level of performance limit, mainly due to low scores in a bird strike and public injuries KPIs that needed intervention to improve KPA score.	

KPA	KPA Score	Feedback	
Core	24,82	This result is poor, it is in the Lower level of performance, not a good result. Very low scores indicate zero or near zero scores in Passengers, Aircraft Movements, OD-Passengers and Destinations-Nonstop KPIs needed urgent intervention to improve KPA score.	
Productivity / Cost Effectiveness	28,71	This result is poor, it is at the lower level of performance, not a good result. Very low scores indicate zero or near zero scores in almost every KPIs that needed urgent intervention, except for Aircraft Movements per Gate and Total Cost per Movements.	
Service Quality	25,83	This result is poor, it is in Lower level of performance, not a good result. Very low scores indicate zero or near zero scores in almost every KPIs needed urgent intervention to improve KPA score, except for Check-in to Gate Time KPI.	
Financial / Commercial	49,34	This is a fair result. However, this result is in the lower end of the middle level of performance limit, especially due to low scores in Aeronautical Revenue per Movement, Non-Aeronautical Operating Revenue per Passenger, EBITDA per Passenger, Non-Aeronautical Operating Revenue as Percentage of Total, and Debt Service as Percentage of Operating Revenue KPIs that needed intervention to improve KPA score.	
Environmental	12,15	This result is poor, it is at the lower end of Lower level of performance limit- not a good result. Very low scores indicate zero or near zero scores in 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 KPIs needed urgent intervention to improve KPA score.	

Table 6. 7 – Self-Benchmarking of the Airport KPI and KPA traffic lights methodology - 2005

Source: Own Elaboration

KPA	KPA Score	Feedback	
Safety and Security	58,67	This is a fair result. However, this result is near the lower end of the higher level of performance limit, especially due to low scores in bird strike and public injuries KPIs that needed intervention to improve KPA score, as in last year.	
Core	31,42	This result is poor, it is in the Lower level of performance, but better than the last two years due to improvement in all KPIs scores, nevertheless needed urgent intervention to improve KPA score.	
Productivity / Cost Effectiveness	29,38	This result is poor, it is in Lower level of performance. very low scores indicates that (zero or near zero) scores in almost every KPIs needed urgent intervention to improve KPA score, except for Aircraft Movements per Gate and Total Cost per Movement KPIs.	
Service Quality	31,09	This result is poor, it is in Lower level of performance. very low scores indicates that (zero or near zero) scores in almost every KPIs needed urgent intervention, except for Boarder Control Clearing Time.	
Financial / Commercial	53,32	This is a fair result. However, this result is in the middle level of performance, especially due to low scores in Aeronautical Revenue per Movement, EBITDA per Passenger, Non-Aeronautical Operating Revenue as Percentage of Total, and Debt Service as Percentage of Operating Revenue KPIs that needed intervention to improve KPA score.	
Environmental	38,56	This is a fair result. However, this result is near the lower end of the middle level of performance limit, especially due to low scores in Carbon Footprint (TONS/PAX) Waste Recycling, Renewable Energy Purchased by the Airport (%), and Utilities / Energy Usage per Square Meter of Terminal KPIs that needed intervention to improve KPA score.	

Table 6. 8 – Self-Benchmarking of the Airport KPI and KPA traffic lights methodology - 2006

Source: Own Elaboration

KPA	KPA Score	Feedback	
Safety and Security	75,22	This is an excellent result. However, this result is in the higher level of performance, especially due to high scores in almost every KPI only Runway Incursions and Bird Strikes KPIs needed some intervention to improve KPA score.	
Core	45,91	This is a fair result. However, this result is near the lower end of the middle level of performance limit, especially due to low scores in Passengers, OD-Passengers and Destinations-Nonstop KPIs that needed intervention to improve KPA score.	

KPA	KPA Score	Feedback	
Productivity / Cost Effectiveness	44,41	This is a fair result. However, this result is near the lower end of the middle level of performance limit, especially due to low scores in Operating Cost per Movement, Total Cost per WLU, Operating Cost per WLU and Operating Cost per Passenger KPIs that needed urgent intervention to improve KPA score.	
Service Quality	37,23	This is a fair result. However, this result is near the lower end of the middle level of performance limit, especially due to low scores in Customer Satisfaction, Baggage Delivery Time, Taxi Departure Delay, Security Clearing Time, Check-in to Gate Time, Practical Hourly Capacity KPIs that needed urgent intervention to improve KPA score.	
Financial / Commercial	45,58	This is a fair result. However, this result is in the middle level of performance, especially due to low scores in 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, and Debt Service as Percentage of Operating Revenue KPIs that needed intervention to improve KPA score.	
Environmental	40,03	This is a fair result. However, this result is in the lower end of the middle level of performance limit, especially due to low scores in Carbon Footprint (TONS/PAX) Waste Recycling, Renewable Energy Purchased by the Airport (%), and Waste Reduction (%) KPIs that needed intervention to improve KPA score.	

Table 6. 9 – Self-Benchmarking of the Airport KPI and KPA traffic lights methodology - 2007

Source: Own Elaboration

KPA	KPA Score	Feedback	
Safety and Security	87,06	This is an excellent result. However, this result is in the higher level of performance limit, especially due to high scores in almost every KPI only Runway Incursions KPI needed some intervention to improve KPA score.	
Core	52,72	This is a fair result. However, this result is in the middle level of performance limit, especially due to low scores in Freight and mail loaded/unloaded and Destinations-Nonstop KPIs that needed intervention to improve KPA score.	
Productivity / Cost Effectiveness	82,13	This is an excellent result. However, this result is above the higher level of performance limit, especially due to high scores in almost every KPI only Total Cost per WLU KPI needed some intervention to improve KPA score.	
Service Quality	50,50	This is a fair result. However, this result is in the middle level of performance limit, especially due to low scores in Customer Satisfaction, Baggage Delivery Time, Security Clearing Time, and Check-in to Gate Time KPIs that needed urgent intervention to improve KPA score.	
Financial / Commercial	46,43	This is a fair result. However, this result is in the middle level of performance, especially due to low scores in Aeronautical Revenue per Passenger, Aeronautical Revenue per Movement, Non-Aeronautical Operating Revenue per Passenger, EBITDA per Passenger, Debt Service as Percentage of Operating Revenue KPIs that needed intervention to improve KPA score.	
Environmental	40,65	This is a fair result. However, this result is in the lower end of the middle level of performance limit, especially due to low scores in Carbon Footprint (TONS/PAX) Waste Recycling, Renewable Energy Purchased by the Airport (%), Waste Reduction (%), and Water Consumption per Passenger KPIs that needed intervention to improve KPA score.	

Table 6. 10 – Self-Benchmarking of the Airport KPI and KPA traffic lights methodology - 2008

Source: Own Elaboration

KPA	KPA Score	Feedback	
Safety and Security	81,75	This is an excellent result. However, this result is in the higher level of performance limit, especially due to high scores in almost every KPI only Runway Incursions KPI needed some intervention to improve KPA score, and Public Injuries KPI (very low score) needed urgent intervention to improve KPA score.	
Core	64,11	This is a fair result. However, this result is near the lower end of the higher level of performance limit, especially due to low scores in Destinations-Nonstop KPI that needed intervention to improve KPA score.	
Productivity / Cost Effectiveness	85,97	This is an excellent result. However, this result is above the higher level of performance limit, especially due to high scores in almost every KPI only Aircraft Movements per Gate KPI needed some intervention to improve KPA score.	
Service Quality	44,32	This is a fair result. However, this result is near the lower end of the middle level of performance limit, especially due to low scores in Customer Satisfaction, Baggage Delivery Time, Security Clearing Time, Border Control Clearing Time, and Practical Hourly Capacity KPIs that needed urgent intervention to improve KPA score.	

Financial / Commercial	40,15	This is a fair result. However, this result is in the lower end of the middle level of performance limit, especially due to low scores in Aeronautical Revenue per Passenger, Aeronautical Revenue per Movement, Non-Aeronautical Operating Revenue per Passenger, EBITDA per Passenger, and Debt Service as Percentage of Operating Revenue KPIs that needed intervention to improve KPA score.	
Environmental	37,92	This is a fair result. However, his result is near the lower end of the middle level of performance limit, especially due to low scores in Waste Recycling, Renewable Energy Purchased by the Airport (%), Waste Reduction (%), Utilities / Energy Usage per Square Meter of Terminal, Water Consumption per Passenger KPIs that needed intervention to improve KPA score.	

Table 6. 11 – Self-Benchmarking of the Airport KPI and KPA traffic lights methodology - 2009
Source: Own Elaboration

KPA	KPA Score	Feedback	
Safety and Security	58,15	This is a fair result. However, this result is near the lower end of the higher level of performance limit, especially due to low scores in bird strike, public injuries KPIs that needed intervention to improve KPA score, and occupational injuries KPI (very low score) needed urgent intervention to improve KPA score.	
Core	51,79	This is a fair result. However, this result is in the middle level of performance, especially due to low scores in Freight and mail loaded/unloaded KPI that needed intervention to improve KPA score.	
Productivity / Cost Effectiveness	68,92	This is an excellent result. However, this result is near the lower level of the high-performance limit, especially due to high scores in almost every KPI only Aircraft Movements per Gate and Aircraft Movements per Employee KPIs needed some intervention to improve KPA score.	
Service Quality	41,72	This is a fair result. However, this result is near the lower end of the middle level of performance limit, especially due to low scores in Customer Satisfaction, Baggage Delivery Time, Security Clearing Time, Check-in to Gate Time, Practical Hourly Capacity KPIs that needed urgent intervention to improve KPA score.	
Financial / Commercial	52,19	This is a fair result. However, this result is in the middle level of performance, especially due to low Aeronautical Revenue per Passenger, Aeronautical Revenue per Movement, Non-Aeronautical Operating Revenue per Passenger, and Debt Service as Percentage of Operating Revenue KPIs that needed intervention to improve KPA score.	
Environmental	53,95	This is a fair result. However, this result is in the middle level of performance, especially due to low scores in Waste Recycling, Renewable Energy Purchased by the Airport (%), Waste Reduction (%), Utilities / Energy Usage per Square Meter of Terminal KPIs that needed intervention to improve KPA score.	

Table 6. 12 – Self-Benchmarking of the Airport KPI and KPA traffic lights methodology - 2010
Source: Own Elaboration

KPA	KPA Score	Feedback	
Safety and Security	50,99	This is a fair result. However, this result is near the lower end of the higher level of performance limit, especially due to low scores in runway incursions and occupational injuries KPIs with a very low score needed urgent intervention to improve KPA score.	
Core	75,70	This is an excellent result. Although this result is in the higher level of performance, mainly due to high scores in almost every KPI) needed some intervention to improve KPA score to accomplish higher results.	
Productivity / Cost Effectiveness	70,67	This is an excellent result. However, this result is near the lower level of the high-performance limit, especially due to high scores in almost every KPI only Aircraft Movements per Gate KPI needed some intervention to improve KPA score.	
Service Quality	59,34	This is a fair result. However, this result is in the middle level of performance, especially due to low scores in Taxi Departure Delay, Check-in to Gate Time, Practical Hourly Capacity KPIs that needed urgent intervention to improve KPA score.	
Financial / Commercial	42,98	This is a fair result. However, this result is near the middle level of performance limit, especially due to low scores in Aeronautical Revenue per Passenger, Aeronautical Revenue per Movement, Non-Aeronautical Operating Revenue per Passenger, EBITDA per Passenger, and Debt Service as Percentage of Operating Revenue KPIs that needed intervention to improve KPA score.	
Environmental	45,50	This is a fair result. However, this result is near the low middle level of performance limit, especially due to low scores in Renewable Energy Purchased by the Airport (%), Waste	

KPA	KPA Score	Feedback
		Reduction (%), Utilities / Energy Usage per Square Meter of Terminal, and Water Consumption per Passenger KPIs that needed intervention to improve KPA score.

Table 6. 13 – Self-Benchmarking of the Airport KPI and KPA traffic lights methodology - 2011
Source: Own Elaboration

KPA	KPA Score	Feedback
Safety and Security	72,51	This is an excellent result. However, this result is in the higher level of performance, especially due to high scores in almost every KPI only Runway Incursions and Bird Strikes KPIs needed some intervention to improve KPA score.
Core	71,50	This is an excellent result. Although this result is in the higher level of performance, especially due to high scores in almost every KPI only Freight and mail loaded/unloaded needed some improve KPA score final.
Productivity / Cost Effectiveness	72,60	This is an excellent result. However, this result is near the lower level of the high-performance limit, especially due to high scores in almost every KPI only Aircraft Movements per Gate KPI needed some intervention to improve KPA score.
Service Quality	62,66	This is a fair result. However, this result is near the lower end of the higher level of performance limit, especially due to low scores in Border Control Clearing Time and Check-in to Gate Time, KPIs that needed urgent intervention to improve KPA score.
Financial / Commercial	55,71	This is a fair result. However, this result is in the middle level of performance, especially due to low scores in Aeronautical Revenue per Passenger, Aeronautical Revenue per Movement, and Non-Aeronautical Operating Revenue per Passenger KPIs that needed intervention to improve KPA score.
Environmental	57,48	This is a fair result. However, this result is in the middle level of performance, especially due to low scores in Renewable Energy Purchased by the Airport (%), Waste Reduction (%), Utilities / Energy Usage per Square Meter of Terminal, and Water Consumption per Passenger KPIs that needed intervention to improve KPA score.

Table 6. 14 – Self-Benchmarking of the Airport KPI and KPA traffic lights methodology - 2012
Source: Own Elaboration

KPA	KPA Score	Feedback
Safety and Security	56,95	This is a fair result. However, this result is in the middle level of performance, especially due to low scores in runway incursions and bird strikes KPIs with a very low score needed urgent intervention to improve KPA score.
Core	74,07	This is an excellent result. Although this result is in the higher level of performance, especially due to high scores in almost every KPI only Freight and mail loaded/unloaded needed some improve KPA score final.
Productivity / Cost Effectiveness	40,90	This is a fair result. However, this result is near the lower end of the middle level of performance limit, especially due to low scores in Total Cost per Movement, Operating Cost per Movement, Aircraft Movements per Gate and Total Cost per WLU KPIs that needed urgent intervention to improve KPA score.
Service Quality	58,06	This is a fair result. However, this result is in the middle level of performance, especially due to low scores in Gate Departure Delay, Security Clearing Time, and Border Control Clearing Time KPIs that needed urgent intervention to improve KPA score.
Financial / Commercial	42,36	This is a fair result. However, this result is in the middle level of performance, especially due to low scores in Aeronautical Revenue per Passenger, Aeronautical Revenue per Movement, Non-Aeronautical Operating Revenue per Passenger, EBITDA per Passenger, and Debt Service as Percentage of Operating Revenue KPIs that needed intervention to improve KPA score.
Environmental	69,55	This is an excellent result. However, this result is near the lower end of the higher level of performance, especially due to high scores in Waste Recycling, and Waste Reduction (%) KPI only Runway Incursions and Bird Strikes KPIs needed some intervention to improve KPA score.

Table 6. 15 – Self-Benchmarking of the Airport KPI and KPA traffic lights methodology - 2013
Source: Own Elaboration

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KPA	KPA Score	Feedback	
Safety and Security	73,47	This is an excellent result. Although, this result is in the higher level of performance, especially due to high scores in almost every KPI, only Bird Strikes KPI needed some intervention to improve KPA score.	
Core	87,19	This is an excellent result. Although this result is in the higher level of performance, especially due to high scores in almost every KPI, Freight and mail loaded/unloaded needed some improve KPA score final.	
Productivity / Cost Effectiveness	36,61	This is a fair result. However, this result is near the lower end of the middle level of performance limit, especially due to low scores in Total Cost per Movement, Operating Cost per Movement, Aircraft Movements per Gate, Total Cost per WLU and Operating Cost per WLU KPIs that needed urgent intervention to improve KPA score.	
Service Quality	65,64	This is a fair result. However, this result is near the higher end of the middle level of performance limit, especially due to low scores in Gate Departure Delay, Security Clearing Time, and Border Control Clearing Time KPIs that needed urgent intervention to improve KPA score.	
Financial / Commercial	15,81	This result is poor, it is at Lower level of performance - not a good result. Very low scores indicates that zero, or near zero, scores in almost every KPIs that needed urgent intervention to improve KPA score, except for Non-Aeronautical Operating Revenue as Percentage of Total.	
Environmental	70,29	This is an excellent result. However, this result is just above the higher level of low-performance limit, mainly due to high scores in Carbon Footprint (TONS/PAX), Renewable Energy Purchased by the Airport (%), and Water Consumption per Passenger KPI only Waste Recycling, Waste Reduction (%), Utilities / Energy Usage per Square Meter of Terminal KPIs, needed some intervention to improve KPA score.	

B. Self-Benchmarking PESA-AGB DASHBOARD

The PEAS-AGB DASHBOARD is depicted in Figure 6. 11. It is possible to choose one year or all years to visualise the graphics in some of the PESA-AGB dashboard areas.

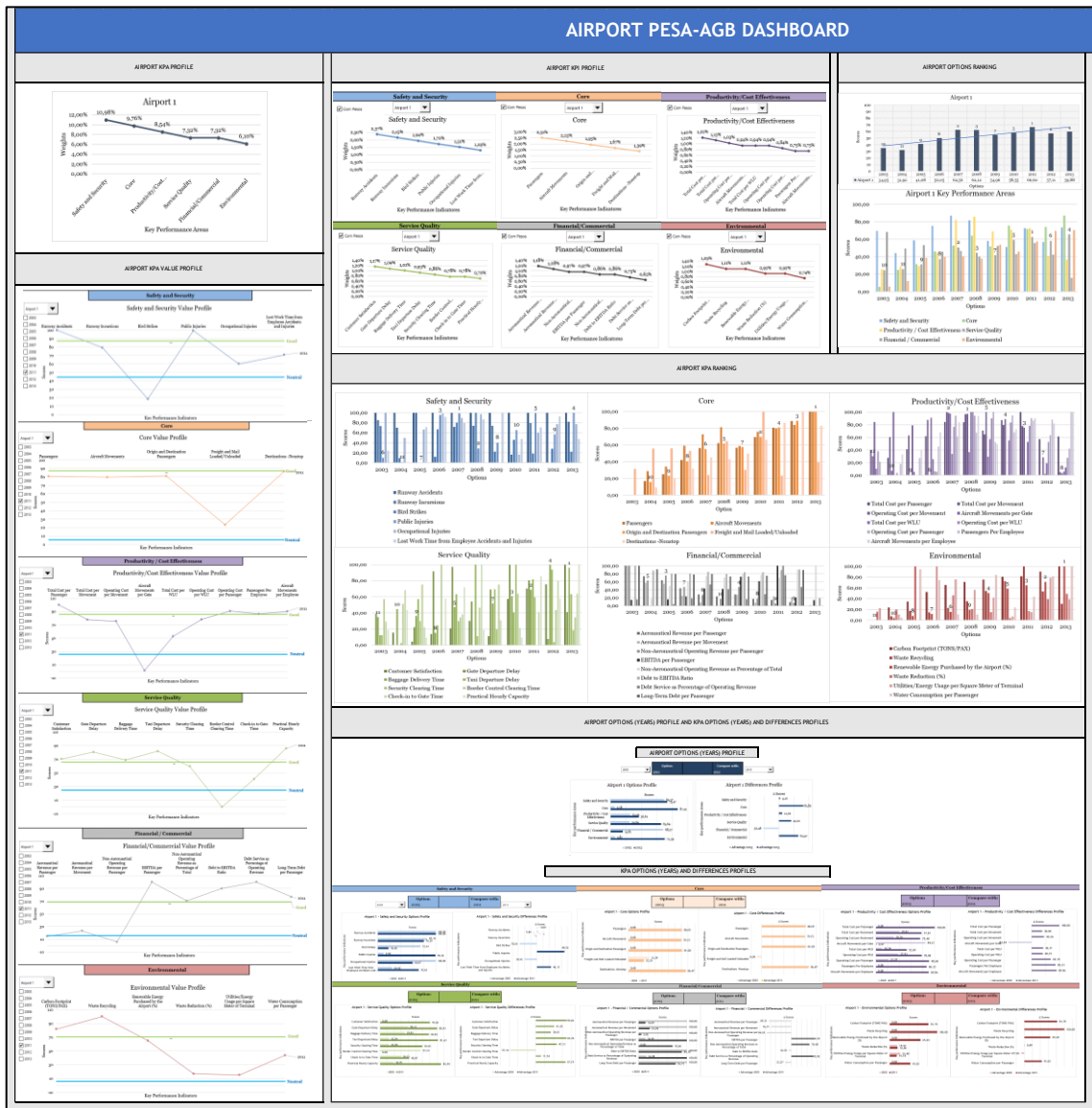


Figure 6. 11 - Airport PESA-AGB DASHBOARD
Source: Own Elaboration

The areas of the PESA-AGB DASHBOARD allows the user to visualise the weights of the KPAs and KPIs established by the expert's survey and see the sensitivity of the KPA weight to the airport score for the 11 years. Also, the KPA ranking area allows the visualisation of the best years for each KPA. Lastly, the airport and KPA options profile and differences profile visualise the scores comparing two years of choice and the advantages in the score difference for those years.

C. Self-Benchmarking GDA DASHBOARD

The PEAS-AGB DASHBOARD is depicted in Figure 6. 12. The graphics in GDA dashboard areas reflect the scoring from PESA-AGB outputs and allows the visualisation of the final airport score for each of the 11 years, giving a perception of a holistic evaluation. The yearly KPA self-benchmarking that highlights the KPA performance level in the colourful manner green, yellow and red indicates whether the performance of the KPAs complies with the three-level scores. The airport and KPA cumulative points show each KPA having 100 points how the airport or the KPAs achieved many points. The user identifies if and when the cumulative points are near or far from the maximum possible points. The Quadrante chart area summarises the behaviour of the option (years) regarding the influence of the KPA Score on the airport score. The airport radar chart depicts the KPA score behaviour to the average score in the 11 years of analysis. Finally, the APE-Label shows the year of the airport and KPA efficiency, making it possible to visualise the overall efficiency of the airport.

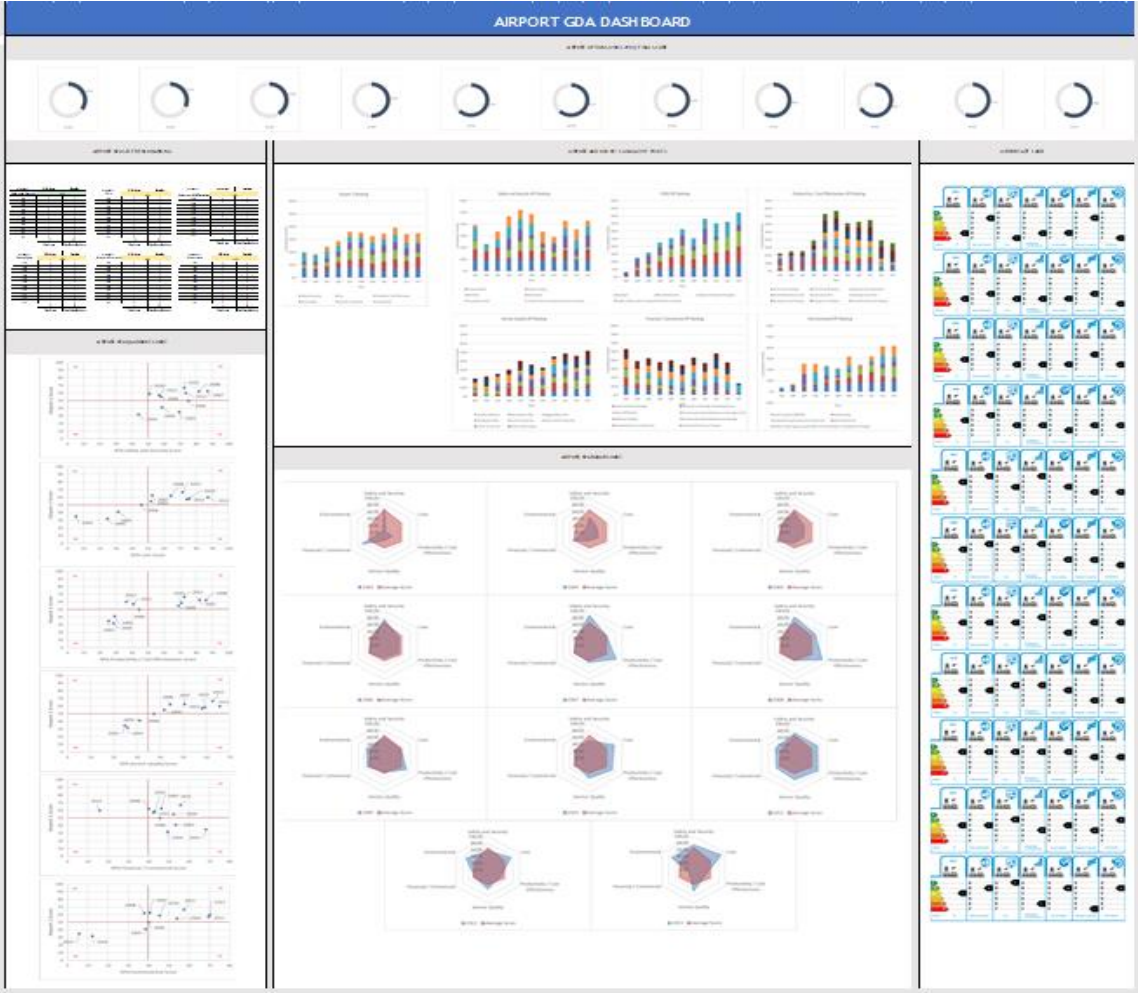


Figure 6. 12 - Airport GDA DASHBOARD
Source: Own Elaboration

6.3.2 GDA Recommendations

The recommendations for the airport in study using KPA ranking and Category Thresholds in Figure 6. 13 and Figure 6. 14 are used to suggest the improvement in the scores.

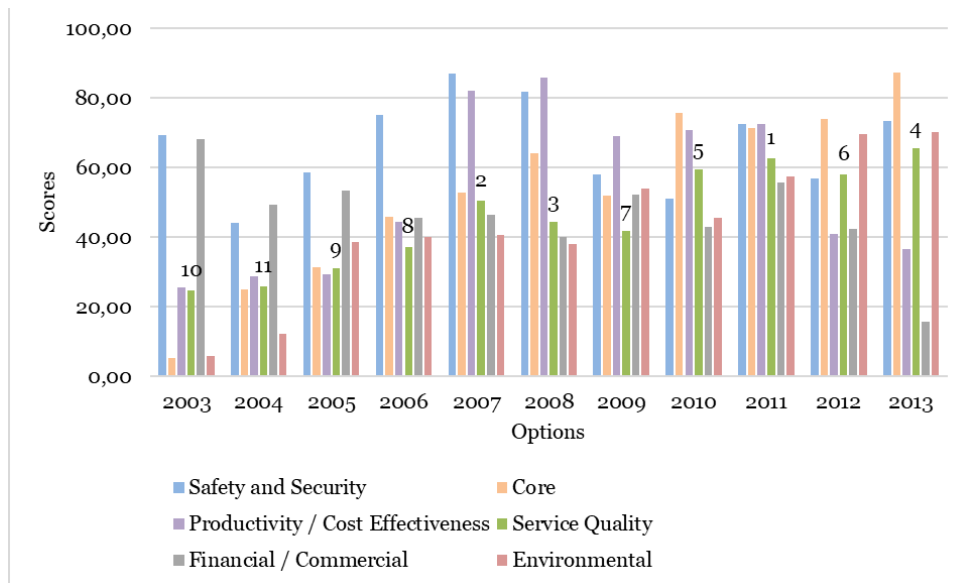


Figure 6. 13 - Airport in study KPA Scores
Source: Own Elaboration

Safety and Security			Core			Productivity / Cost Effectiveness		
Year	Score	Category Thresholds	Year	Score	Category Thresholds	Year	Score	Category Thresholds
2003	69	L3 Satisfactory	2003	5	L0 Catastrophic	2003	26	L1 Alert
2004	44	L2 Poor	2004	25	L1 Alert	2004	29	L1 Alert
2005	59	]L2,L3[Poor-Satisfactory	2005	31	]L1,L2[Alert-Poor	2005	29	L1 Alert
2006	75	]L3,L4[Satisfactory-Good	2006	46	L2 Poor	2006	44	L2 Poor
2007	87	L4 Good	2007	53	]L2,L3[Poor-Satisfactory	2007	82	L4 Good
2008	82	L4 Good	2008	64	L3 Satisfactory	2008	86	L4 Good
2009	58	]L2,L3[Poor-Satisfactory	2009	52	]L2,L3[Poor-Satisfactory	2009	69	L3 Satisfactory
2010	51	]L2,L3[Poor-Satisfactory	2010	76	]L3,L4[Satisfactory-Good	2010	71	]L3,L4[Satisfactory-Good
2011	73	]L3,L4[Satisfactory-Good	2011	71	]L3,L4[Satisfactory-Good	2011	73	]L3,L4[Satisfactory-Good
2012	57	]L2,L3[Poor-Satisfactory	2012	74	]L3,L4[Satisfactory-Good	2012	41	L2 Poor
2013	73	]L3,L4[Satisfactory-Good	2013	87	L4 Good	2013	37	]L1,L2[Alert-Poor

Service Quality			Financial / Commercial			Environmental		
Year	Score	Category Thresholds	Year	Score	Category Thresholds	Year	Score	Category Thresholds
2003	25	L1 Alert	2003	68	L3 Satisfactory	2003	6	L0 Catastrophic
2004	26	L1 Alert	2004	49	L2 Poor	2004	12	]L0,L1[Alert-Catastrophic
2005	31	]L1,L2[Alert-Poor	2005	53	]L2,L3[Poor-Satisfactory	2005	39	]L1,L2[Alert-Poor
2006	37	]L1,L2[Alert-Poor	2006	46	L2 Poor	2006	40	L2 Poor
2007	50	]L2,L3[Poor-Satisfactory	2007	46	L2 Poor	2007	41	L2 Poor
2008	44	L2 Poor	2008	40	L2 Poor	2008	38	]L1,L2[Alert-Poor
2009	42	L2 Poor	2009	52	]L2,L3[Poor-Satisfactory	2009	54	]L2,L3[Poor-Satisfactory
2010	59	]L2,L3[Poor-Satisfactory	2010	43	L2 Poor	2010	46	L2 Poor
2011	63	L3 Satisfactory	2011	56	]L2,L3[Poor-Satisfactory	2011	57	]L2,L3[Poor-Satisfactory
2012	58	]L2,L3[Poor-Satisfactory	2012	42	L2 Poor	2012	70	]L2,L3[Poor-Satisfactory
2013	66	L3 Satisfactory	2013	16	]L0,L1[Alert-Catastrophic	2013	70	]L3,L4[Satisfactory-Good

Figure 6. 14 - Airport KPA Category Thresholds
Source: Own Elaboration

1. Safety and Security KPA, in the 11 years of analysis, the first years show remarkable growth. Still, from 2009 to 2013, some irregularities in the scores. This is the more relevant KPA and needs to be monitored to improve the overall airport score.

Recommendation: improve practice addressing the KPIs with more relevance.

2. CORE KPA has continuous growth in the 11 years of analysis and is expected to continue forward. The year 2009 reflects the economic crisis of this year, but 2010 is a recovery year.

Recommendation: maintain good practice.

3. Productivity / Cost Effectiveness KPA, excellent scores apart from the last two years, 2012 and 2013.

Recommendation: improve practice addressing the KPIs with more relevance.

4. Service Quality KPA has a linear growth tendency, with an exceptional score last year.

Recommendation: maintain good practice.

5. Financial / Commercial KPA, in the 11 years of analysis, the first years show an excellent score. Still, from 2009 to 2013, some irregularities in the scores are not the more relevant KPA but need to be monitored to improve the overall airport score.

Recommendation: improve practice addressing the KPIs with more relevance.

6. Environmental KPA has continued growth in the 11 years of analysis and is expected to continue forward. The year 2009 reflects the economic crisis of this year, but 2010 is a recovery year.

Recommendation: maintain good practice.

6.4 Conclusion

The three stages of GDA were applied to the airport in study. Once completed the airport performance assessment with PESA-AGB, the processed results allow a report to be generated showing the comparison of the self-assessed performance against the good level of the airport practice over 11 years from 2003 to 2013. The report provides a valuable snapshot of the airport performance against the maximum, minimum and average scores of all benchmarked years. The report will summarise strengths and weaknesses and suggest KPA and KPIs for improvement or recommend actions.

The two dashboards developed help to visualise data in a more organised way. Having a dashboard for managers to access helps to include different sectors of an airport, informing and signalling everyone to the same goal. The dashboards save time, which for many airports means money and agility in decision making. With that, problems and losses tend to decrease.

Much data is generated, and the airport's managers already know that this data, transformed into information, helps make proactive decisions. The dashboards facilitate these decisions, being a quick access panel, and its main objective is to visualise the analysed object at a given moment. It can be automatically updated at the periodicity provided by the data source and may even be minute by minute if the source allows it. Due to its characteristic of automating the data collection and presentation process, it significantly reduces the time needed to visualise the information and avoid human errors and even fraudulent manipulations.

A good-looking visual alone is not the centre differential of the dashboards, but it must be visually pleasing, with graphics and colours related to its evaluation. PESA-AGB and GDA are uniform in maintaining the same colours for each KPA and Respective KPIs making the visual flow continue. As a process optimiser, with updates that can occur in real-time, it processes information in certain "aspects", which facilitates decision making quickly. Its main objective is communication, and for this, it is necessary that the data presented is of quality and relevant, having a simple design and easy access and understanding.

Chapter 7

7.1 Final Conclusions

7.2 Future Work

7.1 Final Conclusions

The framework of this thesis is the performance-driven development approach that is applied within the GDA model. It represents a framework to ensure that the model develops a holistic and ubiquitous concept and technical enablers needed to meet the airport performance ambitions associated with airport manager decision-making to improve airport overall efficiency. The GDA model encompasses both the performance management process and the application of relevant performance framework concepts of Key Performance Areas (KPAs), Key Performance Indicators (KPIs) to measure performance and track the accomplishment of goals. The airport performance and efficiency highlights as part of the air transportation system and possible potential developments focusing on the infrastructure, technology, airport, and airline operators were described. SESAR and NEXTGEN show that overseeing airspace more actively can improve capacity while lowering delays and emissions. Hence, a GDA model applied to the airport as part of the air transportation global improvement is a user-friendly solution to improving global efficiency objectives.

All assumptions resulting from this thesis were tested in the Transportation Research Laboratory to produce unequivocal evidence of the proposed concepts and techniques. The analysis of the methodologies used by decision support models in airport infrastructures and applying the proposed decision support model GDA to these infrastructures was implemented to validate its holistic application through Microsoft Excel combined with the MACBETH multicriteria methodology programmed in the software.

The main proposed objective regarding developing an integrated, holistic model for monitoring an airport infrastructure was accomplished. Using a secure database and, in addition, a decision support system throughout dashboards that can generate real-time alerts and feedback for airport managers. At the same time, GDA provides the integration of the database and the decision support system and allows to obtain the annual performance and efficiency rating through an online platform and Microsoft Excel.

Effective inclusion of experts and decision-makers, interoperability and holistic application of airport performance and efficiency monitoring systems raise challenges and concerns for their application, design and development. The user-friendly interaction with the GDA model makes it possible to enhance the best decisions and follow-up based on monitoring systems aimed at more accurate results and optimization of decisions.

Thus, there are several limitations to the various approaches that have been proposed in the literature. First, most airport assessment models are designed to interact directly with managers without considering the strategic lines of management. Second, sharing and accessing information is often non-existent or impractical. Thirdly, these models are generally limited in data integration with all areas of analysis of airport infrastructure. Fourth, the reliability and

accuracy of these systems are rarely demonstrated. Fifth, the study on the holistic assessment of airport infrastructure remains scarce or even non-existent.

Thus, the main objective was to propose an alternative that is not limited by the aforementioned restrictions. The secondary objectives were established to divide the research work into a theoretical and practical component to achieve the main objective.

The theoretical component was based on the study of existing solutions related to the MACBETH multicriteria methodology used as decision support. In addition, questionnaires and scores were the content management techniques found in the literature.

The practical component was to implement in an actual airport the GDA model. The APE-Label is demonstrative that a visual and complete label helps guide all airport stakeholders in their decision-making for an optimal balance of their interests. APE-label is a tool to increase the air traveller perceived airport choice to travellers. The airport evaluation was done using 85 % of the actual data for the 2003-2013 evaluation period, and the rest was collected from airports with similar characteristics to the Lisbon airport. It was not possible to acquire all the data needed from Lisbon airport. Nevertheless, it was possible to demonstrate and validate the GDA model to apply the GDA model to an actual set of data contributing to a more friendly understanding of the improvements and gaps in the airport performance and efficiency throughout dashboards.

7.2 Future Work

Due to 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 in the case of the Hinterland, also introducing the traffic, socio-economic and tourism KPIs of the airports' hinterland.
- II. Establish formal cooperation with airports managers to apply GDA to new airports in real case scenarios.
- III. One of the facts that should be analysed in future studies is the operation seasonality in some airports. Another factor is to study the sensitivity of the KPA scores concerning the expert's weights for each KPI and KPA, allowing the decision-maker to observe the cost of increasing or decreasing these weights. This analysis should be made in a pairwise form between years (options).
- IV. Extend the case studies to the other levels of the bottom-up process, understating airport KPAs and each of the 42 KPIs and an airports' group overall performance scores with different airport characteristics like cargo insular, remote and LCC types.

- V. Developing a web-based for creating a central database within ICAO, ACI, or EUROCONTROL would allow classifying all airports according to the same standards.
- VI. Future research could further examine the interaction of the APE-Label with the sensibility of the KPIs and KPA to more expert opinions and the possibility of applying this APE-Label to a large set of airports.

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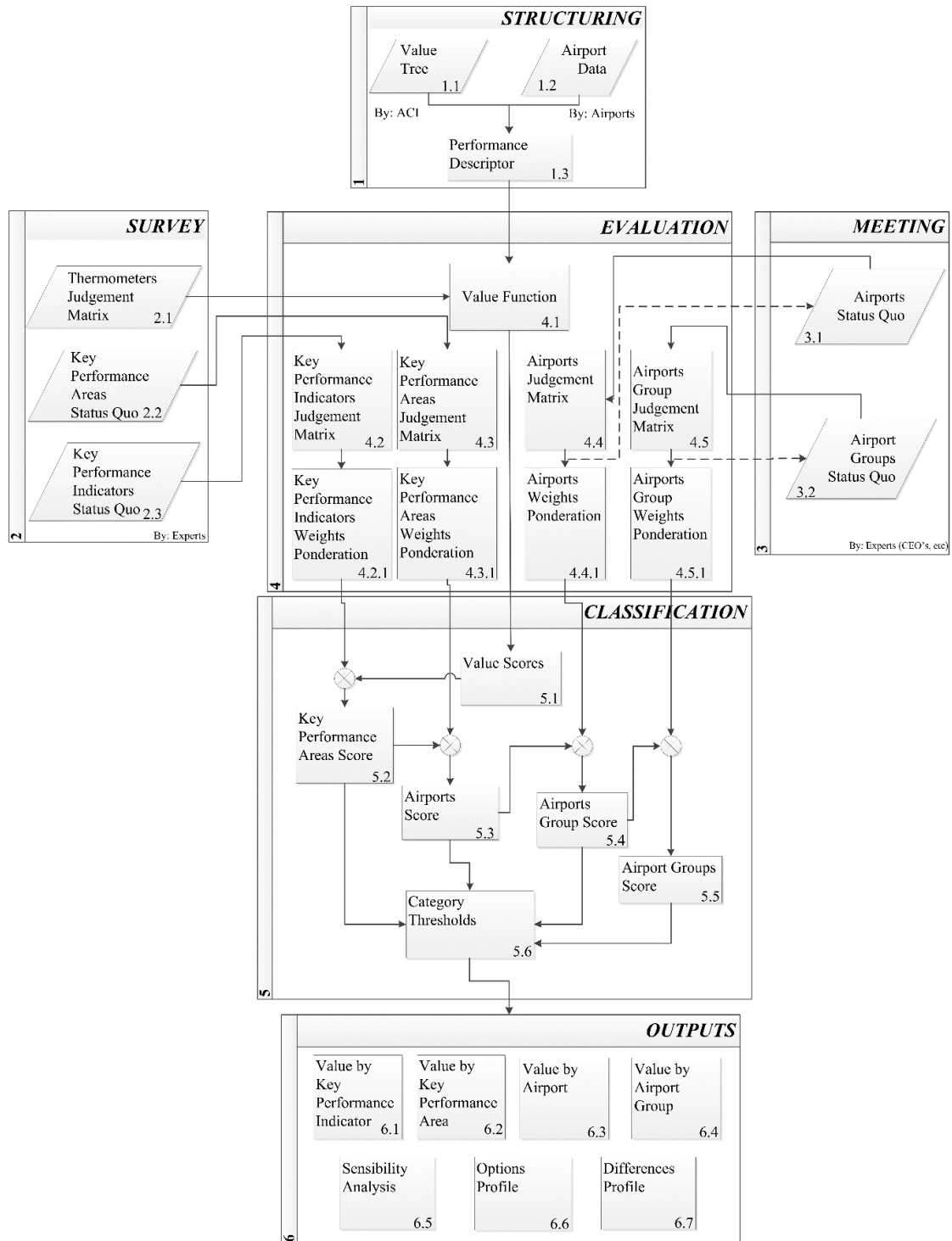
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Appendix 1 - PESA-AGB Model Flowchart and KPA, KPI Definition

A.1.1 - PESA-AGB Model Flowchart



A.1.2 KPA - KEY PERFORMANCE AREAS, KPI - KEY PERFORMANCE INDICATORS

Definition

A.1.2.1 KPA - KEY PERFORMANCE AREAS

The following six Key Performance Areas are defined by ACI [92], in order of relevance by PESA-AGB Safety and Security, Core, Productivity/Efficiency, Service Quality, Financial/Commercial, and Environmental:

Safety and Security – these are the most critical airport responsibilities, and therefore they are categorized separately.

Core – these are the core measures used to characterize and categorize airports, such as the number of passengers and operations. Although airports may have little control over these core indicators, especially in the short term, they are essential indicators of overall airport activity and important drivers and components of other indicators.

Productivity/Efficiency – these measures are closely related/overlapping measures of an airport's performance. They are sometimes separated into productivity measures, which track output on a non-cost basis—e.g., passengers per airport employee or departures per gate—and efficiency measures, which track output on a cost basis—e.g., total or operating cost per passenger.

Service Quality – this increasingly important area reflects the evolution of airport management from having a primary focus on facilities and operations to having a solid customer service focus in an increasingly competitive environment.

Financial/Commercial – this includes measures relating to airport charges, airport financial strength and sustainability, and the performance of individual commercial functions.

Environmental – this evolving area has become a strong focus for airport management striving to minimize environmental impacts.

A.1.2.2 KEY PERFORMANCE INDICATORS (KPIs) INCLUDED WITHIN EACH KPA

For each Key Performance Indicator, the following information is provided with the title, definition of GDA-PESA-AGB: GOOD and NEUTRAL level and G stands for GOOD and N stands for NEUTRAL, and the complete list of the key indicators, in order of relevance by PESA-AGB, included within each area is provided below.

KPA.1 - SAFETY AND SECURITY

Safety indicators are used to track airfield safety issues and safety issues involving other portions of the airport, including roadways and general employee safety. Security indicators may be used to track security violations, thefts and crimes, and responsiveness. Equations A.1.1 – A.1.6 are depicted in the definition KPIs.

KPI.1.1 - Runway Accidents

Definition: Aircraft accidents involving a runway per thousand aircraft movements (take-offs and landings are counted separately), measured over a year. For the last ten years, using the Aircraft accidents involving a runway per thousand aircraft movements, it was used the following metrics were:

$$\left\{ \begin{array}{l} G = \min \left(\frac{\text{accidents}}{1000\text{movs}} \right)_i \\ N = \max \left(\frac{\text{accidents}}{1000\text{movs}} \right)_i \end{array} \right. \quad i = (1 \text{ to } 10)\text{years} \quad \text{Equation A.1. 1}$$

KPI.1.2 Runway Incursions

Definition: Number of occurrences per thousand movements involving the incorrect presence of an aircraft, vehicle, or person on the protected area of a surface designated for the landing and take-off of aircraft, measured over a year. For the last ten years, using the Number of occurrences per thousand movements, it was used the following metrics were:

$$\left\{ \begin{array}{l} G = \min \left(\frac{\text{incursions}}{1000\text{movs}} \right)_i \\ N = \max \left(\frac{\text{incursions}}{1000\text{movs}} \right)_i \end{array} \right. \quad i = (1 \text{ to } 10)\text{years} \quad \text{Equation A.1. 2}$$

KPI.1.3 Bird Strikes

Definition: Number of incidents per thousand movements involving bird strikes, collisions of airborne animals (usually birds, but also including bats) with aircraft, measured over a year. Using the Number of occurrences per thousand movements for the last ten years, it was used the following metrics were:

$$\left\{ \begin{array}{l} G = \min \left(\frac{BS}{1000\text{movs}} \right)_i \\ N = \max \left(\frac{BS}{1000\text{movs}} \right)_i \end{array} \right. \quad i = (1 \text{ to } 10)\text{years} \quad \text{Equation A.1. 3}$$

KPI.1.4 Public Injuries

Definition: Number of public injuries per thousand passengers, measured over a year. Using the Number of occurrences per thousand movements for the last 10 years, it was used the following metrics were:

$$\left\{ \begin{array}{l} G = \min \left(\frac{PI}{1000PAX} \right)_i \\ N = \max \left(\frac{PI}{1000PAX} \right)_i \end{array} \right. \quad i = (1 \text{ to } 10)\text{years} \quad \text{Equation A.1. 4}$$

KPI.1.5 Occupational Injuries

Definition: Occupational injuries to airport authority employees per thousand hours worked. Using the Occupational injuries to airport authority employees per thousand hours worked for the last 10 years, it was used the following metrics were:

$$\left\{ \begin{array}{l} G = \min \left(\frac{OI}{1000\text{HoursWorked}} \right)_i \\ N = \max \left(\frac{OI}{1000\text{HoursWorked}} \right)_i \end{array} \right. \quad i = (1 \text{ to } 10)\text{years} \quad \text{Equation A.1. 5}$$

$$N = \max \left(\frac{OI}{1000HoursWorked} \right)_i$$

KPI.1.6 Lost Work Time from Employee Accidents and Injuries

Definition: Lost time due to employee accidents and injuries, measured per thousand hours worked. Using the Lost time due to employee accidents and injuries, measured per thousand hours worked for the last 10 years, it was used the following metrics were:

$$\left\{ \begin{array}{l} G = \min \left(\frac{LT}{1000HoursWorked} \right)_i \\ N = \max \left(\frac{LT}{1000HoursWorked} \right)_i \end{array} \right. \quad i = (1 \text{ to } 10) \text{ years} \quad \text{Equation A.1. 6}$$

with $LT = \frac{TLT}{TTotal}$ Where TLT=total lost time due to Occupational Injuries and TTotal=Total working hours in a year according to legislation.

KPA.2 CORE

These indicators are essential determinants of the financial health of the airport, the airport’s regional economic impact, and the quality of air transportation offered at the airport. Changes in Core indicators are primarily the result of airline decisions that are mainly beyond airports’ control. In most cases, airports have only a limited ability to influence core indicators by establishing favourable airport charges, offering efficient and passenger-friendly infrastructure and services, effectively marketing themselves to airlines and passengers, and sometimes offering financial incentives or marketing support for new services. Core indicators are critical drivers of many other performance indicators. For example, higher passenger volume drives increased airport revenue through passenger charges, landing fees, car parking, food, and beverage spending, etc. Whether expressed in passengers, movements, or freight tones, core indicator values influence asset utilization and airport costs per passenger or movement. Core indicators also are critical drivers of some aspects of service quality, particularly delays, as airports approach saturation [72]. Equations A.1.7 – A.1.11 are depicted in the definition KPIs.

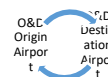
KPI.2.1 Passengers

Definition: Passengers, including enplaning and deplaning, measured over a year. Using the number of passengers for the last 10 years, it was used the following metrics were:

$$\left\{ \begin{array}{l} G = \max (n^o PAX)_i \\ N = \min (n^o PAX)_i \end{array} \right. \quad i=[1 - 10] \text{ in years} \quad \text{Equation A.1. 7}$$

KPI.2.2 Origination and Destination Passengers

Definition: Passengers whose air travel begins or ends at the airport, measured over a year. Excludes passengers who are changing planes at the airport to embark on a flight to another destination. A passenger who makes round-trip is counted as two (2) Origination and Destination (O&D) Passengers. Using the number of passengers Origination and Destination (O&D) for the last 10 years, it was used the following metrics were:



$$\left\{ \begin{array}{l} G = \max (n^o PAX O\&D)_i \\ N = \min (n^o PAX O\&D)_i \end{array} \right. \quad i=[1 - 10] \text{ in years} \quad \text{Equation A.1. 8}$$

KPI.2.3 Aircraft Movements

Definition: Aircraft take-offs or landings at an airport, measured over a year. One arrival and one departure are counted as one movement. Using the number of aircraft movements for the last 10 years, it was used the following metrics were:

$$\left\{ \begin{array}{l} G = \max (n^{\circ} \text{ MOVs})_i \\ N = \min (n^{\circ} \text{ MOVs})_i \end{array} \right. \quad \begin{array}{l} \text{↘ Arrival} \rightarrow \text{↗ Departure} \\ \text{Equation A.1. 9} \end{array}$$

$i=[1 - 10] \text{ in years}$

KPI.2.4 Freight or Mail Loaded/Unloaded

Definition: Freight or mail loaded or unloaded at the airport, measured in metric tonnes over a year. Using the freight or mail loaded or unloaded tones for the last 10 years, it was used the following metrics were:

$$\left\{ \begin{array}{l} G = \max (\text{TONs})_i \\ N = \min (\text{TONs})_i \end{array} \right. \quad \text{Equation A.1. 10}$$

$i=[1 - 10] \text{ in years}$

KPI.2.5 Destinations—Nonstop

Definition: Number of airports with nonstop service, including destinations with only seasonal service, measured over a year.



Using the number of airports with nonstop service for the last 10 years, it was used the following metrics were:

$$\left\{ \begin{array}{l} G = \max (n^{\circ} \text{ AIRPnon-stop})_i \\ N = \min (n^{\circ} \text{ AIRPnon-stop})_i \end{array} \right. \quad \text{Equation A.1. 11}$$

$i=[1 - 10] \text{ in years}$

KPA 3 PRODUCTIVITY/COST-EFFECTIVENESS

These indicators of airport efficiency measure the resources used to produce a specific volume of activity, e.g., departures per gate or total passengers per airport employee. Equations A.1.12 – A.1.20 are depicted in the definition KPIs.

KPI 3.1 Passengers Per Employee

Definition: Total passengers per employee, expressed as full-time equivalents (FTEs), measured over a year. Using the Total passengers per employee for the last 10 years, it was used the following metrics were:

$$\left\{ \begin{array}{l} B = \max \left(\frac{n^{\circ} \text{ PAX}}{n^{\circ} \text{ EMP}} \right)_i \\ N = \min \left(\frac{n^{\circ} \text{ PAX}}{n^{\circ} \text{ EMP}} \right)_i \end{array} \right. \quad \begin{array}{l} \text{Equation A.1. 12} \\ i=[1 - 10] \text{ in years} \end{array}$$

KPI 3.2 Aircraft Movements per Employee

$$B = \min \left(\frac{EUROSop}{n^{\circ} PAX} \right)_i \quad i=[1 - 10] \text{ in years} \quad \text{Equation A.1. 18}$$

$$N = \max \left(\frac{EUROSop}{n^{\circ} PAX} \right)_i$$

KPI 3.8 Operating Cost per Movement

Definition: Airport operating cost per movement, measured over a year. Using the Airport operating cost per movement for the last 10 years, it was used the following metrics were:

$$\left\{ \begin{array}{l} G = \min \left(\frac{EUROSop}{n^{\circ} MOVs} \right)_i \\ N = \max \left(\frac{EUROSop}{n^{\circ} MOVs} \right)_i \end{array} \right. \quad i=[1 - 10] \text{ in years} \quad \text{Equation A.1. 19}$$

KPI 3.9 Operating Cost per WLU

Definition: Airport operating costs per Work Load Unit, measured over a year. Using the Airport operating costs per Work Load Unit for the last 10 years, it was used the following metrics were:

$$\left\{ \begin{array}{l} G = \min \left(\frac{EUROSop}{WLU} \right)_i \\ N = \max \left(\frac{EUROSop}{WLU} \right)_i \end{array} \right. \quad i=[1 - 10] \text{ in years} \quad \text{Equation A.1. 20}$$

KPA.4 SERVICE QUALITY

Service quality indicators focus both on how passengers perceive the level of service provided by the airport. Equations A.1.21 – A.1.28 are depicted in the definition KPIs.

KPI.4.1 Customer Satisfaction

Definition: Overall level of passenger satisfaction as measured by survey responses. Using the Overall level of passenger satisfaction for the last 10 years, it was used the following metrics were:

$$\left\{ \begin{array}{l} G = \max ([A-E])_i \\ N = \min ([A-E])_i \end{array} \right. \quad i=[1 - 10] \text{ in years} \quad \text{Equation A.1. 21}$$

Year 1	Satisfaction	(...)	Satisfaction	Year 10	Satisfaction
A = 20 %	B	A = %	(…)	A = 60%	A
B = 40 %		B = %		B = 20%	
C = 30 %		C = %		C = 10%	
D = 6 %		D = %		D = 5%	
E = 4 %		E = %		E = 5%	

KPI.4.2 Gate Departure Delay

Definition: Average gate departure delay per flight in minutes - measured from scheduled departure time at average and peak times. Using the Average gate departure delay per flight in minutes for the last 10 years, it was used the following metrics were:

$$\left\{ \begin{array}{l} G = \min \left(\frac{\sum_{j=1}^n \Delta T_j}{n} \right)_i \\ \text{Hour: Average [00:00 - 24:00]} \\ \text{Peak [06:00-10:00] + [18:00-20:00]} \end{array} \right. \quad \text{Equation A.1. 22}$$

$i=[1-10]$ in years

$$N = \max \left(\frac{\sum_{j=1}^n \Delta T_j}{n} \right)_i$$

$\Delta T_n \geq 15 \text{ min DELAY}$ or $\Delta T_n \leq 15 \text{ min DELAY} = 0$, in ACRP 2011 [140].

		GATE DELAY	
Gate1	hour	Flight	$\Delta T(\text{gate})_1$
	00:00-01:00	FL1	ΔT_1
	(...)	(...)	(...)
	23:00-00:00	FLn	ΔT_n
Gate p	hour	Flight	$\Delta T(\text{gate})_n$
	00:00-01:00	FL1	ΔT_1
	(...)	(...)	(...)
	23:00-00:00	FLn	ΔT_n
		#FL = n	$\sum_{j=1}^n \Delta T_j$

KPI 4.3 Baggage Delivery Time

Definition: Average time for delivery of first bag and last bag—measured over a year. Using the Average time for delivery of the first bag and last bag for the last 10 years, it was used the following metrics were:

$$\left\{ \begin{array}{l} G = \min \left(\frac{\sum_{j=1}^n \Delta T_j}{n} \right)_i \\ N = \max \left(\frac{\sum_{j=1}^n \Delta T_j}{n} \right)_i \end{array} \right. \quad i=[1 - 10] \text{ in years} \quad \text{Equation A.1. 23}$$

BAGGAGE DELIVERY TIME		
#	Flight	$\Delta T(\text{baggage delivery})$
1	FL1	$\Delta T_1 = T_{1\text{final}} - T_{1\text{initial}}$
	(...)	(...)
n	FLn	$\Delta T_n = T_{n\text{final}} - T_{n\text{initial}}$
	#FL = n	$\sum_{j=1}^n \Delta T_j$

KPI.4.4 Taxi Departure Delay

Definition: 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. Using the Average taxi delay for departing aircraft per flight in minutes for the last 10 years, it was used the following metrics were:

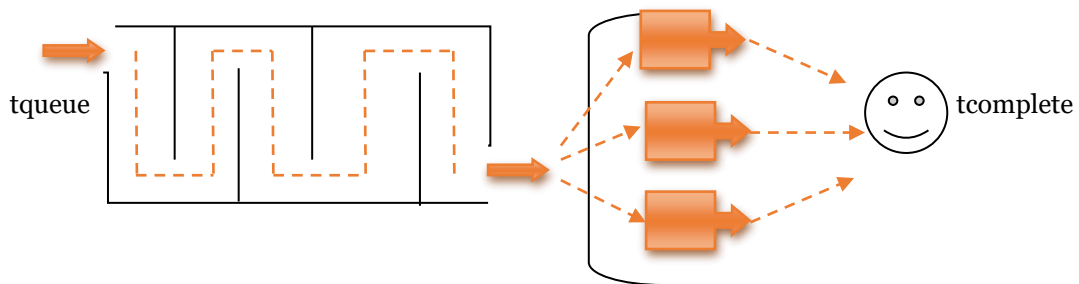
$$\left\{ \begin{array}{l} G = \min \left(\frac{\sum_{j=1}^n \Delta T_j}{n} \right)_i \\ N = \max \left(\frac{\sum_{j=1}^n \Delta T_j}{n} \right)_i \end{array} \right. \quad \begin{array}{l} \text{Hour: Average [00:00 - 24:00]} \\ \text{Peak [06:00 - 10:00]+[18:00 - 20:00]} \\ i=[1-10] \text{ in years} \end{array} \quad \text{Equation A.1. 24}$$

TAXI DELAY			
Hour (365 days)	Flight	$\Delta T(\text{gate})_n$	Tunimpeded
00:00-01:00	FL1	$\Delta T_1 = T_1 - T_{\text{unimpeded}}$	constant
(...)	(...)	(...)	
23:00-00:00	FLn	$\Delta T_n = T_n - T_{\text{unimpeded}}$	

#FL = n	$\sum_{j=1}^n \Delta T_j$
---------	---------------------------

KPI 4.5 Security Clearing Time

Definition: Average security clearing time from entering the queue to processing - measured at average and peak times. Using the Average security clearing time from entering queue to completion of processing for the last 10 years, , it was used the following metrics were:



hour	PAX	tcomplete	tqueue	$\Delta T(\text{tcomplete-tqueue})$
00:00-01:00	100	tc1	tq1	ΔT_1
(...)	(...)			(...)
23:00-00:00	263	tc24	tq24	ΔT_{24}
	$\sum_1^{24} PAX = n$			$\sum_{j=1}^{24} \Delta T_j$

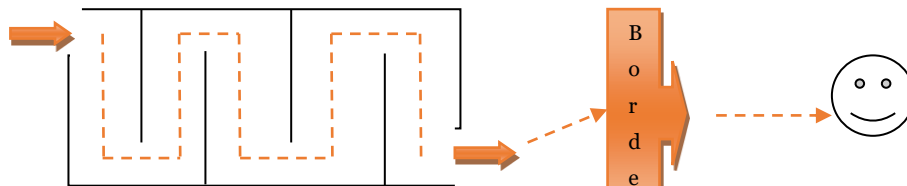
$$\left\{ \begin{array}{l} G = \min \left[\left(\left(\frac{\sum_{j=1}^{24} (\Delta T_j)}{n} \right)_{k,m} \right)_i \right] \\ N = \max \left[\left(\left(\frac{\sum_{j=1}^{24} (\Delta T_j)}{n} \right)_{k,m} \right)_i \right] \end{array} \right.$$

j=[0-24] in hours
 , K=[1-30] in days
 m=[1-12] in months
 i=[1-10] in years

Equation A.1. 25

KPI 4.6 Border Control Clearing Time

Definition: Average border control clearing time from entering the queue to completion of processing - measured at average and peak times. Using the Average border control clearing time from entering the queue to completion of processing for the last 10 years, , it was used the following metrics were:



hour	PAX	tcomplete	tqueue	$\Delta T(\text{tcomplete-tqueue})$
00:00-01:00	100	tc1	tq1	ΔT_1

(...)	(...)			(...)
23:00-00:00	263	tc24	tq24	ΔT_{24}
	$\sum_1^{24} PAX = n$			$\sum_{j=1}^{24} \Delta T_j$

$$\left\{ \begin{array}{l}
 \text{B} = \min \left[\left(\left(\frac{\sum_{j=1}^{24} (\Delta T_j)}{n} \right)_k \right)_{m,i} \right] \\
 \text{N} = \max \left[\left(\left(\frac{\sum_{j=1}^{24} (\Delta T_j)}{n} \right)_k \right)_{m,i} \right]
 \end{array} \right.$$

j=[0-24] in hours – average or
 j= Peak [06:00 – 10:00] + [18:00 – 20:00]
 K=[1-30] in days
 m=[1-12] in months
 i=[1-10] in years

Equation A.1. 26

KPI 4.7 Check-in to Gate Time

Definition: Average time from entering the check-in queue to arrival at the boarding gate - measured at average and peak times. Using the average time from entering the check-in queue to arrival at the boarding gate for the last 10 years, it was used the following metrics were:

hour	PAX	t boarding gate	tqueue check-in	$\Delta T(t \text{ boarding gate} - t\text{queue}...)$
00:00-01:00	100	tc1	tq1	ΔT_1
(...)	(...)			(...)
23:00-00:00	263	tc24	tq24	ΔT_{24}
	$\sum_1^{24} PAX = n$			$\sum_{j=1}^{24} \Delta T_j$

$$\left\{ \begin{array}{l}
 \text{G} = \min \left[\left(\left(\frac{\sum_{j=1}^{24} (\Delta T_j \times PAX_j)}{\sum_1^{24} PAX} \right)_k \right)_{m,i} \right] \\
 \text{N} = \max \left[\left(\left(\frac{\sum_{j=1}^{24} (\Delta T_j \times PAX_j)}{\sum_1^{24} PAX} \right)_k \right)_{m,i} \right]
 \end{array} \right.$$

j=[0-24] in hours – average or
 j= Peak [06:00 – 10:00]+ [18:00 – 20:00]
 K=[1-30] in days
 m=[1-12] in months
 i=[1-10] in years

Equation A.1. 27

KPI.4.8 Practical Hourly Capacity

Definition: Maximum aircraft movements per hour assuming average delay of no more than four minutes or such other number of delay minutes as the airport may set. Using the Maximum aircraft movements per hour for the last 10 years, it was used the following metrics were:

$$\left\{ \begin{array}{l}
 \text{G} = \max \max \left[\left(\left(\left(\frac{MOV_s}{h} \right)_w \right)_k \right)_j \right]_i \\
 \text{N} = \min \max \left[\left(\left(\left(\frac{MOV_s}{h} \right)_w \right)_k \right)_j \right]_i
 \end{array} \right.$$

W=[0-24] in hours
 K=[1-30] in days
 j=[1-12] in months
 i=[1-10] in years

Equation A.1. 28

KPA 5 FINANCIAL/COMMERCIAL

Financial/commercial performance indicators are used to track the airport’s financial performance, including airport charges, airport financial strength and sustainability, and the

performance of individual commercial functions. Equations A.1.29 – A.1.36 are depicted in the definition KPIs.

KPI 5.1 Aeronautical Revenue per Movement

Definition: Aeronautical charges per movement, measured over a year. Average of aeronautical revenues collected per movement for airfield use (landing fees, ramp/apron fees), gate charges, terminal space, passenger-related charges, and ground-handling revenue. Using the aeronautical revenue per movement for the last 10 years, it was used the following metrics were:

$$\left\{ \begin{array}{l} G = \max \left(\frac{\text{Euros}}{\text{Movement}} \right)_i \\ N = \min \left(\frac{\text{Euros}}{\text{Movement}} \right)_i \end{array} \right. \quad i = [1 - 10] \text{ in years} \quad \text{Equation A.1. 29}$$

KPI 5.2 Aeronautical Revenue per Passenger

Definition: Aeronautical charges per passenger, measured over a year. Average of aeronautical revenues collected per passenger for airfield use (landing fees, ramp/apron fees), gate charges, terminal space, passenger-related charges, and ground-handling user fees. Using the aeronautical revenue per passenger for the last 10 years, it was used the following metrics were:

$$\left\{ \begin{array}{l} G = \max \left(\frac{\text{Euros}}{\text{Pax}} \right)_i \\ N = \min \left(\frac{\text{Euros}}{\text{Pax}} \right)_i \end{array} \right. \quad i = [1 - 10] \text{ in years} \quad \text{Equation A.1. 30}$$

KPI 5.3 Non-Aeronautical Operating Revenue per Passenger

Definition: Total non-aeronautical operating revenue per passenger, measured over a year. Using the non-aeronautical operating revenue per passenger for the last 10 years, it was used the following metrics were:

$$\left\{ \begin{array}{l} G = \max \left(\frac{\text{Euros}}{\text{Pax}} \right)_i \\ N = \min \left(\frac{\text{Euros}}{\text{Pax}} \right)_i \end{array} \right. \quad i = [1 - 10] \text{ in years} \quad \text{Equation A.1. 31}$$

KPI 5.4 EBITDA per Passenger

Definition: EBITDA (Earnings Before Interest Taxes Depreciation and Amortization) per Passenger, measured over a year. Using the EBITDA per passenger for the last 10 years, it was used the following metrics were:

$$\left\{ \begin{array}{l} G = \max \left(\frac{\text{Euros}}{\text{Pax}} \right)_i \\ N = \min \left(\frac{\text{Euros}}{\text{Pax}} \right)_i \end{array} \right. \quad i = [1 - 10] \text{ in years} \quad \text{Equation A.1. 32}$$

KPI 5.5 Non-Aeronautical Operating Revenue as Percentage of Total Operating Revenue

Definition: Total non-aeronautical operating revenue as a percentage of total operating revenue, measured over a year. Using the non-aeronautical operating revenue for the last 10 years, it was used the following metrics were:

$$\left\{ \begin{array}{l} G = \max \left(\frac{\text{Euros}}{\text{Euros}} \right)_i \\ N = \min \left(\frac{\text{Euros}}{\text{Euros}} \right)_i \end{array} \right. \quad i = [1 - 10] \text{ in years} \quad \text{Equation A.1. 33}$$

$$N = \min \left(\frac{\text{Euros}}{\text{Euros}} \right)_i$$

KPI 5.6 Debt to EBITDA Ratio

Definition: Debt-to-EBITDA (earnings before interest, taxes, depreciation, and amortization) measured at the end of the year. Using the debt to EBITDA ratio for the last 10 years, it was used the following metrics were:

$$\left\{ \begin{array}{l} G = \min \left(\frac{\text{Euros}}{\text{Euros}} \right)_i \\ N = \max \left(\frac{\text{Euros}}{\text{Euros}} \right)_i \end{array} \right. \quad i=[1 - 10] \text{ in years} \quad \text{Equation A.1. 34}$$

KPI 5.7 Debt Service as Percentage of Operating Revenue

Definition: Debt service (principal plus interest) as a percentage of operating revenue, measured over a year. Using the debt service for the last 10 years, it was used the following metrics were:

$$\left\{ \begin{array}{l} G = \min \left(\frac{\text{Euros}}{\text{Euros}} \right)_i \\ N = \max \left(\frac{\text{Euros}}{\text{Euros}} \right)_i \end{array} \right. \quad i=[1 - 10] \text{ in years} \quad \text{Equation A.1. 35}$$

KPI 5.8 Long-Term Debt per Passenger

Definition: 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 measured at the end of the year. Using the long-term debt per passenger for the last 10 years, it was used the following metrics were:

$$\left\{ \begin{array}{l} G = \min \left(\frac{\text{Euros}}{\text{Pax}} \right)_i \\ N = \max \left(\frac{\text{Euros}}{\text{Pax}} \right)_i \end{array} \right. \quad i=[1 - 10] \text{ in years} \quad \text{Equation A.1. 36}$$

KPA 6 ENVIRONMENTAL

Environmental indicators are used to track an airport’s progress in minimizing the environmental impacts of its operations. Equations A.1.37 – A.1.42 are depicted in the definition KPIs.

KPI 6.1 Carbon Footprint

Definition: 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 per passenger. The KPI excludes emissions caused by airline/tenant operations and the public. Using the carbon footprint for the last 10 years, it was used the following metrics were:

$$\left\{ \begin{array}{l} G = \min \left(\frac{\text{GHG}}{\text{m}^2} \right)_i \\ N = \max \left(\frac{\text{GHG}}{\text{m}^2} \right)_i \text{ with } i = (1 \text{ to } 10) \text{ years} \end{array} \right. \quad \text{Equation A.1. 37}$$

KPI 6.2 Waste Recycling

Definition: Percentage of solid waste that is recycled/reused/composted, including pre-consumer organics and post-consumer compostable, as well as airfield trash, measured over a year. Does not include construction waste. Using the Percentage of solid waste that is recycled/reused/composted for the last 10 years, it was used the following metrics were:

$$G = \max(\% \text{WasteRecycling})_i$$

$$\left\{ \begin{array}{l} N = \min(\%WasteRecycling)_i \text{ with } i = (1 \text{ to } 10) \text{ years} \end{array} \right. \quad \text{Equation A.1. 38}$$

KPI 6.3 Renewable Energy Purchased by the Airport (%)

Definition: Amount of renewable energy purchased by the airport as a percentage of total energy consumed by the airport. Excludes energy purchases by tenants. Using the Amount of renewable energy purchased for the last 10 years, it was used the following metrics were:

$$\left\{ \begin{array}{l} G = \max(\%PRE)_i \\ N = \min(\%PRE)_i \text{ with } i = (1 \text{ to } 10) \text{ years} \end{array} \right. \quad \text{Equation A.1. 39}$$

KPI 6.4 Waste Reduction Percentage

Definition: Percentage reduction over the previous year in tons of solid waste, including pre-consumer organics and post-consumer compostables, as well as airfield trash, does not include construction waste. Using the Waste Reduction Percentage for the last 10 years, it was used the following metrics were:

$$\left\{ \begin{array}{l} G = \max(\%WasteReduction)_i \\ N = \min(\%WasteReduction)_i \text{ with } i = (1 \text{ to } 10) \text{ years} \end{array} \right. \quad \text{Equation A.1. 40}$$

KPI 6.5 Utilities/Energy Usage per Square Meter of Terminal

Definition: Utilities and energy used per square meter of the terminal building (conditioned space), measured in kilowatt-hours and therms over a year. Using the Utilities and energy used per square meter of the terminal building for the last 10 years, it was used the following metrics were:

$$\left\{ \begin{array}{l} G = \min\left(\frac{KW}{m^2}\right)_i \\ N = \max\left(\frac{KW}{m^2}\right)_i \text{ with } i = (1 \text{ to } 10) \text{ years} \end{array} \right. \quad \text{Equation A.1. 41}$$

KPI 6.6 Water Consumption per Passenger

Definition: Water consumption in the terminal complex divided by the number of passengers, measured over a year. Using the Water consumption in the terminal complex for the last 10 years, it was used the following metrics were:

$$\left\{ \begin{array}{l} G = \min\left(\frac{H_2O (lts)}{Pax}\right)_i \\ N = \max\left(\frac{H_2O (lts)}{Pax}\right)_i \text{ with } i = (1 \text{ to } 10) \text{ years} \end{array} \right. \quad \text{Equation A.1. 42}$$

Appendix 2 - PESA-AGB: Airport in study Outputs

A2.1 - Airport Data

Airport data is depicted in Figure A2. 1.

Airport 1

KPA (Criteria)	KPI (Sub Criteria)	Ano											Metric	
		2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013		
Safety and Security	Runway Accidents	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	Accidents / 1000MOVs
	Runway Incursions	0,0592	0,0628	0,0556	0,0768	0,0624	0,0619	0,0618	0,0758	0,0606	0,0798	0,0600	0,0600	Incursions / 1000MOVs
	Bird Strikes	0,4100	0,7600	0,8130	0,4440	0,3720	0,2640	0,6900	0,5610	0,7120	0,6570	0,6900	0,6900	BS / 1000MOVs
	Public Injuries	0,4889	0,5319	0,5399	0,1132	0,1021	0,3928	0,3324	0,2172	0,1004	0,2484	0,0984	0,0984	Pinj / 1000MOVs
	Occupational Injuries*100	0,5330	1,0205	0,8590	0,5447	0,6353	0,5596	1,5080	1,3503	0,9223	0,7551	0,7541	0,7541	Ocplnj / 1000HoursWorked
	Lost Work Time from Employee Accidents and Injuries	7,7397	9,6380	4,1339	2,5163	3,4327	2,9101	1,8895	5,9443	4,1639	2,4670	5,9443	5,9443	LWT / 1000HoursWorked
Core	Passengers	9636257	10731861	11236476	12314917	13393182	13603616	13265268	14049808	14806537	15314800	16025510	16025510	n°PAX
	Orination and Destination Passengers	9414564	10510168	11015669	12130014	13240879	13532558	13245926	14026154	14790440	15294210	16009049	16009049	n° PAX O&D
	Aircraft Movements	112500	122200	124187	132458	144800	140016	136286	138147	139497	140909	142333	142333	n° MOVs
	Freight and Mail Loaded /Unloaded	95766	100075	100103	99556	82880	88832	83345	105304	94356	90282	97179	97179	Metric TONs
	Destinations—Nonstop	74	78	83	169	126	124	126	102	108	112	107	107	n° AIRP non-stop
Productivity/Cost Effectiveness	Passengers Per Employee	14757	16394	17205	18858	20275	20832	19473	20870	22543	22702	23776	23776	PAX / EMP
	Aircraft Movements per Employee	172	187	190	203	210	214	194	205	213	209	217	217	MOVs / EMP
	Aircraft Movements per Gate	5114	5555	4964	5298	5484	3784	3578	2763	2790	2818	2927	2927	MOVs / GATE
	Total Cost per Passenger	19,468	18,272	17,584	16,253	15,238	15,261	15,833	15,110	14,562	16,551	16,262	16,262	TCost / PAX
	Total Cost per Movement	1667,556	1600,655	1591,861	1511,068	1471,457	1482,688	1587,098	1538,578	1543,761	1797,259	1780,541	1780,541	TCost / MOVs
	Total Cost per WLU	18,474	19,288	18,866	17,274	16,635	11,415	14,774	14,946	15,143	17,808	18,325	18,325	TCost / WLU
	Operating Cost per Passenger	4,958	5,465	5,481	5,348	3,189	3,197	3,054	3,189	3,280	3,941	4,463	4,463	OP Cost / Pax
	Operating Cost per Movement	424,667	478,718	496,230	497,198	307,978	310,582	305,926	324,677	347,749	427,912	488,638	488,638	OP Cost / MOVs
Operating Cost per WLU	4,705	5,769	5,881	5,684	3,482	2,391	2,848	3,154	3,411	4,240	5,029	5,029	OP Cost / WLU	
Service Quality	Practical Hourly Capacity	39	41	38	42	43	39	37	38	44	42	45	45	MaxMOVs/hour
	Gate Departure Delay	12,30	14,40	13,20	10,10	9,90	11,50	10,90	9,80	10,50	14,00	12,20	12,20	ΣΔGTJ / nFlights
	Taxi Departure Delay	3,20	3,50	2,10	2,90	2,00	1,40	1,90	2,50	1,70	1,50	2,00	2,00	ΣΔTJ / nFlights
	Customer Satisfaction	65,40	67,20	65,90	67,00	67,80	68,70	66,70	70,80	71,80	72,20	74,10	74,10	A-100-90 % B-90-70 % C-70-50 % D-50-30 % E- 30-0 %
	Baggage Delivery Time	27,30	25,40	27,00	31,10	24,90	34,00	24,00	22,50	21,50	17,50	18,00	18,00	ΣΔBDTj / nFlights
	Security Clearing Time	25,60	26,40	24,30	26,60	24,30	25,70	25,00	20,50	22,70	26,30	25,10	25,10	ΣΔSCTj / nPAX
	Border Control Clearing Time	8,60	9,00	7,80	6,70	10,10	9,30	7,80	8,30	12,40	9,50	10,10	10,10	ΣΔBCCTj / nPAX
Check-in to Gate Time	22,40	19,70	23,00	25,30	21,80	17,50	22,30	23,10	21,60	18,90	20,00	20,00	Σ (ΔTj x PAXj) / ΣnPAX	
Financial/Commercial	Aeronautical Revenue per Passenger	9,599	8,734	8,411	7,755	7,232	7,075	7,239	6,859	6,780	6,593	6,295	6,295	REV / PAX
	Aeronautical Revenue per Movement	822,222	765,139	761,483	720,994	698,349	687,421	725,185	698,358	718,811	715,902	689,239	689,239	REV / MOVs
	Non-Aeronautical Operating Revenue as Percentage of Total Operating Revenue	0,322	0,328	0,340	0,344	0,349	0,348	0,351	0,350	0,347	0,355	0,358	0,358	NonAeroOp REV / TotalOp REV(%)
	Non-Aeronautical Operating Revenue per Passenger	4,216	3,980	4,061	3,876	3,746	3,685	3,878	3,689	3,611	3,621	3,573	3,573	NonAeroOp REV / PAX
	Debt Service as Percentage of Operating Revenue	0,331	0,367	0,358	0,327	0,286	0,299	0,330	0,313	0,234	0,293	0,244	0,244	Debt / OP REV(%)
	Long-Term Debt per Passenger	9,020	12,787	17,982	18,445	18,023	20,643	20,691	19,964	19,219	13,606	52,845	52,845	LT Debt / PAX
	Debt to EBITDA Ratio	2,540	4,001	5,007	4,893	4,379	5,043	4,504	4,529	3,816	3,669	14,924	14,924	Debt/EBITDA
EBITDA per Passenger	3,551	3,196	3,591	3,769	4,116	4,093	4,594	4,408	5,036	3,708	3,541	3,541	EBITAD/PAX	
Environmental	Carbon Footprint (TONS)	3334	3308	3282	3256	3230	3204	3096	3235	3145	3050	3050	3050	GHG
	Carbon Footprint (TONS/PAX)	0,0003	0,0003	0,0003	0,0003	0,0002	0,0002	0,0002	0,0002	0,0002	0,0002	0,0002	0,0002	GHG/1000 PAX
	Waste Recycling	5,78	7,57	10,17	9,39	11,48	14,56	19,46	23,95	30,84	19,11	13,33	13,33	%water recycled
	Waste Reduction Percentage	-3,31	-0,55	27,63	-14,53	8,69	-0,26	-3,95	-11,84	-2,68	6,17	9,78	9,78	Waste red (%)
	Renewable Energy Purchased by the Airport (%)	24,20	26,10	28,00	29,90	31,80	33,70	48,80	53,00	56,00	59,00	73,10	73,10	REP (%)
	Utilities/Energy Usage per Square Meter of Terminal	555,38	581,42	604,08	417,73	452,55	481,31	513,02	589,15	571,16	448,15	520,30	520,30	KWh/m²
Water Consumption per Passenger	40,00	39,60	31,10	33,00	39,00	39,00	32,10	37,80	35,90	32,30	30,60	30,60	H2O (Lit)/PAX	

Figure A2. 1 - Airport data 2003-2013
Source: Own Elaboration

A2.2 - Airport Survey Results

Step 2 - Thermometers Judgement Matrix, Key Performance Areas - Status Quo, Key Performance Indicators - Status Quo

A2.2.1 – KPI Thermometers Judgement Matrix

The KPI Thermometers Judgement Matrix construction was instructed to the airport experts in the survey, and to avoid inconsistencies, to follow the model to fulfil the judgement matrix as depicted in Figure A2. 2, with six semantic attractiveness difference categories, offered: “very weak”, “weak”, “moderate”, “strong”, “very strong” or “extreme”.

	A	B	C	D
A	No	AB	AC	AD
B		No	BC	BD
C			No	CD
D				No

THE BIGGEST DIFFERENCE (points to AB, AC, AD)
 THE INTERMEDIATE DIFFERENCE (points to BC, BD)
 THE SMALLEST DIFFERENCE (points to CD)

Figure A2. 2 – Rules to fulfil the judgement matrix
Source: Own Elaboration

KPA Safety and Security

The KPI Thermometers Judgement Matrix of the KPA Safety and Security is built with the 19 airport experts answers as distributed as in Figure A2. 3 below.

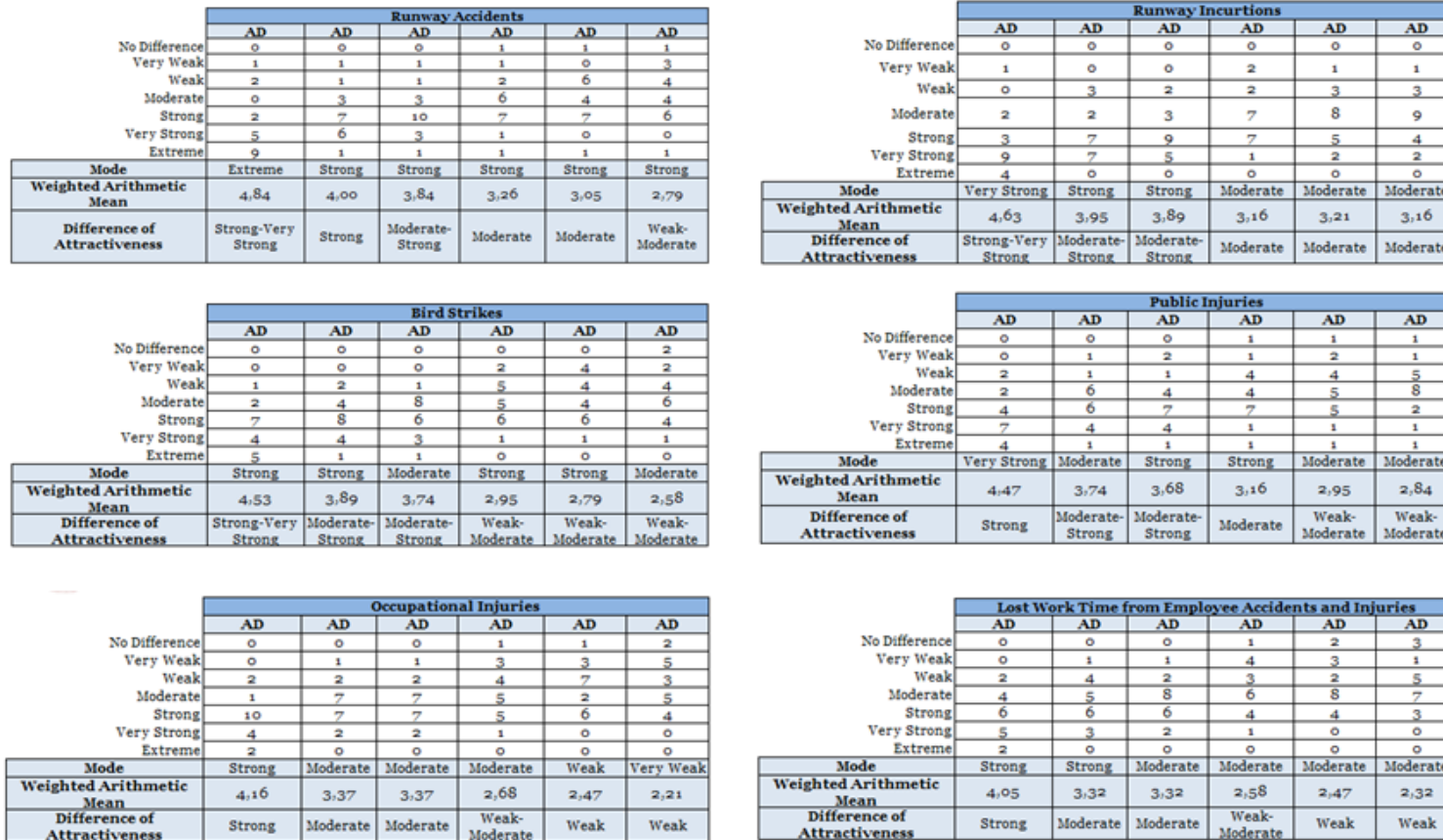


Figure A2. 3 - KPA Safety and Security KPI Thermometers Judgement Matrix
Source: Own Elaboration

KPA CORE

The KPI Thermometers Judgement Matrix of the KPA CORE is built with the 19 airport experts answers as distributed as in Figure A2. 4 below.

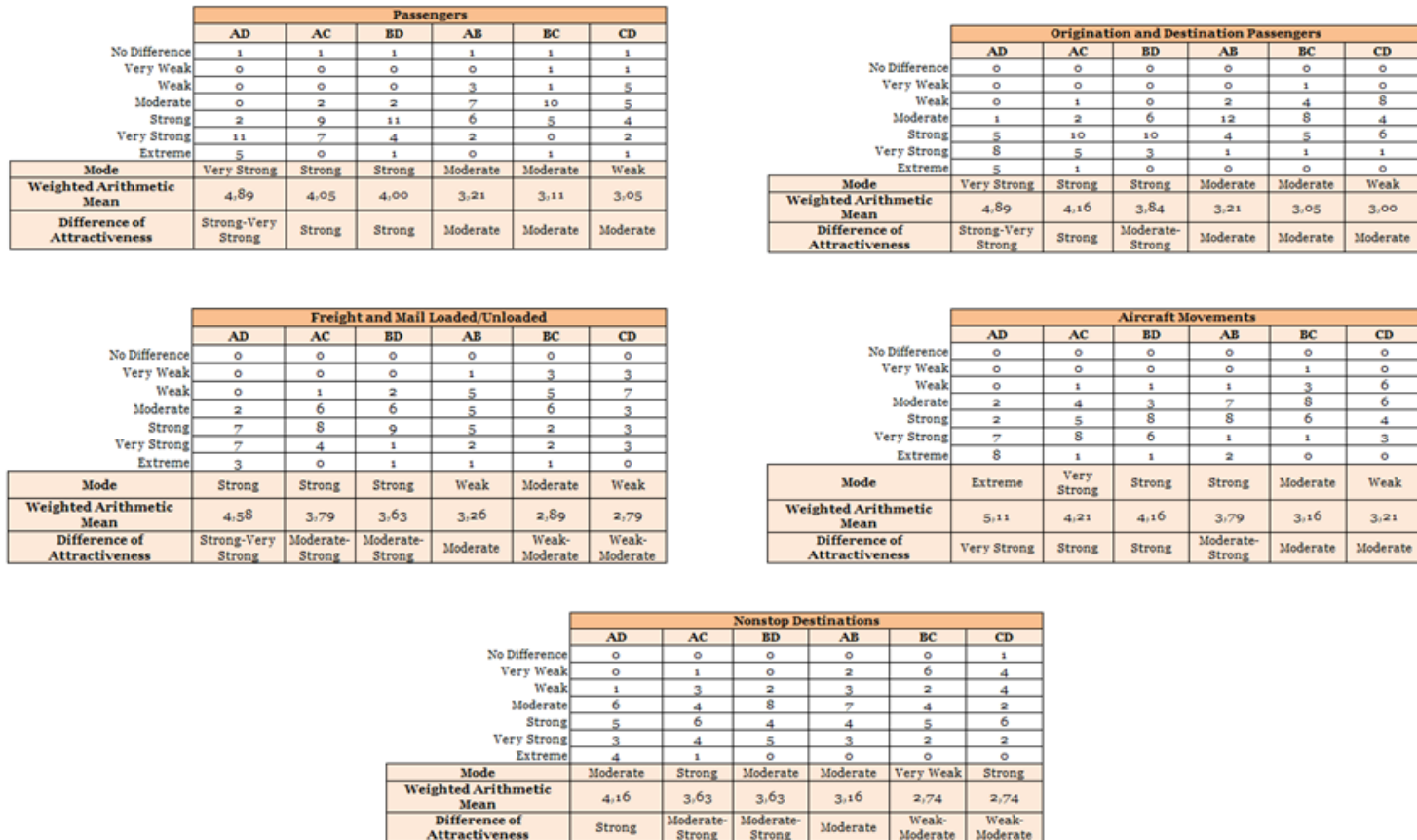


Figure A2. 4 - KPA CORE KPI Thermometers Judgement Matrix
Source: Own Elaboration

KPA Productivity / Cost Effectiveness

The KPI Thermometers Judgement Matrix of the KPA Productivity / Cost Effectiveness is built with the 12 airport experts answers as distributed as in Figure A2. 5 below below.

Passengers per Employee						
	AD	AC	BD	AB	BC	CD
No Difference	0	0	0	0	0	0
Very Weak	0	1	1	2	1	2
Weak	1	0	0	2	3	2
Moderate	1	2	4	5	6	6
Strong	2	7	6	3	1	2
Very Strong	5	1	1	0	1	0
Extreme	3	1	0	0	0	0
Mode	Very Strong	Strong	Strong	Moderate	Moderate	Moderate
Weighted Arithmetic Mean	4,67	3,83	3,50	2,75	2,83	2,67
Difference of Attractiveness	Strong-Very Strong	Moderate-Strong	Moderate	Weak-Moderate	Weak-Moderate	Weak-Moderate

Aircraft Movements per Employee						
	AD	AC	BD	AB	BC	CD
No Difference	0	0	0	1	0	0
Very Weak	0	1	1	1	2	2
Weak	1	0	0	1	1	3
Moderate	1	4	3	6	7	5
Strong	3	5	6	2	2	2
Very Strong	5	1	2	1	0	0
Extreme	2	1	0	0	0	0
Mode	Very Strong	Strong	Strong	Moderate	Moderate	Moderate
Weighted Arithmetic Mean	4,50	3,67	3,67	2,83	2,75	2,58
Difference of Attractiveness	Strong	Moderate-Strong	Moderate-Strong	Weak-Moderate	Weak-Moderate	Weak-Moderate

Total Cost per Passenger						
	AD	AC	BD	AB	BC	CD
No Difference	0	0	0	0	0	0
Very Weak	0	0	0	1	0	0
Weak	0	0	0	1	3	3
Moderate	1	3	3	6	7	6
Strong	2	5	6	4	2	3
Very Strong	8	4	3	0	0	0
Extreme	1	0	0	0	0	0
Mode	Very Strong	Strong	Strong	Moderate	Moderate	Moderate
Weighted Arithmetic Mean	4,75	4,08	4,00	3,08	2,92	3,00
Difference of Attractiveness	Strong-Very Strong	Strong	Strong	Moderate	Weak-Moderate	Moderate

Total Cost per Movement						
	AD	AC	BD	AB	BC	CD
No Difference	0	0	0	0	0	0
Very Weak	0	0	0	1	0	0
Weak	0	0	0	1	2	3
Moderate	2	3	3	5	6	6
Strong	1	5	6	5	4	3
Very Strong	7	4	3	0	0	0
Extreme	2	0	0	0	0	0
Mode	Very Strong	Strong	Strong	Moderate	Moderate	Moderate
Weighted Arithmetic Mean	4,75	4,08	4,00	3,17	3,17	3,00
Difference of Attractiveness	Strong-Very Strong	Strong	Strong	Moderate	Moderate	Moderate

Total Cost per WLU						
	AD	AC	BD	AB	BC	CD
No Difference	0	0	0	0	0	0
Very Weak	0	1	1	3	2	3
Weak	1	1	1	1	4	2
Moderate	2	2	3	5	3	5
Strong	1	6	4	2	3	2
Very Strong	6	1	3	1	0	0
Extreme	2	1	0	0	0	0
Mode	Very Strong	Strong	Strong	Moderate	Weak	Moderate
Weighted Arithmetic Mean	4,50	3,67	3,58	2,75	2,58	2,50
Difference of Attractiveness	Strong	Moderate-Strong	Moderate-Strong	Weak-Moderate	Weak-Moderate	Weak

Aircraft Movements per Gate						
	AD	AC	BD	AB	BC	CD
No Difference	0	0	0	1	0	0
Very Weak	0	1	1	1	2	1
Weak	1	0	1	2	3	5
Moderate	1	3	5	7	5	4
Strong	3	7	3	1	2	1
Very Strong	6	1	2	0	0	1
Extreme	1	0	0	0	0	0
Mode	Very Strong	Strong	Moderate	Moderate	Moderate	Weak
Weighted Arithmetic Mean	4,42	3,58	3,33	2,50	2,58	2,67
Difference of Attractiveness	Strong	Moderate-Strong	Moderate	Weak	Weak-Moderate	Weak-Moderate

Operating Cost per Passenger						
	AD	AC	BD	AB	BC	CD
No Difference	0	0	0	0	0	0
Very Weak	0	0	0	1	0	1
Weak	0	1	2	3	5	4
Moderate	2	3	3	6	5	5
Strong	3	6	6	1	1	1
Very Strong	5	1	1	1	0	1
Extreme	2	1	0	0	1	0
Mode	Very Strong	Strong	Strong	Moderate	Weak	Moderate
Weighted Arithmetic Mean	4,58	3,83	3,50	2,83	2,92	2,75
Difference of Attractiveness	Strong-Very Strong	Moderate-Strong	Moderate	Weak-Moderate	Weak-Moderate	Weak-Moderate

Operating Cost per Movement						
	AD	AC	BD	AB	BC	CD
No Difference	0	0	0	0	0	0
Very Weak	0	0	0	1	0	1
Weak	0	1	1	1	3	3
Moderate	2	1	1	7	6	6
Strong	0	7	9	2	3	1
Very Strong	9	2	1	1	0	1
Extreme	1	1	0	0	0	0
Mode	Very Strong	Strong	Strong	Moderate	Moderate	Moderate
Weighted Arithmetic Mean	4,75	4,08	3,83	3,08	3,00	2,83
Difference of Attractiveness	Strong-Very Strong	Strong	Moderate-Strong	Moderate	Moderate	Weak-Moderate

Operating Cost per WLU						
	AD	AC	BD	AB	BC	CD
No Difference	0	0	0	0	0	0
Very Weak	0	1	1	2	1	1
Weak	1	0	0	2	3	2
Moderate	1	3	3	5	5	6
Strong	2	4	6	1	0	0
Very Strong	6	3	1	2	3	3
Extreme	2	1	1	0	0	0
Mode	Very Strong	Strong	Strong	Moderate	Moderate	Moderate
Weighted Arithmetic Mean	4,58	3,92	3,75	2,92	3,08	3,17
Difference of Attractiveness	Strong-Very Strong	Moderate-Strong	Moderate-Strong	Weak-Moderate	Moderate	Moderate

Figure A2. 5 - KPA Productivity / Cost Effectiveness KPI Thermometers Judgement Matrix
Source: Own Elaboration

KPA Service Quality

The KPI Thermometers Judgement Matrix of the KPA Service Quality is built with the 14 airport experts answers as distributed as in Figure A2. 6 below.

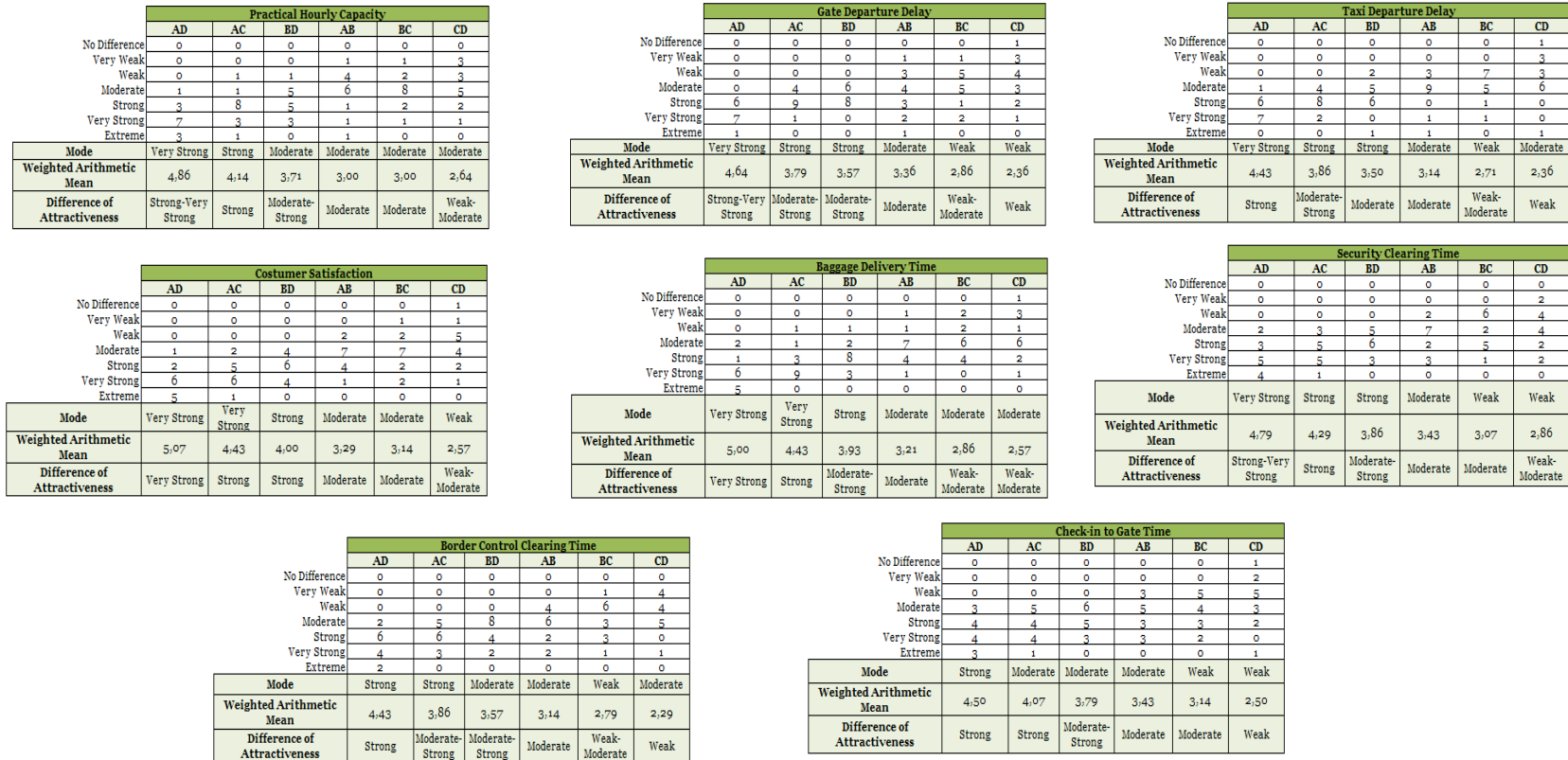


Figure A2. 6 - KPA Service Quality KPI Thermometers Judgement Matrix
Source: Own Elaboration

KPA Financial / Commercial

The KPI Thermometers Judgement Matrix of the KPA Financial / Commercial is built with the nine airport experts answers as distributed as in Figure A2. 7 below.

		Aeronautical Revenue per Passenger					
		AD	AC	BD	AB	BC	CD
No Difference	0	0	0	0	0	0	1
Very Weak	0	0	0	1	2	1	1
Weak	0	1	1	2	0	0	0
Moderate	1	2	1	3	4	5	0
Strong	2	3	2	3	3	2	2
Very Strong	3	2	2	0	0	0	0
Extreme	3	1	0	0	0	0	0
Mode	Very Strong	Strong	Strong	Moderate	Moderate	Moderate	
Weighted Arithmetic Mean	4,89	4,00	3,89	2,89	2,89	2,67	
Difference of Attractiveness	Strong-Very Strong	Strong	Moderate-Strong	Weak-Moderate	Weak-Moderate	Weak-Moderate	

		Aeronautical Revenue per Movement					
		AD	AC	BD	AB	BC	CD
No Difference	0	0	0	0	0	0	0
Very Weak	0	0	0	2	2	2	2
Weak	0	2	2	1	1	1	1
Moderate	3	1	1	3	4	5	0
Strong	0	3	3	3	2	1	0
Very Strong	3	2	3	0	0	0	0
Extreme	3	1	0	0	0	0	0
Mode	Moderate	Strong	Strong	Moderate	Moderate	Moderate	Moderate
Weighted Arithmetic Mean	4,67	3,89	3,78	2,78	2,67	2,56	
Difference of Attractiveness	Strong-Very Strong	Moderate-Strong	Moderate-Strong	Weak-Moderate	Weak-Moderate	Weak-Moderate	

		NON-Aeronautical Operating Revenue as Percentage of Total					
		AD	AC	BD	AB	BC	CD
No Difference	0	0	0	0	0	0	0
Very Weak	0	0	0	1	1	1	2
Weak	0	0	1	1	1	1	2
Moderate	1	2	1	5	7	5	0
Strong	3	4	7	2	0	0	0
Very Strong	3	3	0	0	0	0	0
Extreme	2	0	0	0	0	0	0
Mode	Strong	Strong	Strong	Moderate	Moderate	Moderate	
Weighted Arithmetic Mean	4,67	4,11	3,67	2,89	2,67	2,33	
Difference of Attractiveness	Strong-Very Strong	Strong	Moderate-Strong	Weak-Moderate	Weak-Moderate	Weak-Moderate	

		Non-Aeronautical Operating Revenue per Passenger					
		AD	AC	BD	AB	BC	CD
No Difference	0	0	0	0	0	0	0
Very Weak	0	0	0	1	2	2	2
Weak	0	0	2	3	0	1	1
Moderate	2	3	1	4	6	5	0
Strong	2	4	5	1	1	1	0
Very Strong	4	2	1	0	0	0	0
Extreme	1	0	0	0	0	0	0
Mode	Very Strong	Strong	Strong	Moderate	Moderate	Moderate	
Weighted Arithmetic Mean	4,44	3,89	3,56	2,56	2,67	2,56	
Difference of Attractiveness	Strong	Moderate-Strong	Moderate-Strong	Weak-Moderate	Weak-Moderate	Weak-Moderate	

		Debt Service as Percentage of Operating Revenue					
		AD	AC	BD	AB	BC	CD
No Difference	0	0	0	0	0	0	2
Very Weak	0	0	0	3	3	1	1
Weak	1	3	2	1	2	2	2
Moderate	2	2	4	5	4	4	0
Strong	1	3	3	0	0	0	0
Very Strong	5	1	0	0	0	0	0
Extreme	0	0	0	0	0	0	0
Mode	Very Strong	Weak	Moderate	Moderate	Moderate	Moderate	Moderate
Weighted Arithmetic Mean	4,11	3,22	3,11	2,22	2,11	1,89	
Difference of Attractiveness	Strong	Moderate	Moderate	Weak	Weak	Very Weak	Weak

		Long-Term Debt per Passenger					
		AD	AC	BD	AB	BC	CD
No Difference	0	0	0	0	0	0	0
Very Weak	0	0	0	2	2	2	2
Weak	1	2	1	1	2	3	3
Moderate	2	2	3	4	3	3	0
Strong	2	3	4	2	2	1	0
Very Strong	3	2	1	0	0	0	0
Extreme	1	0	0	0	0	0	0
Mode	Very Strong	Strong	Strong	Moderate	Moderate	Moderate	Weak
Weighted Arithmetic Mean	4,11	3,56	3,56	2,67	2,56	2,33	
Difference of Attractiveness	Strong	Moderate-Strong	Moderate-Strong	Weak-Moderate	Weak-Moderate	Weak-Moderate	Weak

		Debt to EBITDA Ratio					
		AD	AC	BD	AB	BC	CD
No Difference	0	0	0	1	1	1	1
Very Weak	1	1	1	1	1	1	1
Weak	0	1	0	1	1	2	2
Moderate	1	1	2	3	3	3	0
Strong	2	3	4	3	3	2	0
Very Strong	3	2	2	0	0	0	0
Extreme	2	1	0	0	0	0	0
Mode	Very Strong	Strong	Strong	Moderate	Moderate	Moderate	
Weighted Arithmetic Mean	4,33	3,78	3,67	2,67	2,67	2,44	
Difference of Attractiveness	Strong	Moderate-Strong	Moderate-Strong	Weak-Moderate	Weak-Moderate	Weak-Moderate	

		EBITDA per Passenger					
		AD	AC	BD	AB	BC	CD
No Difference	0	0	0	0	0	0	0
Very Weak	0	0	0	0	0	0	1
Weak	0	0	0	1	1	1	2
Moderate	1	1	2	5	5	5	3
Strong	3	6	5	3	3	3	0
Very Strong	3	1	2	0	0	0	0
Extreme	2	1	0	0	0	0	0
Mode	Strong	Strong	Strong	Moderate	Moderate	Moderate	Moderate
Weighted Arithmetic Mean	4,67	4,22	4,00	3,22	3,22	2,89	
Difference of Attractiveness	Strong-Very Strong	Strong	Strong	Moderate	Moderate	Moderate	Weak-Moderate

Figure A2. 7 - KPA Financial / Commercial KPI Thermometers Judgement Matrix
 Source: Own Elaboration

KPA Environmental

The KPI Thermometers Judgement Matrix of the KPA Environmental is built with the eight airport experts answers as distributed as in Figure A2. 8.

Carbon Footprint per Passenger						
	AD	AC	BD	AB	BC	CD
No Difference	0	0	0	0	0	0
Very Weak	0	0	0	0	1	0
Weak	0	0	0	0	0	2
Moderate	0	0	0	3	5	3
Strong	2	3	6	4	1	2
Very Strong	2	4	1	1	1	1
Extreme	4	1	1	0	0	0
Mode	Extreme	Very Strong	Strong	Strong	Moderate	Moderate
Weighted Arithmetic Mean	5,25	4,75	4,38	3,75	3,13	3,25
Difference of Attractiveness	Very Strong	Strong-Very Strong	Strong	Moderate-Strong	Moderate	Moderate

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
Mode	Very Strong	Moderate	Strong	Weak	Weak	Strong
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

Waste Reduction Percentage						
	AD	AC	BD	AB	BC	CD
No Difference	1	1	1	2	2	2
Very Weak	1	1	1	0	0	2
Weak	0	0	0	1	3	2
Moderate	1	2	3	4	2	1
Strong	2	4	3	1	1	1
Very Strong	3	0	0	0	0	0
Extreme	0	0	0	0	0	0
Mode	Very Strong	Strong	Moderate	Moderate	Weak	No Difference
Weighted Arithmetic Mean	3,38	2,88	2,75	2,25	2,00	1,63
Difference of Attractiveness	Moderate	Weak-Moderate	Weak-Moderate	Weak	Weak	Very Weak

Renewable Energy Purchased by the Airport (%)						
	AD	AC	BD	AB	BC	CD
No Difference	1	1	1	1	1	1
Very Weak	0	0	0	0	0	0
Weak	0	0	0	1	2	2
Moderate	0	1	2	5	5	5
Strong	3	6	4	1	0	0
Very Strong	4	0	1	0	0	0
Extreme	0	0	0	0	0	0
Mode	Very Strong	Strong	Strong	Moderate	Moderate	Moderate
Weighted Arithmetic Mean	4,00	3,38	3,38	2,63	2,38	2,38
Difference of Attractiveness	Strong	Moderate	Moderate	Weak-Moderate	Weak	Weak

Utilities / Energy Usage per Square Meter of Terminal						
	AD	AC	BD	AB	BC	CD
No Difference	0	0	0	0	0	1
Very Weak	0	0	0	0	1	0
Weak	0	0	0	2	2	3
Moderate	0	2	2	4	4	3
Strong	4	4	5	2	1	1
Very Strong	3	2	1	0	0	0
Extreme	1	0	0	0	0	0
Mode	Strong	Strong	Strong	Moderate	Moderate	Weak
Weighted Arithmetic Mean	4,63	4,00	3,88	3,00	2,63	2,38
Difference of Attractiveness	Strong-Very Strong	Strong	Moderate-Strong	Moderate	Weak-Moderate	Weak

Water Consumption per Passenger						
	AD	AC	BD	AB	BC	CD
No Difference	1	1	1	1	1	1
Very Weak	0	0	0	2	2	2
Weak	0	0	2	1	1	1
Moderate	2	2	0	1	3	3
Strong	0	3	4	3	1	1
Very Strong	2	2	1	0	0	0
Extreme	3	0	0	0	0	0
Mode	Extreme	Strong	Strong	Strong	Moderate	Moderate
Weighted Arithmetic Mean	4,25	3,50	3,13	2,38	2,13	2,13
Difference of Attractiveness	Strong	Moderate	Moderate	Weak	Weak	Weak

Figure A2. 8 - KPA Environmental KPI Thermometers Judgement Matrix
Source: Own Elaboration

A2.2.2 – KPA - Status Quo

Key Performance Areas - Status Quo depicted in Figure A2. 9, with Answers = 19

	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
Mode	Very Strong (5)	Very Strong (5)	Strong (4)	Very Strong (5)	Very Strong (5)	Weak (2)
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

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

Figure A2. 9 - Key Performance Areas - Status Quo
Source: Own Elaboration

A2.2.3 –KPI - Status Quo

Key Performance Indicators - Status Quo (1/3) Figure A2. 10

**Safety and Security
Answers = 19**

	Runway Accidents	Runway Incursions	Bird Strikes	Public Injuries	Occupational Injuries	Lost Work Time from Employee Accidents and Injuries
Very Weak	0	0	0	0	0	0
Weak	0	0	3	2	1	1
Moderate	0	1	1	4	7	9
Strong	2	3	6	5	5	6
Very Strong	6	10	4	4	3	2
Extreme	11	5	5	4	3	1
Mode	Extreme (6)	Very Strong (5)	Strong (4)	Strong (4)	Moderate (3)	Moderate (3)
Weighted Arithmetic Mean	5,47	5,00	4,37	4,21	4,00	3,63
All Worst	Very Strong	Very Strong	Strong	Strong	Strong	Moderate-Strong

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

**CORE
Answers = 19**

	Passengers	Origination and Destination Passengers	Aircraft Movements	Freight and Mail Loaded / Unloaded	Nonstop Destinations
Very Weak	0	0	0	0	1
Weak	0	1	0	2	2
Moderate	0	0	2	5	5
Strong	0	8	0	3	7
Very Strong	10	7	14	9	2
Extreme	9	3	3	0	2
Mode	Very Strong (5)	Strong (4)	Very Strong (5)	Very Strong (5)	Strong (4)
Weighted Arithmetic Mean	5,47	4,58	4,95	4,00	3,68
All Worst	Very Strong	Strong-Very Strong	Strong-Very Strong	Strong	Moderate-Strong

Core	Status Quo
Passengers	5,47
Aircraft Movements	4,95
Aircraft Movements	4,58
Freight and Mail Loaded / Unloaded	4,00
Nonstop Destinations	3,68

**Figure A2. 10 - Key Performance Indicators - Status Quo: Safety and Security and CORE KPA
Source: Own Elaboration**

Key Performance Indicators - Status Quo (2/3) Figure A2. 11

Productivity / Cost Effectiveness
Answers = 12

	Passengers per Employee	Aircraft Movements per Employee	Aircraft Movements per Gate	Total Cost per Passenger	Total Cost per Movement	Total Cost per WLU	Operating Cost per Passenger	Operating Cost per Movement
Very Weak	1	1	0	0	0	0	0	0
Weak	1	0	0	0	0	0	1	0
Moderate	1	3	2	0	0	2	0	0
Strong	3	2	3	2	4	5	5	5
Very Strong	5	5	7	8	7	3	6	6
Extreme	1	1	0	2	1	2	0	1
Mode	Very Strong (5)	Very Strong (5)	Very Strong (5)	Very Strong (5)	Very Strong (5)	Strong (4)	Very Strong (5)	Very Strong (5)
Weighted Arithmetic Mean	4,08	4,08	4,42	5,00	4,75	4,42	4,33	4,67
All Worst	Strong	Strong	Strong	Very Strong	Strong-Very Strong	Strong	Strong	Strong-Very Strong

Productivity / Cost Effectiveness		Status Quo
Total Cost per Passenger		5,00
Total Cost per Movement		4,75
Operating Cost per Movement		4,67
Aircraft Movements per Gate		4,42
Total Cost per WLU		4,42
Operating Cost per WLU		4,42
Operating Cost per Passenger		4,33
Passengers per Employee		4,08
Aircraft Movements per Employee		4,08

Service Quality
Answers = 14

	Practical Hourly Capacity	Gate Departure Delay	Taxi Departure Delay	Customer Satisfaction	Baggage Delivery Time	Security Clearing Time	Border Control Clearing Time	Check-in to Gate Time
Very Weak	1	0	0	0	0	0	0	0
Weak	2	1	0	0	0	0	0	0
Moderate	2	1	3	2	2	2	3	5
Strong	2	4	5	3	5	7	6	3
Very Strong	4	4	4	3	6	4	5	5
Extreme	3	4	2	6	1	1	0	1
Mode	Very Strong (5)	Strong (4)	Strong (4)	Extreme (6)	Very Strong (5)	Strong (4)	Strong (4)	Moderate (3)
Weighted Arithmetic Mean	4,07	4,64	4,36	4,93	4,43	4,29	4,14	4,14
All Worst	Strong	Strong-Very Strong	Strong	Strong-Very Strong	Strong	Strong	Strong	Strong

Service Quality		Status Quo
Customer Satisfaction		4,93
Gate Departure Delay		4,64
Baggage Delivery Time		4,43
Taxi Departure Delay		4,36
Security Clearing Time		4,29
Border Control Clearing Time		4,14
Check-in to Gate Time		4,14
Practical Hourly Capacity		4,07

Figure A2. 11 - Key Performance Indicators - Status Quo: Productivity / Cost Effectiveness and Service Quality KPA
Source: Own Elaboration

Key Performance Indicators - Status Quo (3/3) Figure A2. 12

Financial / Commercial
Answers = 9

	Aeronautical Revenue per Passenger	Aeronautical Revenue per Movement	Non-Aeronautical Operating Revenue as Percentage of Total Operating Revenue	Non-Aeronautical Operating Revenue per Passenger	Debt Service as Percentage of Total Operating Revenue	Long-Term Debt per Passenger	Debt to EBITDA Ratio	EBITDA per Passenger
Very Weak	0	0	0	0	0	0	0	0
Weak	0	0	0	0	0	2	1	1
Moderate	0	0	1	1	2	2	1	0
Strong	1	1	4	3	3	2	2	2
Very Strong	3	4	2	2	3	2	2	3
Extreme	5	4	2	3	1	1	3	3
Mode	Extreme (6)	Very Strong (5)	Strong (4)	Strong (4)	Strong (4)	Weak (2)	Extreme (6)	Very Strong (5)
Weighted Arithmetic Mean	5,44	5,33	4,56	4,78	4,33	3,78	4,56	4,78
All Worst	Very Strong	Very Strong	Strong-Very Strong	Strong-Very Strong	Strong	Moderate-Strong	Strong-Very Strong	Strong-Very Strong

Financial / Commercial	Status Quo
Aeronautical Revenue per Passenger	5,44
Aeronautical Revenue per Movement	5,33
Non-Aeronautical Operating Revenue per Passenger	4,78
EBITDA per Passenger	4,78
Non-Aeronautical Operating Revenue as Percentage of Total Operating Revenue	4,56
Debt to EBITDA Ratio	4,56
Debt Service as Percentage of Total Operating Revenue	4,33
Long-Term Debt per Passenger	3,78

Environmental
Answers = 8

	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
Mode	Very Strong (5)	Strong (4)	Strong (4)	Strong (4)	Strong (4)	Moderate (3)
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

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

Figure A2. 12 - Key Performance Indicators - Status Quo: Financial / Commercial and Environmental KPA
Source: Own Elaboration

A2.3. – Airports Evaluation

Step 4 evaluation, the criteria functions and the KPIs, KPAs and airport’s judgment matrices are constructed using the performance descriptors and the ordinal value scales are depicted in Table A2. 1 – A2.3 and Figures A2.13-A2.20.

A2.3.1 – Value Functions

Table A2. 1 - Airport in study KPI value functions (1/3)
Source: Own Elaboration

Safety and Security					CORE						
Runway Accidents					Passengers						
L4	0,0000		0,0020	0,0040	0,0060	L4	16024950		13895433	11765917	9636400
L3	0,0020	0,0000	Moderate	Strang	Strang-Very Strang	L3	13895433	16024950	Moderate	Strang	Strang-Very Strang
L2	0,0040		0,0020	Moderate	Moderate-Strang	L2	11765917		13895433	Moderate	Strang
L1	0,0060			0,0040	Weak-Moderate	L1	9636400			11765917	Moderate
Runway Incursions					Originations and Destination Passengers						
L4	0,0556		0,0637	0,0717	0,0798	L4	16009049		13840033	11671016	9502000
L3	0,0637	0,0556	Moderate	Moderate-Strang	Strang-Very Strang	L3	13840033	16009049	Moderate	Strang	Strang-Very Strang
L2	0,0717		0,0637	Moderate	Moderate-Strang	L2	11671016		13840033	Moderate	Moderate-Strang
L1	0,0798			0,0717	Moderate	L1	9502000			11671016	Moderate
Bird Striker					Aircraft Movements						
L4	0,2640		0,4470	0,6300	0,8130	L4	146360		135073	123787	112500
L3	0,4470	0,2640	Weak-Moderate	Moderate-Strang	Strang-Very Strang	L3	135073	146360	Moderate-Strang	Strang	Very Strang
L2	0,6300		0,4470	Weak-Moderate	Moderate-Strang	L2	123787		135073	Moderate	Strang
L1	0,8130			0,6300	Weak-Moderate	L1	112500			123787	Moderate
Public Injuries					Freight and Mail Loaded / Unloaded						
L4	0,0984		0,2455	0,3927	0,5399	L4	105304		100297	95289	90282
L3	0,2455	0,0984	Moderate	Moderate-Strang	Strang	L3	100297	105304	Moderate	Moderate-Strang	Strang-Very Strang
L2	0,3927		0,2455	Weak-Moderate	Moderate-Strang	L2	95289		100297	Weak-Moderate	Moderate-Strang
L1	0,5399			0,3927	Weak-Moderate	L1	90282			95289	Weak-Moderate
Occupational Injuries					Hourly Destinations						
L4	0,5330		0,8580	1,1830	1,5080	L4	112		99	87	74
L3	0,8580	0,5330	Weak-Moderate	Moderate	Strang	L3	99	112	Moderate	Moderate-Strang	Strang
L2	1,1830		0,8580	Weak	Moderate	L2	87		99	Weak-Moderate	Moderate-Strang
L1	1,5080			1,1830	Weak	L1	74			87	Weak-Moderate
Lost Work Time from Employee Accidents and Injuries											
L4	1,8895		4,47	7,06	9,64						
L3	4,4723	1,8895	Weak-Moderate	Moderate	Strang						
L2	7,0552		4,47	Weak	Moderate						
L1	9,6380			7,06	Weak						

Table A2. 2 - Airport in study KPI value functions (2/3)
Source: Own Elaboration

Productivity / Cost Effectiveness					Service Quality						
Passengers per Employee					Practical Hourly Capacity						
L4	23775,89		20769,63	17763,38	14757,12	L4	45,00		42,33	39,67	37,00
L3	20769,63	23775,89	Weak-Moderate	Moderate-Strong	Strong-Very Strong	L3	42,33	45,00	Moderate	Strong	Strong-Very Strong
L2	17763,38		20769,63	Weak-Moderate	Moderate	L2	39,67		42,33	Moderate	Moderate-Strong
L1	14757,12			17763,38	Weak-Moderate	L1	37,00			39,67	Weak-Moderate
Aircraft Movements per Employee					Gate Departure Delay						
L4	217,15		202,19	187,24	172,28	L4	9,80		11,33	12,87	14,40
L3	202,19	217,15	Weak-Moderate	Moderate-Strong	Strong	L3	11,33	9,80	Moderate	Moderate-Strong	Strong-Very Strong
L2	187,24		202,19	Weak-Moderate	Moderate-Strong	L2	12,87		11,33	Weak-Moderate	Moderate-Strong
L1	172,28			187,24	Weak-Moderate	L1	14,40			12,87	Weak
Aircraft Movements per Gate					Taxi Departure Delay						
L4	5554,55		4624,01	3693,48	2762,94	L4	1,40		2,10	2,80	3,50
L3	4624,01	5554,55	Weak	Moderate-Strong	Strong	L3	2,10	1,40	Moderate	Moderate-Strong	Strong
L2	3693,48		4624,01	Weak-Moderate	Moderate	L2	2,80		2,10	Weak-Moderate	Moderate
L1	2762,94			3693,48	Weak-Moderate	L1	3,50			2,80	Weak
Total Cost per Passenger					Customer Satisfaction						
L4	14,56		16,20	17,83	19,47	L4	74,10		71,20	68,30	65,40
L3	16,20	14,56	Moderate	Strong	Strong-Very Strong	L3	71,20	74,10	Moderate	Strong	Very Strong
L2	17,83		16,20	Weak-Moderate	Strong	L2	68,30		71,20	Moderate	Strong
L1	19,47			17,83	Moderate	L1	65,40			68,30	Weak-Moderate
Total Cost per Movement											
L4	1471,46		1580,06	1688,66	1797,26						
L3	1580,06	1471,46	Moderate	Strong	Strong-Very Strong						
L2	1688,66		1580,06	Moderate	Strong						
L1	1797,26			1688,66	Moderate						
Total Cost per WLU											
L4	11,42		14,04	16,66	19,29						
L3	14,04	11,42	Weak-Moderate	Moderate-Strong	Strong						
L2	16,66		14,04	Weak-Moderate	Moderate-Strong						
L1	19,29			16,66	Weak						

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Productivity / Cost Effectiveness					Service Quality						
Operating Cost per Passenger					Baggage Delivery Time						
L4	3,95		3,86	4,67	5,48	L4	17,50		23,00	28,50	34,00
L3	3,86	3,95	Weak-Moderate	Moderate-Strong	Strong-Very Strong	L3	23,00	17,50	Moderate	Strong	Very Strong
L2	4,67		3,86	Weak-Moderate	Moderate	L2	28,50		23,00	Weak-Moderate	Moderate-Strong
L1	5,48			4,67	Weak-Moderate	L1	34,00			28,50	Weak-Moderate
Operating Cost per Movement					Security Clearing Time						
L4	305,93		369,68	433,44	497,20	L4	20,50		22,53	24,57	26,60
L3	369,68	305,93	Moderate	Strong	Strong-Very Strong	L3	22,53	20,50	Moderate	Strong	Strong-Very Strong
L2	433,44		369,68	Moderate	Moderate-Strong	L2	24,57		22,53	Moderate	Moderate-Strong
L1	497,20			433,44	Weak-Moderate	L1	26,60			24,57	Weak-Moderate
Operating Cost per WLU					Border Control Clearing Time						
L4	2,39		3,55	4,72	5,88	L4	6,70		8,60	10,50	12,40
L3	3,55	2,39	Weak-Moderate	Moderate-Strong	Strong-Very Strong	L3	8,60	6,70	Moderate	Moderate-Strong	Strong
L2	4,72		3,55	Moderate	Moderate-Strong	L2	10,50		8,60	Weak-Moderate	Moderate-Strong
L1	5,88			4,72	Moderate	L1	12,40			10,50	Weak
					Check-in to Gate Time						
L4	17,50		20,10	22,70	25,30	L4	17,50		20,10	22,70	25,30
L3	20,10	17,50	Moderate	Strong	Strong	L3	20,10	17,50	Moderate	Strong	Strong
L2	22,70		20,10	Moderate	Moderate-Strong	L2	22,70		20,10	Moderate	Moderate-Strong
L1	25,30			22,70	Weak	L1	25,30			22,70	Weak

Table A2. 3 - Airport in study KPI value functions (3/3)
Source: Own Elaboration

Financial / Commercial					Environmental								
Aeronautical Revenue per Passenger					Carbon Footprint per Passenger								
L4	9,60		8,50	7,40	6,29	L4	0,000190	0,000242	0,000294	0,000346			
L3	8,50	9,60	Weak-Moderate	Strong	Strong-Very Strong	L3	0,000242	0,000190	Moderate-Strong	Strong-Very Strong	Very Strong		
L2	7,40		8,50	Weak-Moderate	Moderate-Strong	L2	0,000294		0,000242	Moderate	Strong		
L1	6,29			7,40	Weak-Moderate	L1	0,000346			0,000294	Moderate		
Aeronautical Revenue per Movement					Waste Recycling								
L4	822,22		777,29	732,36	687,42	L4	30,84		22,49	14,13	5,78		
L3	777,29	822,22	Weak-Moderate	Moderate-Strong	Strong-Very Strong	L3	22,49	30,84	Weak-Moderate	Moderate-Strong	Strong		
L2	732,36		777,29	Weak-Moderate	Moderate-Strong	L2	14,13		22,49	Weak	Moderate		
L1	687,42			732,36	Weak-Moderate	L1	5,78			14,13	Weak		
Non-Aeronautical Operating Revenue as Percentage of Total Operating Revenue					Waste Reduction Percentage								
L4	0,3582		0,3461	0,3340	0,3220	L4	27,63		13,58	-0,48	-14,53		
L3	0,3461	0,3582	Weak-Moderate	Strong	Strong-Very Strong	L3	13,58	27,63	Weak	Weak-Moderate	Moderate		
L2	0,3340		0,3461	Weak-Moderate	Moderate-Strong	L2	-0,48		13,58	Weak	Weak-Moderate		
L1	0,3220			0,3340	Weak	L1	-14,53			-0,48	Very Weak-Weak		
Non-Aeronautical Operating Revenue per Passenger					Renewable Energy Purchased by the Airport (%)								
L4	4,22		4,00	3,79	3,57	L4	73,10		56,80	40,50	24,20		
L3	4,00	4,22	Weak-Moderate	Moderate-Strong	Strong	L3	56,80	73,10	Weak-Moderate	Moderate	Strong		
L2	3,79		4,00	Weak-Moderate	Moderate-Strong	L2	40,50		56,80	Weak	Moderate		
L1	3,57			3,79	Weak-Moderate	L1	24,20			40,50	Weak		
Debt Service as Percentage of Total Operating Revenue					Utilities/Energy Usage per Square Meter of Terminal								
L4	0,23		0,2785	0,3227	0,3670	L4	417,73		479,85	541,96	604,08		
L3	0,28	0,2342	Weak	Moderate	Strong	L3	479,85	417,73	Moderate	Strong	Strong-Very Strong		
L2	0,32		0,2785	Weak	Moderate	L2	541,96		479,85	Weak-Moderate	Moderate-Strong		
L1	0,37			0,3227	Very Weak-Weak	L1	604,08			541,96	Weak		
					Water Consumption per Passenger								
L4	30,60				33,73	36,87	40,00	L4	30,60		33,73	36,87	40,00
L3	33,73	30,60	Weak	Moderate	Strong	L3	33,73	30,60	Weak	Moderate	Strong		
L2	36,87				33,73	36,87	L2	36,87		33,73	Weak	Moderate	
L1	40,00					36,87	L1	40,00			36,87	Weak	

Air Transport Performance and Global Decision Analysis

Financial / Commercial					Environmental				
Long-Term Debt per Passenger									
L4	9,02		23,63	38,24	52,84				
L3	23,63	9,02	Weak-Moderate	Moderate-Strong	Strong				
L2	38,24		23,63	Weak-Moderate	Moderate-Strong				
L1	52,84			38,24	Weak				
Debt to EBITDA Ratio									
L4	2,54		6,67	10,80	14,92				
L3	6,67	2,54	Weak-Moderate	Moderate-Strong	Strong				
L2	10,80		6,67	Weak-Moderate	Moderate-Strong				
L1	14,92			10,80	Weak				
EBITDA per Passenger									
L4	5,04		4,42	3,81	3,20				
L3	4,42	5,04	Moderate	Strong	Strong-Very Strong				
L2	3,81		4,42	Moderate	Strong				
L1	3,20			3,81	Weak-Moderate				

A2.3.2 – Key Performance Areas Judgement Matrix and Weights Ponderations



Figure A2. 13 - Key Performance Areas Judgement Matrix and Weights Ponderations
 Source: Own Elaboration

A2.3.3 – Key Performance Indicators Judgement Matrix and Weights Ponderation

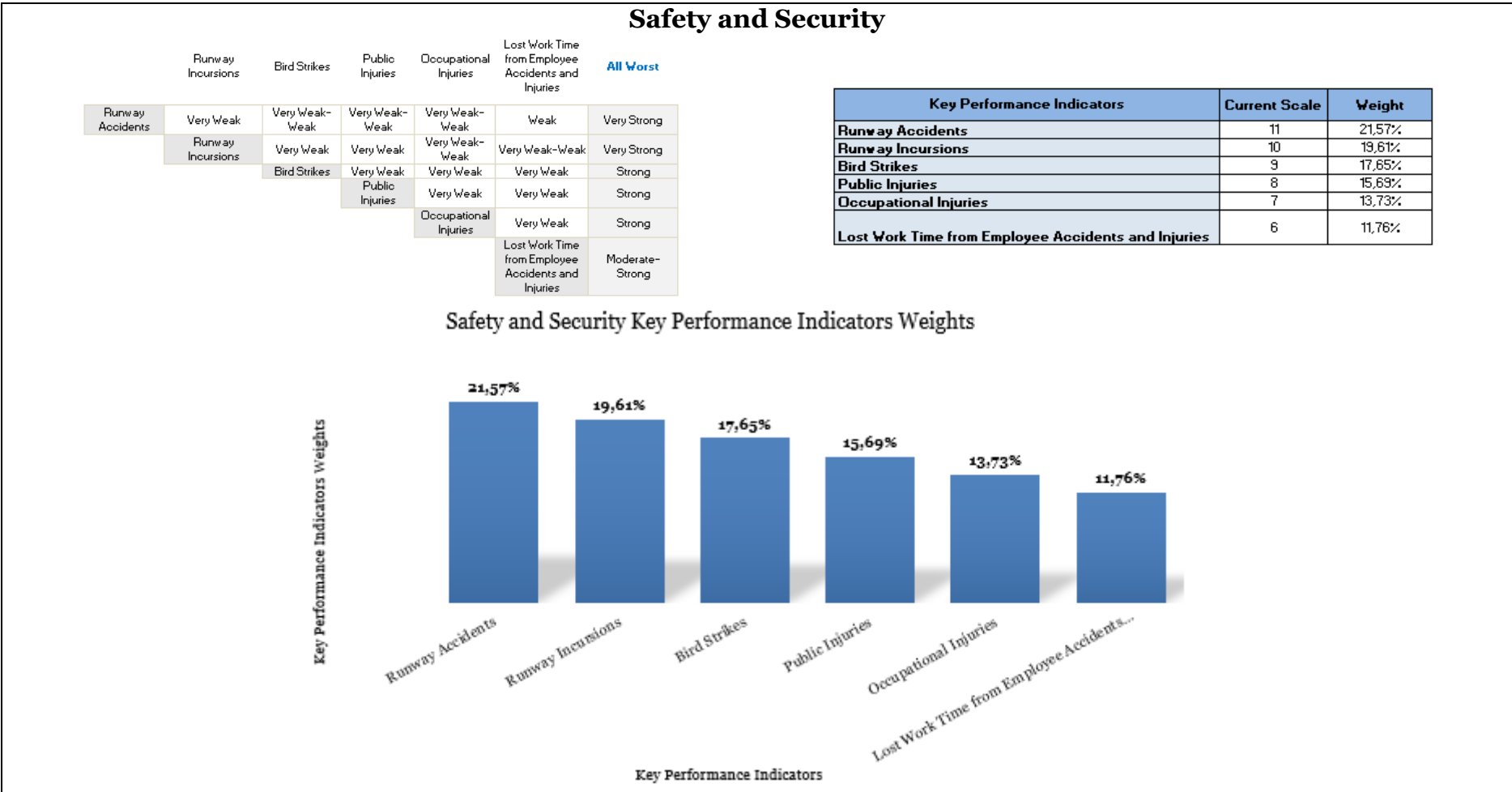


Figure A2. 14 - Key Performance Indicators Judgement Matrix and Weights Ponderation For Safety and Security KPA
 Source: Own Elaboration

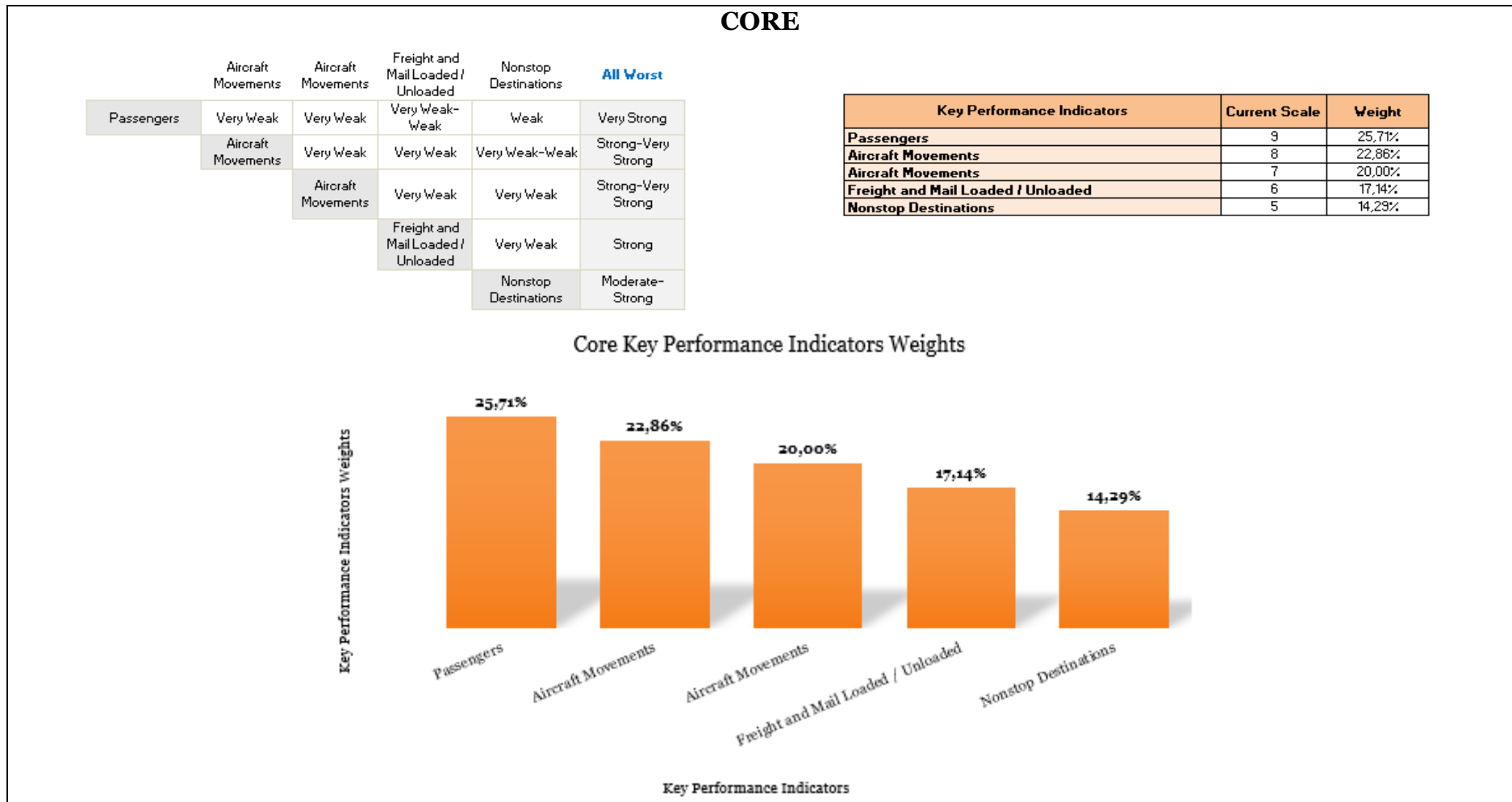


Figure A2. 15 - Key Performance Indicators Judgement Matrix and Weights Ponderation for CORE KPA
 Source: Own Elaboration

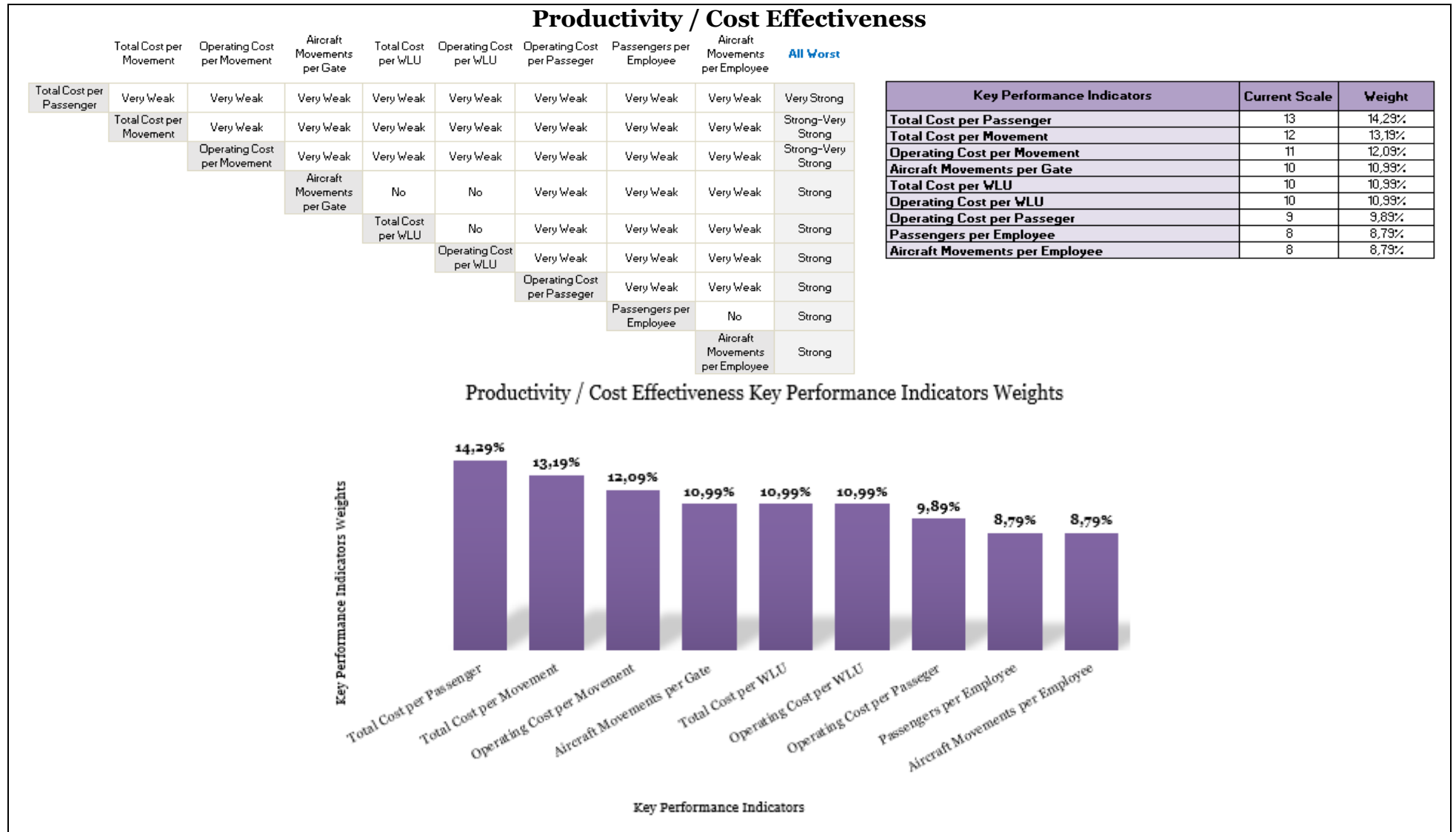


Figure A2. 16 - Key Performance Indicators Judgement Matrix and Weights Ponderation for Productivity / Cost Effectiveness KPA
 Source: Own Elaboration

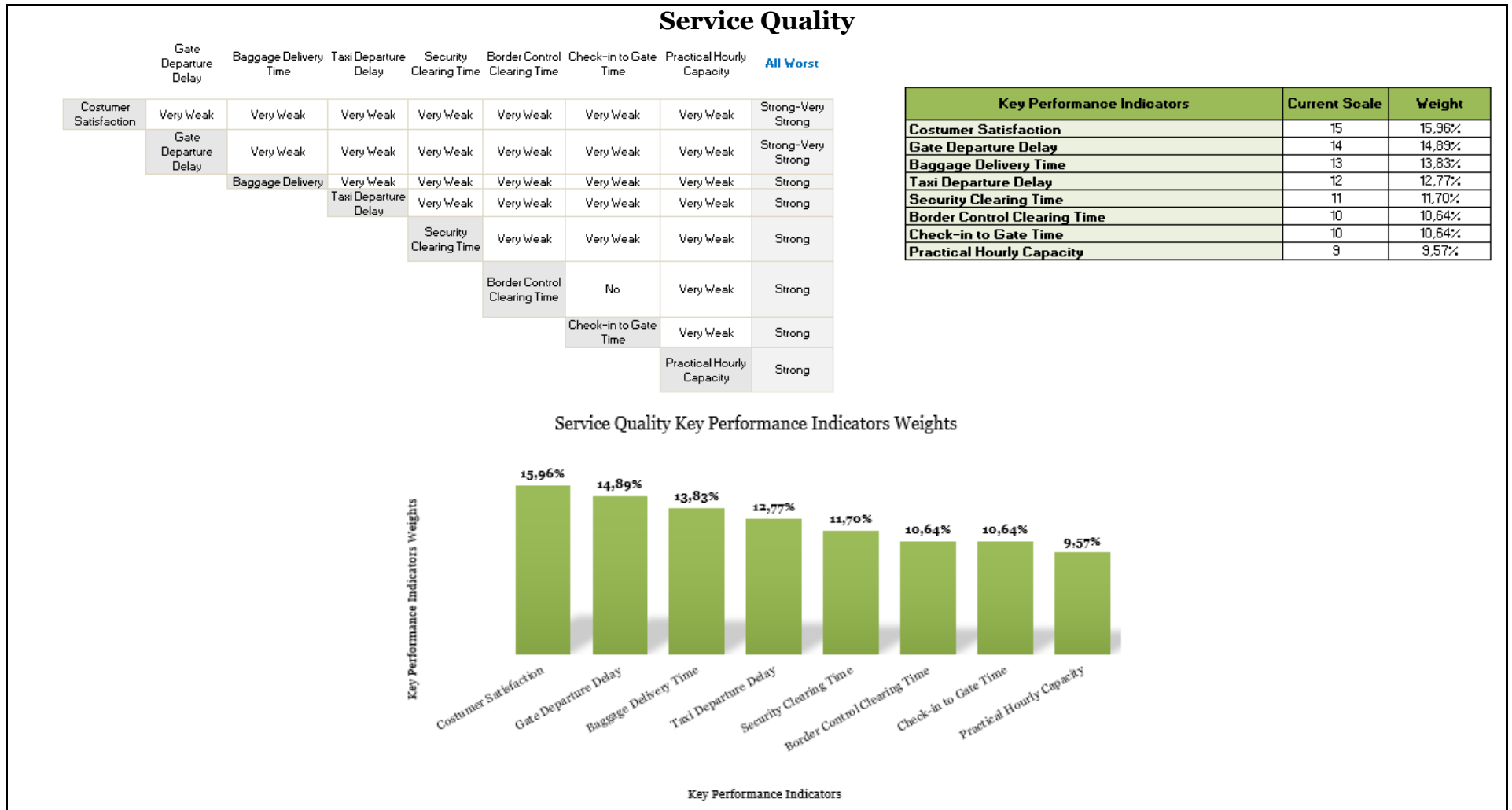


Figure A2. 17 - Key Performance Indicators Judgement Matrix and Weights Ponderation for Service Quality KPA
Source: Own Elaboration

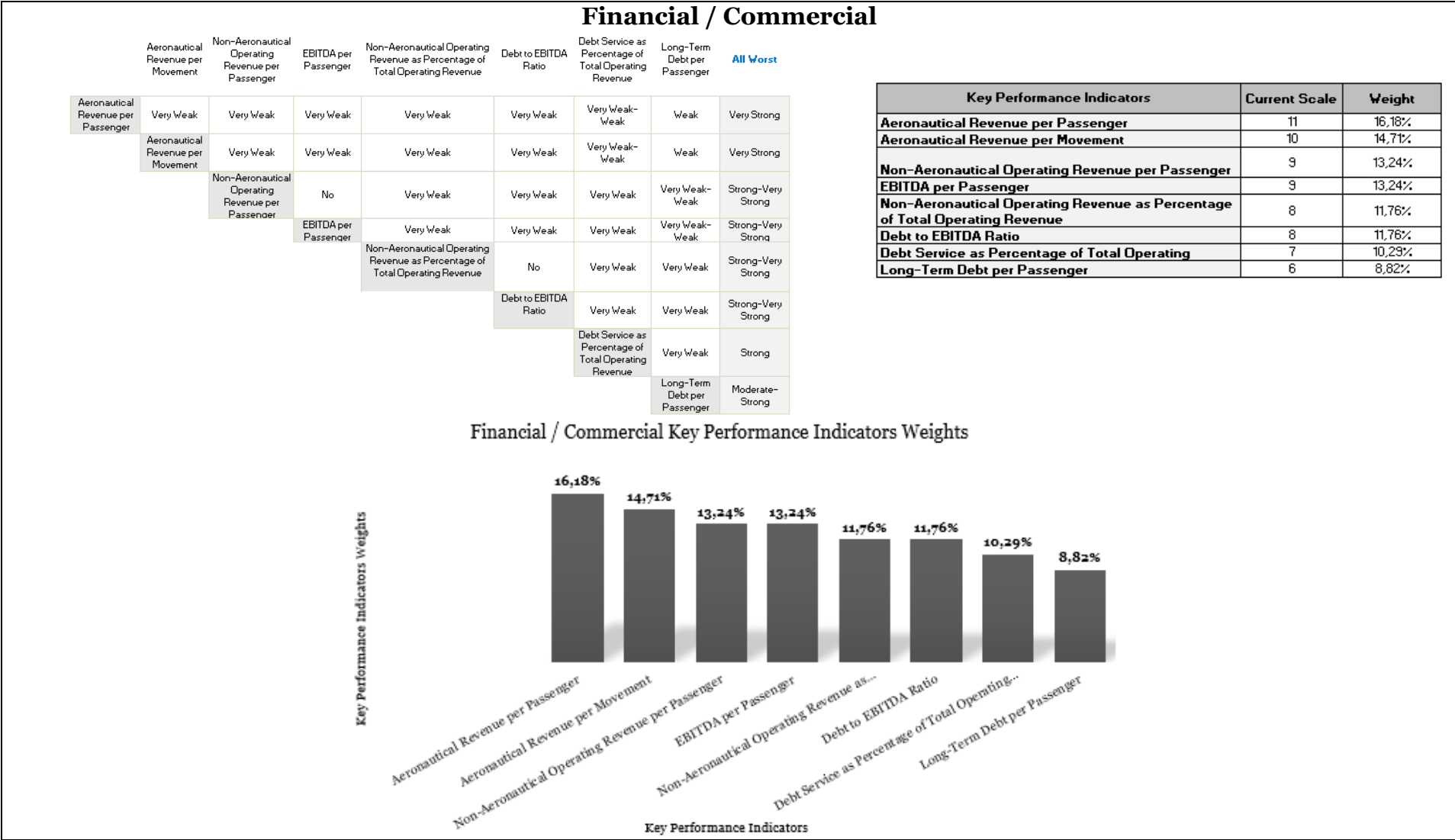


Figure A2. 18 - Key Performance Indicators Judgement Matrix and Weights Ponderation for Financial / Commercial KPA
 Source: Own Elaboration

Environmental

		Waste Recycling	Renewable Energy Purchased by the Airport (%)	Waste Reduction Percentage	Utilities / Energy Usage per Square Meter of Terminal	Water Consumption per Passenger	All Worst
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	

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%

Environmental Key Performance Indicators Weights

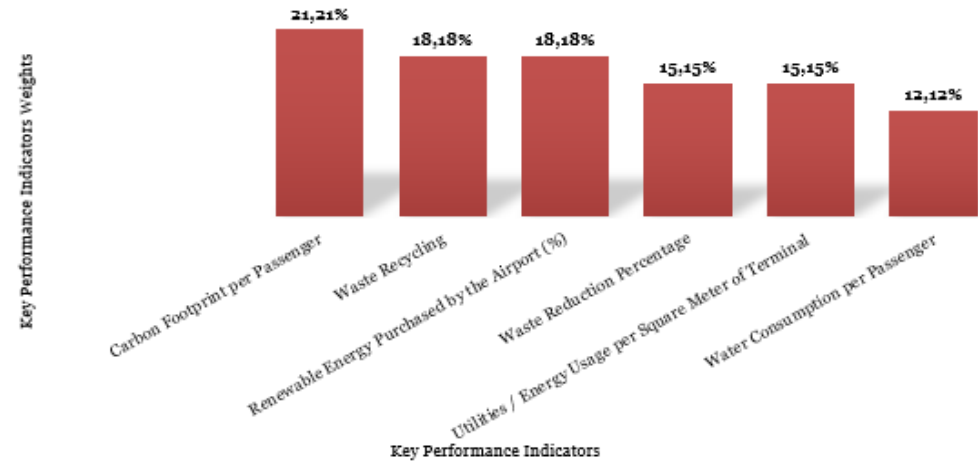


Figure A2. 19 - Key Performance Indicators Judgement Matrix and Weights Ponderation for Environmental KPA
 Source: Own Elaboration

A2.3.4 – Airports Judgement Matrix and Weights Ponderation

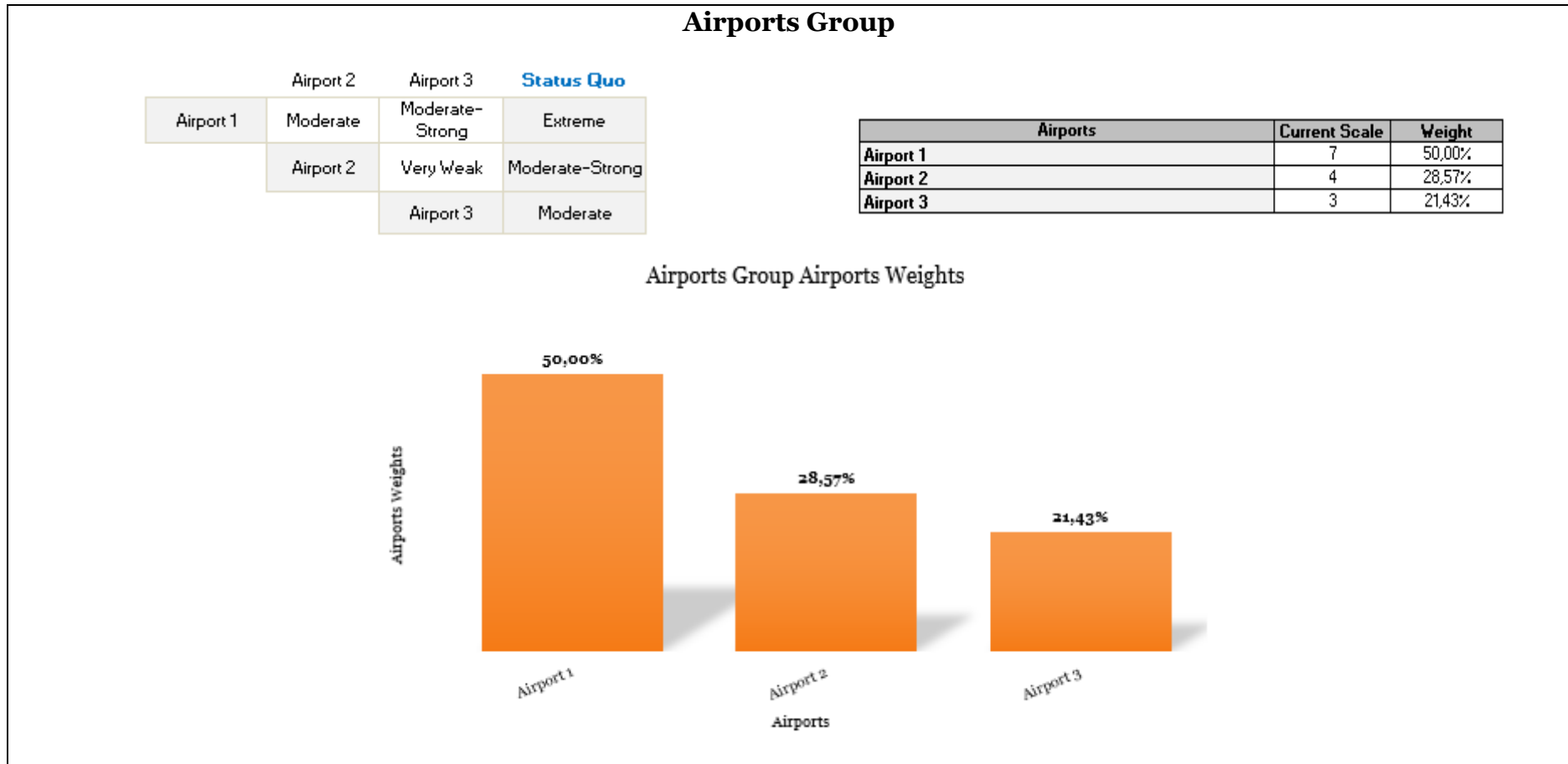


Figure A2. 20 - Airports Judgement Matrix and Weights Ponderation
Source: Own Elaboration

A2.4 – Airports Classification

Airports Classification (Step 5) uses the value functions, and weight ponderations from step 4 to obtain each KPI, KPA and airport score for each option are depicted in Figures A2.21 – A2.36.

A2.4.1 – Value Scores

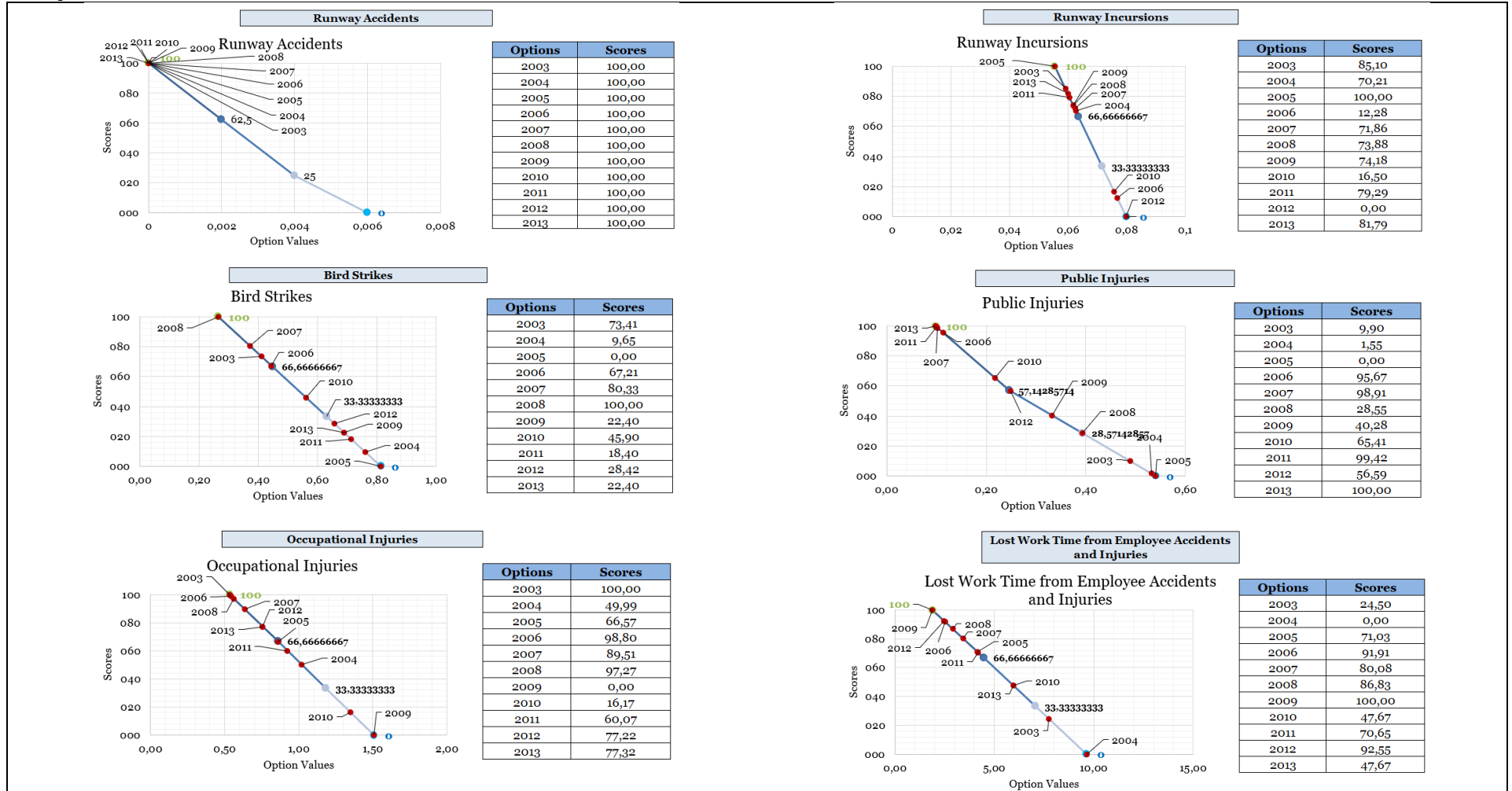


Figure A2. 21 - AIRPORT IN STUDY (1/6) – Safety and Security KPI value funcios
Source: Own Elaboration

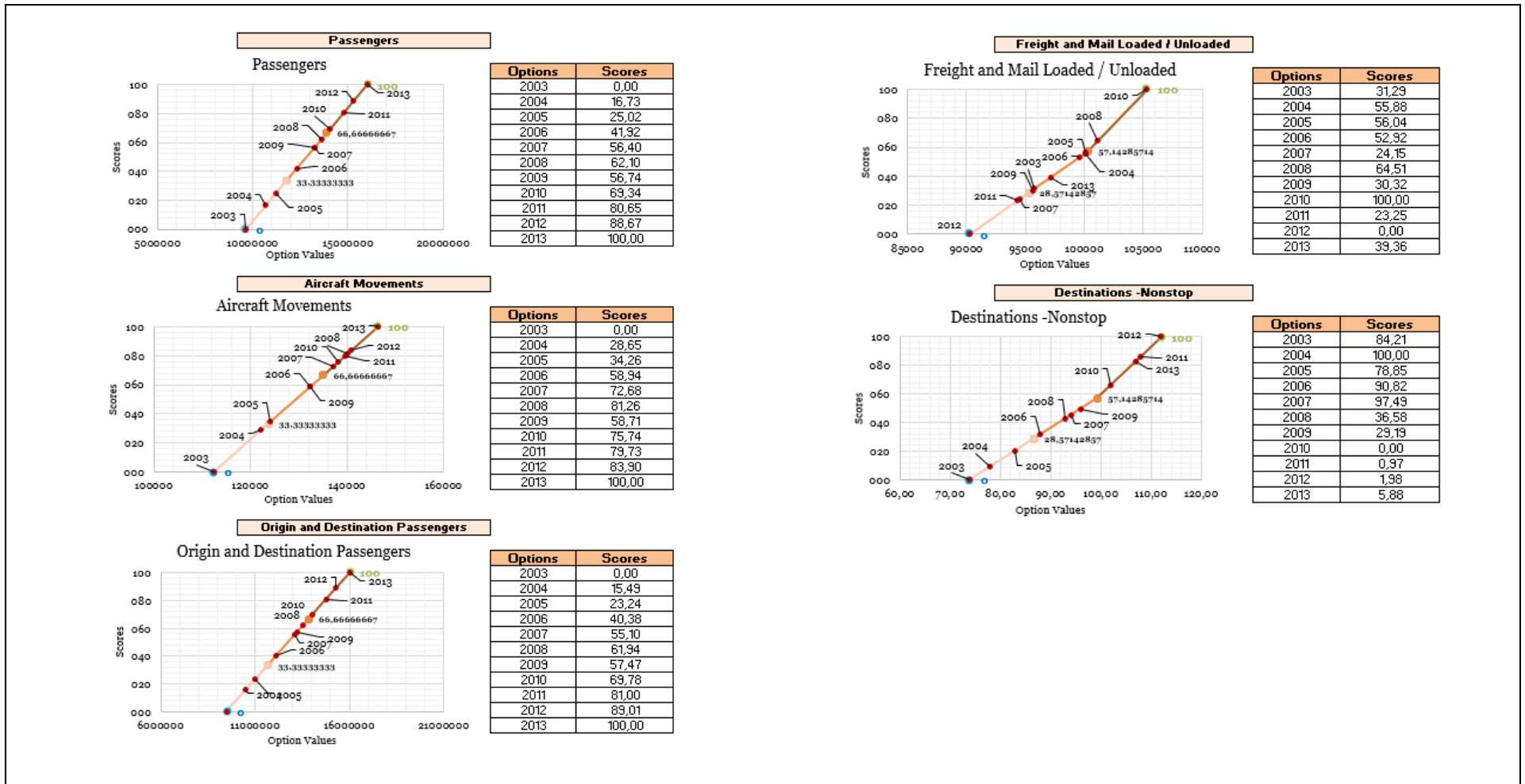


Figure A2. 22 - AIRPORT IN STUDY (2/6) – CORE KPI value functions
Source: Own Elaboration

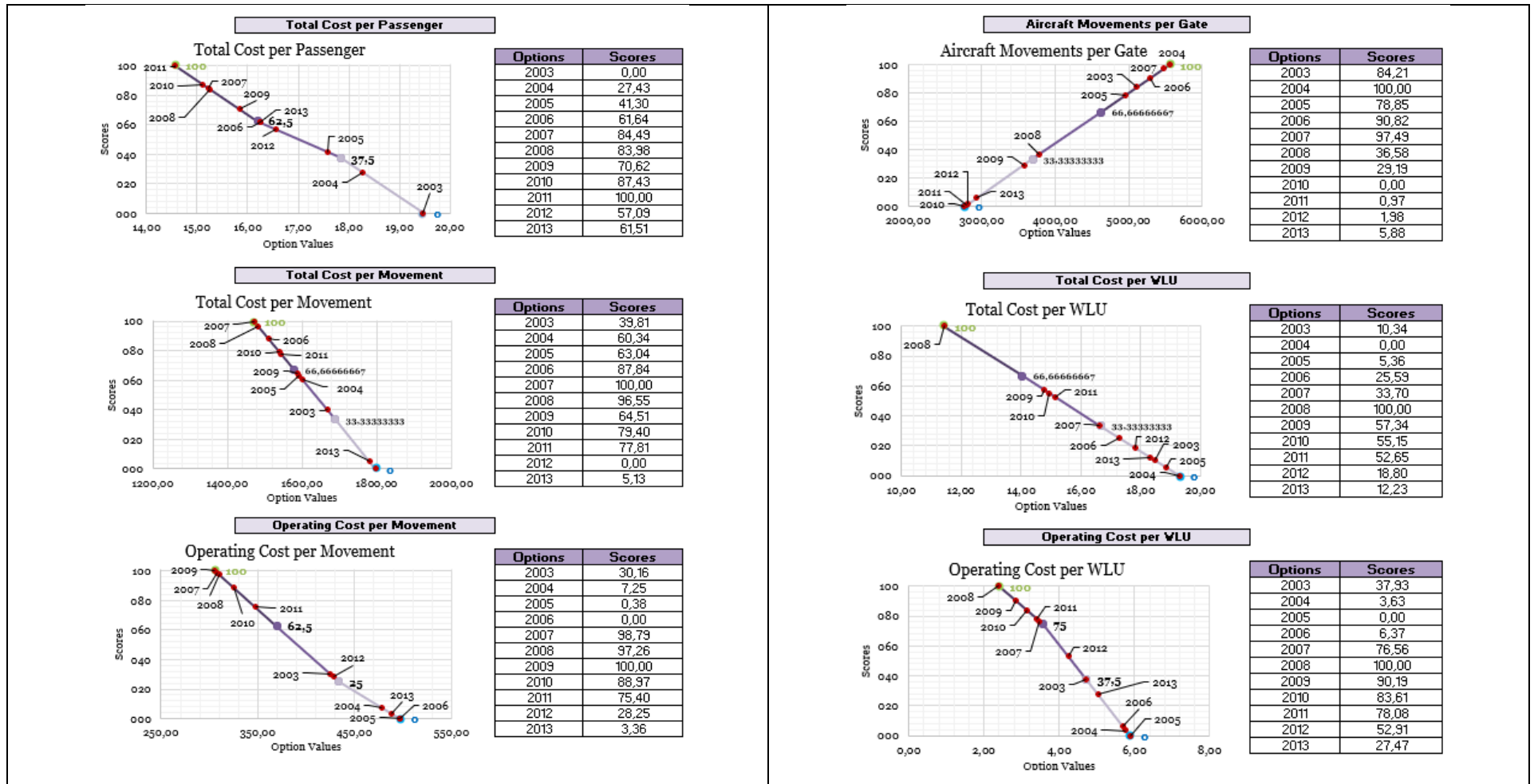


Figure A2. 23 - AIRPORT IN STUDY (3-1/6) – Productivity / Cost Effectiveness KPI value functions
Source: Own Elaboration

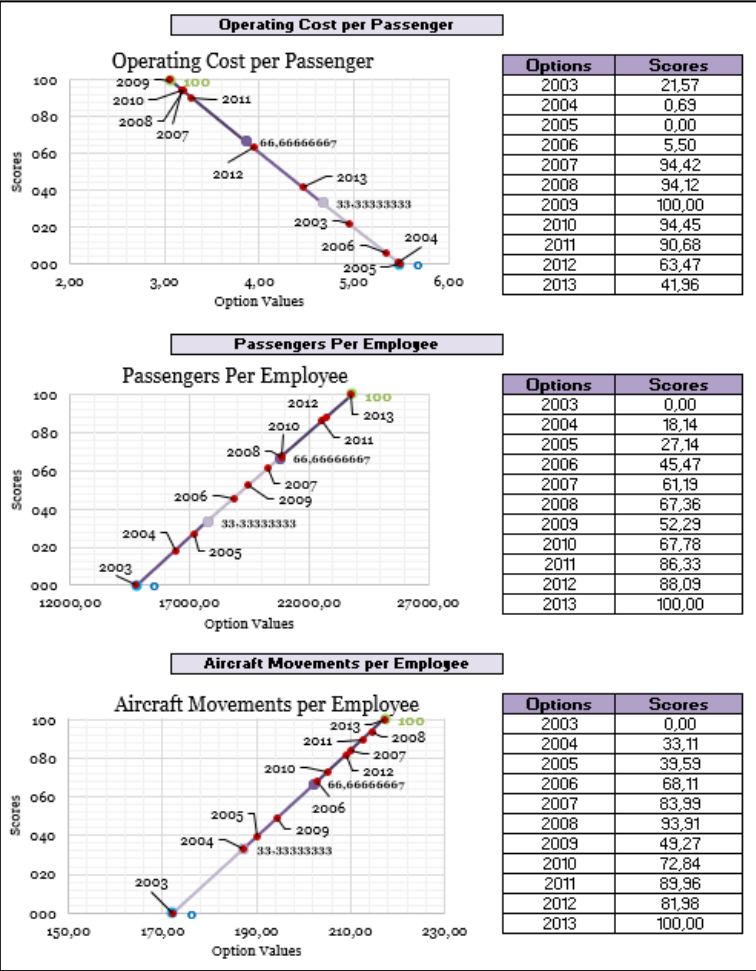


Figure A2. 24 - AIRPORT IN STUDY (3-2/6) – Productivity / Cost Effectiveness KPI value functions
 Source: Own Elaboration

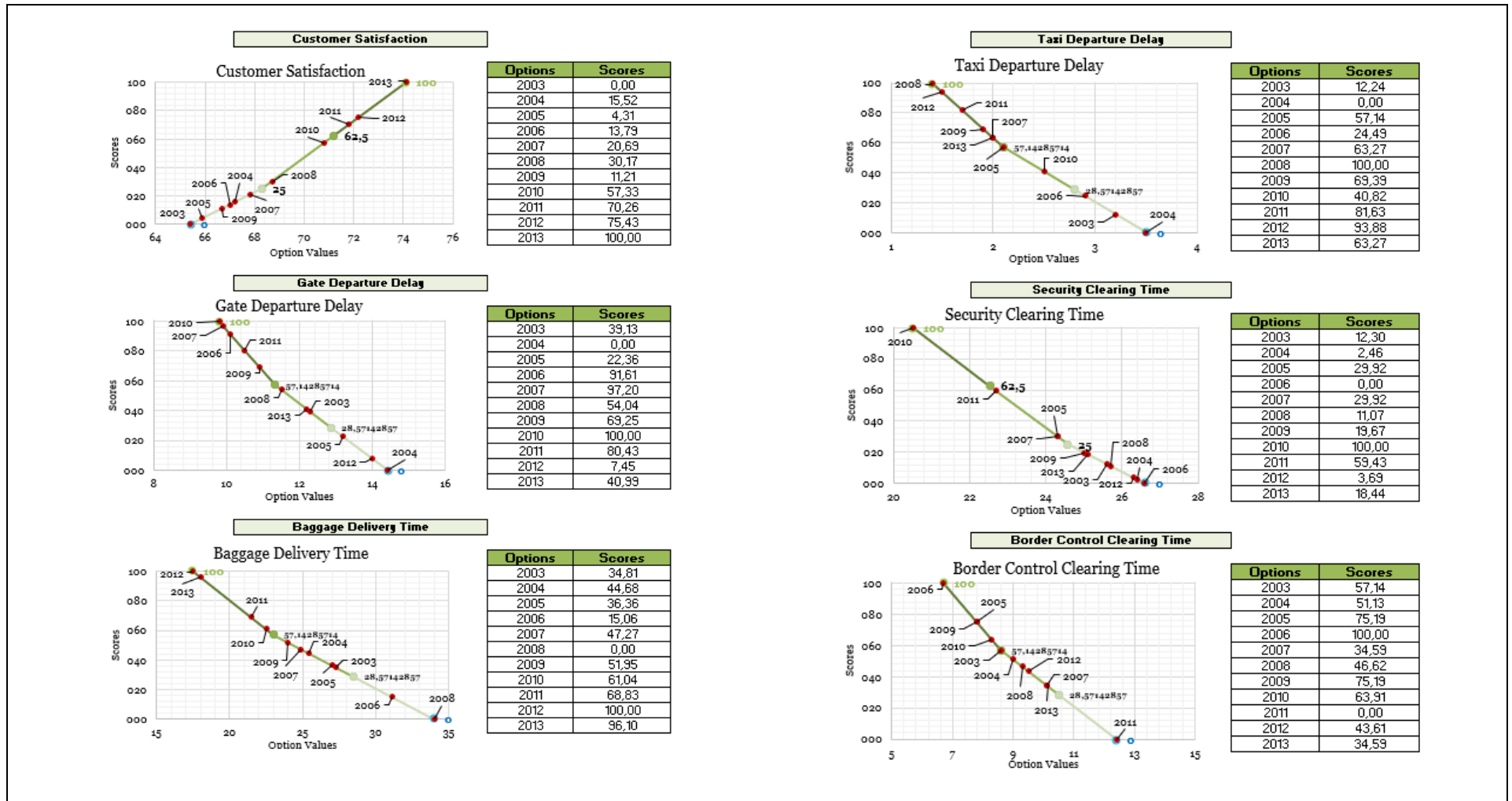


Figure A2. 25 - AIRPORT IN STUDY (4-1/6) – Service Quality KPI value functions
Source: Own Elaboration

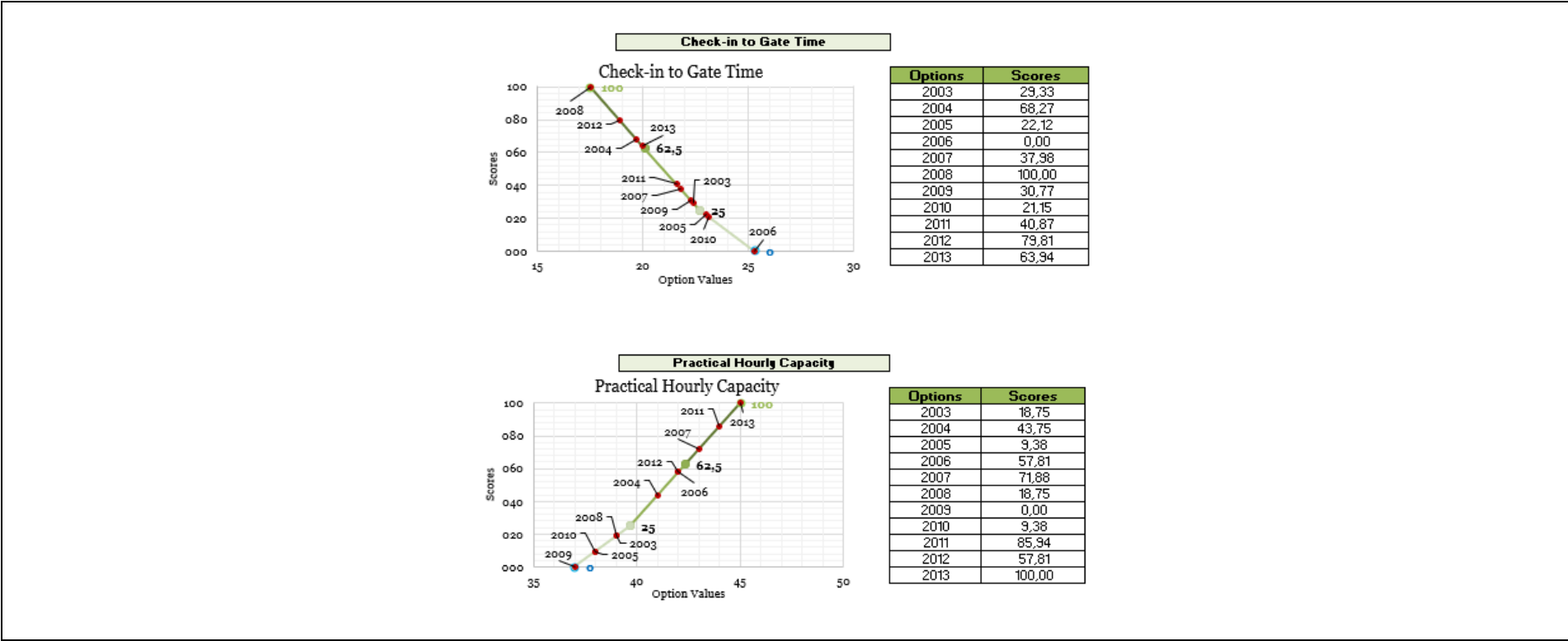


Figure A2. 26 - AIRPORT IN STUDY (4-2/6) – Service Quality KPI value functions
Source: Own Elaboration

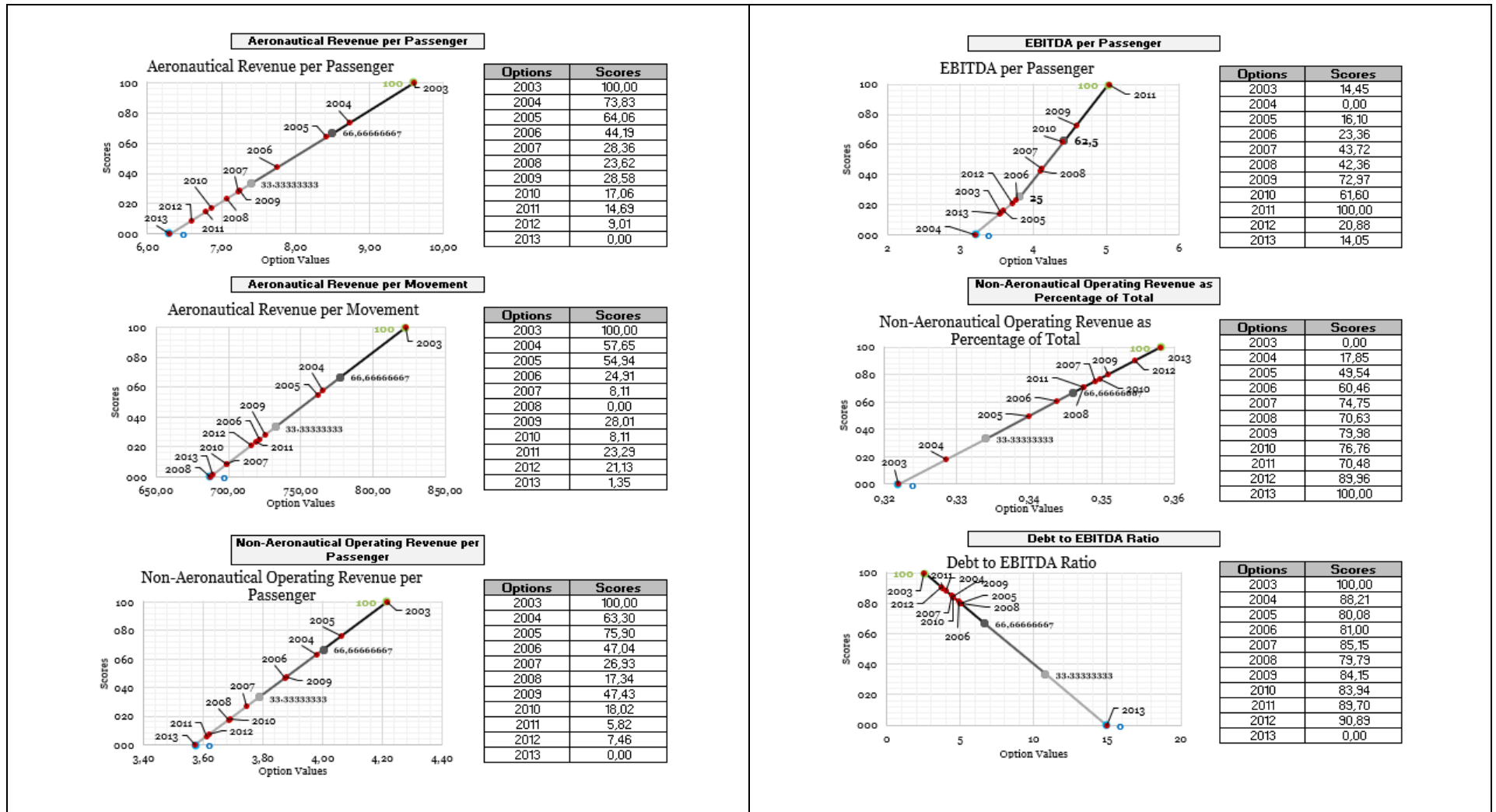


Figure A2. 27 - AIRPORT IN STUDY (5-1/6) – Financial / Commercial KPI value functions
Source: Own Elaboration

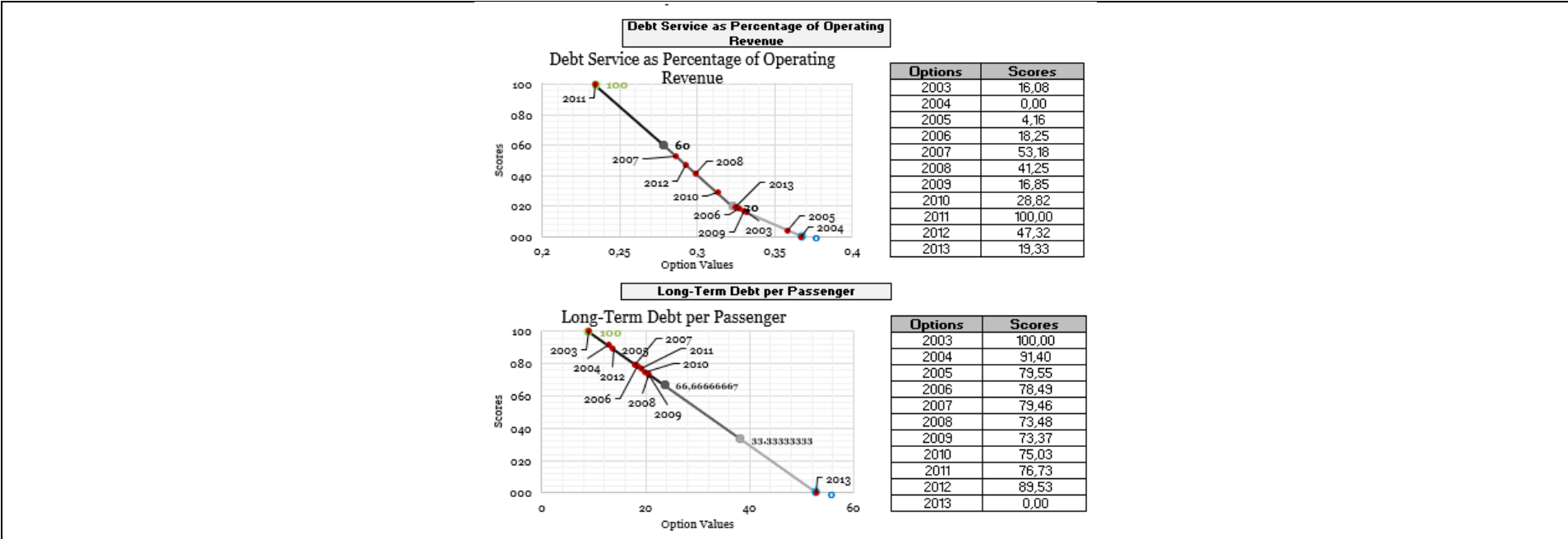


Figure A2. 28 - AIRPORT IN STUDY (5-2/6) – Financial / Commercial KPI value functions
 Source: Own Elaboration

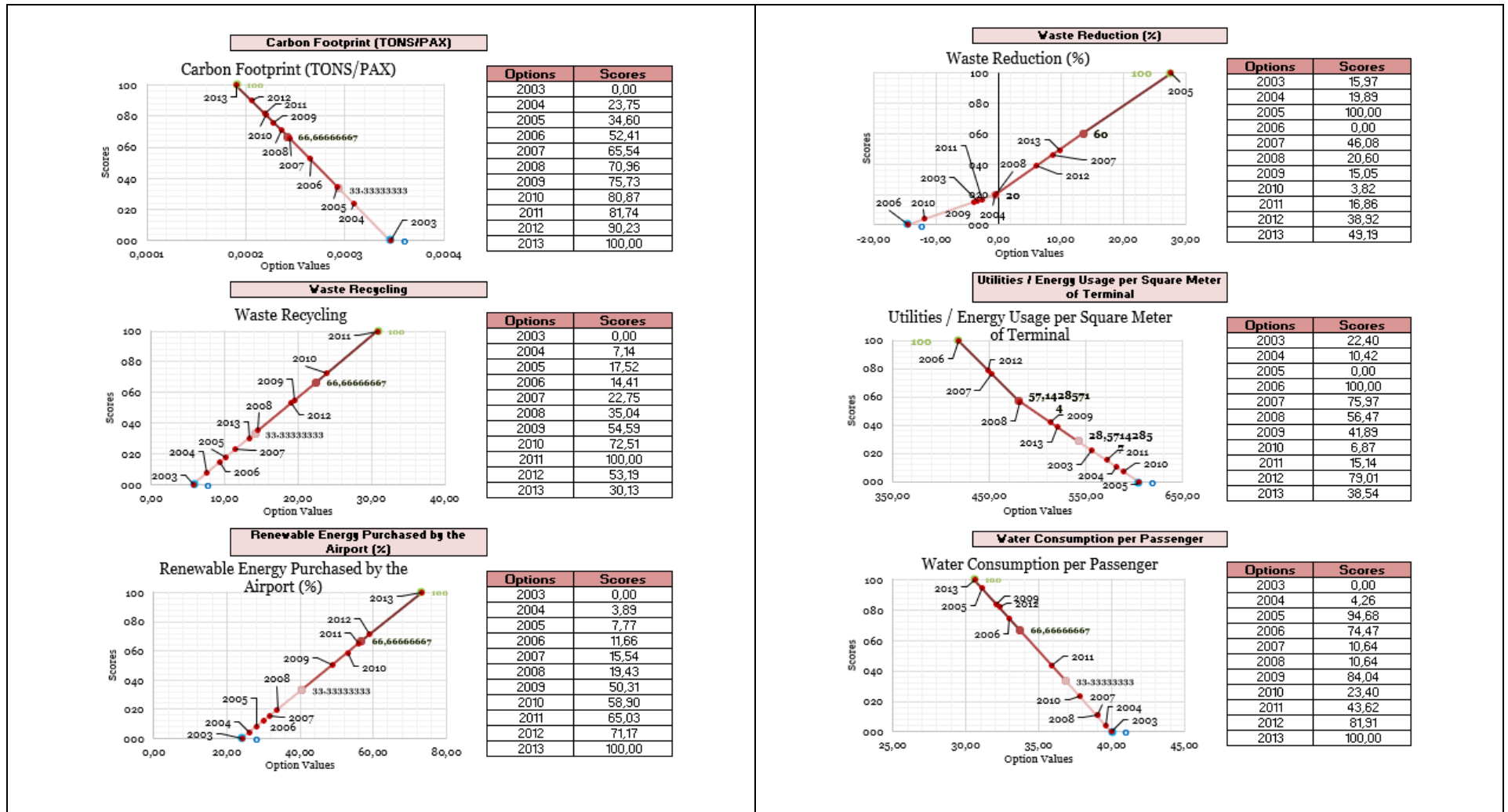


Figure A2. 29 - AIRPORT IN STUDY (5-2/6) – Environmental KPI value functions
Source: Own Elaboration

A2.4.2 – Airports Key Performance Areas Scores

	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%	

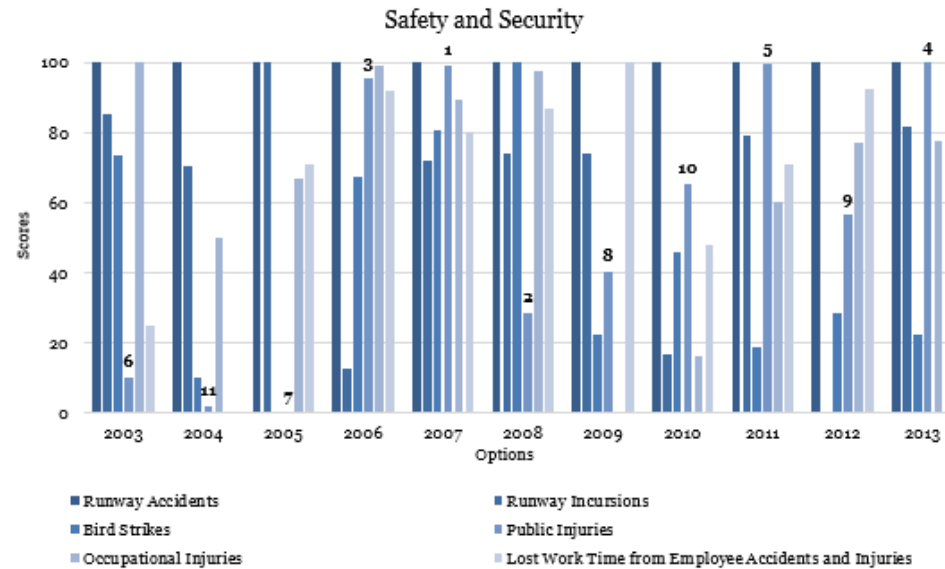


Figure A2. 30 - AIRPORT IN STUDY (1/6) – 2003-2013 Safety and Security Scores
 Source: Own Elaboration

	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	63,34	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
Weights	25,71%	22,86%	20,00%	17,14%	14,29%	

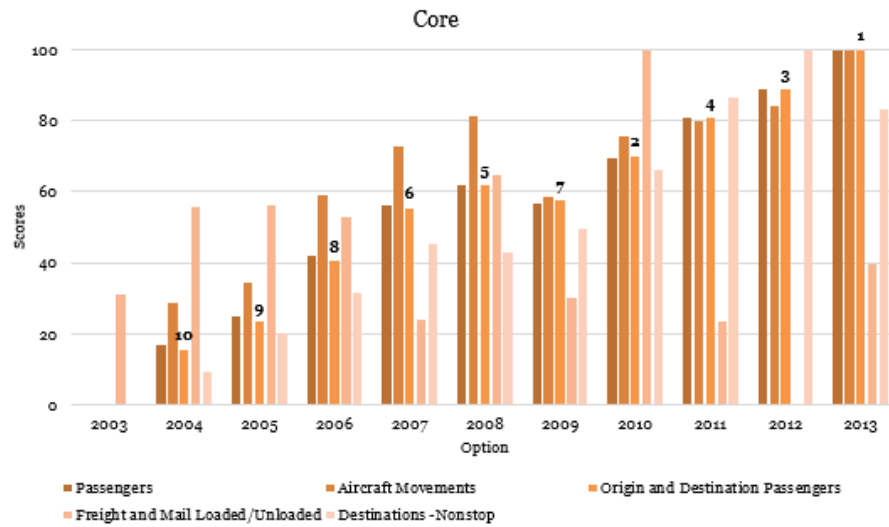


Figure A2. 31 - AIRPORT IN STUDY (2/6) – 2003-2013 CORE Scores
Source: Own Elaboration

	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
Weights	14,29%	13,13%	12,09%	10,93%	10,99%	10,99%	9,89%	8,79%	8,79%	

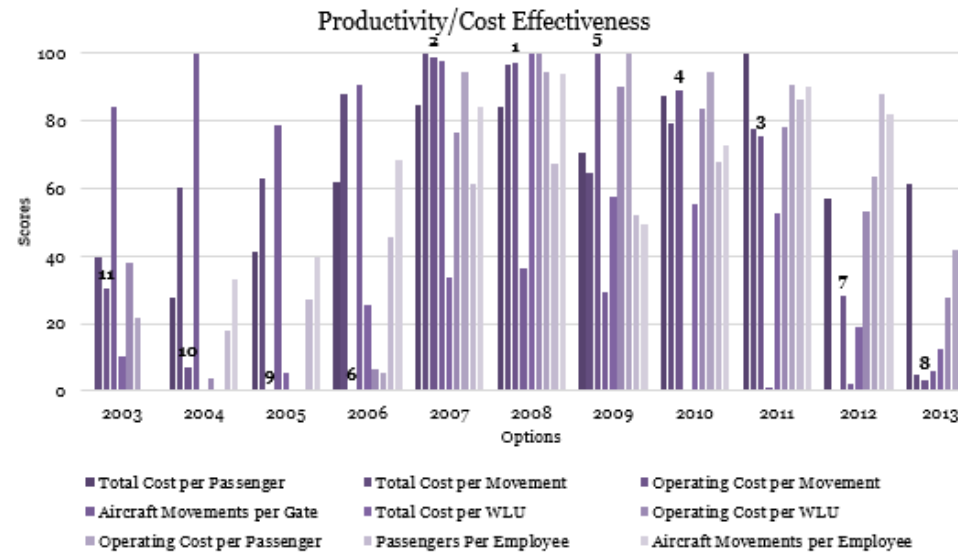


Figure A2. 32 - AIRPORT IN STUDY (3/6) – 2003-2013 Productivity/Cost-Effectiveness Scores
Source: Own Elaboration

	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
Weights	15,96%	14,89%	13,83%	12,77%	11,70%	10,64%	10,64%	9,57%	



Figure A2. 33 - AIRPORT IN STUDY (3/6) – 2003-2013 Service Quality Scores
Source: Own Elaboration

	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
Weights	16,18%	14,71%	13,24%	13,24%	11,76%	11,76%	10,29%	8,82%	

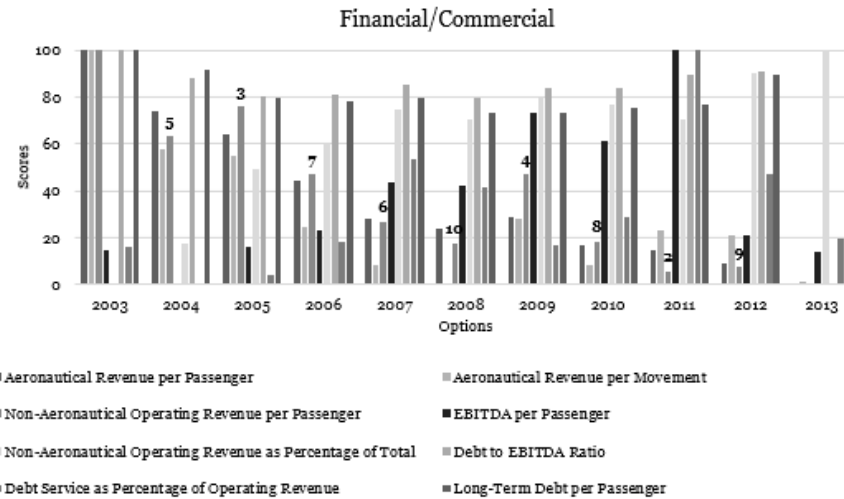


Figure A2. 34 - AIRPORT IN STUDY (3/6) – 2003-2013 Financial / Commercial Scores
Source: Own Elaboration

	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
Weights	21,21%	18,18%	18,18%	15,15%	15,15%	12,12%	

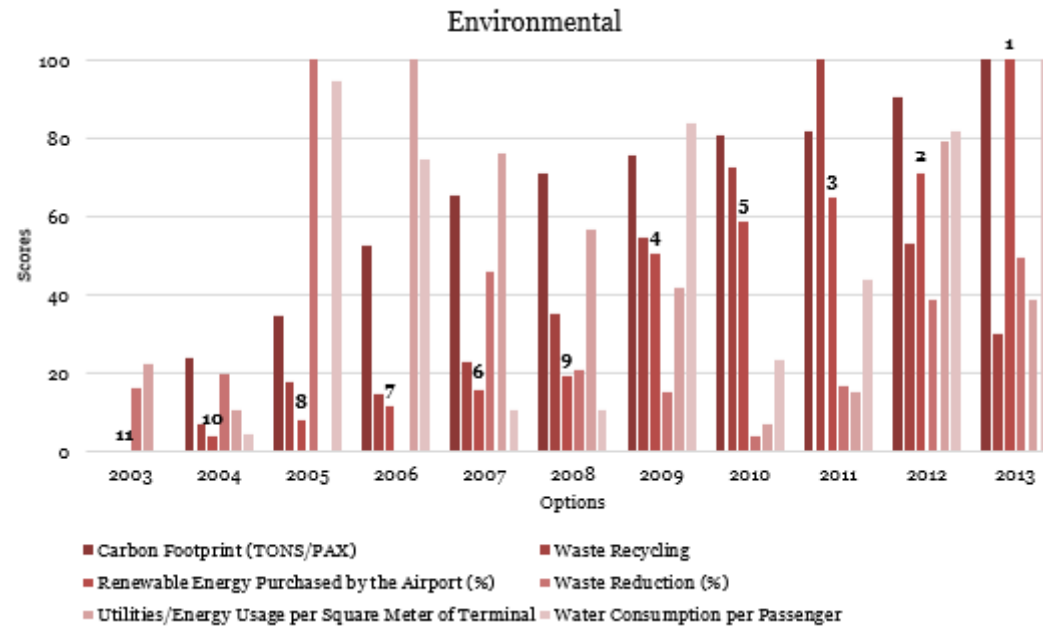


Figure A2. 35 - AIRPORT IN STUDY (3/6) – 2003-2013 Environmental Scores
 Source: Own Elaboration

	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%	

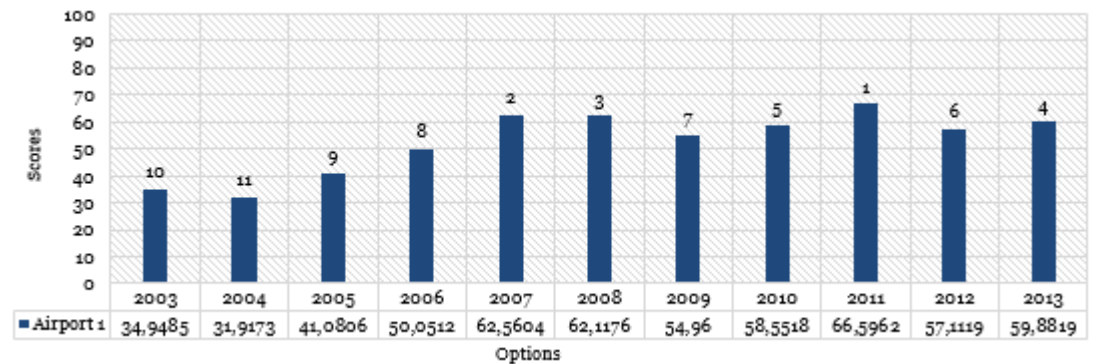
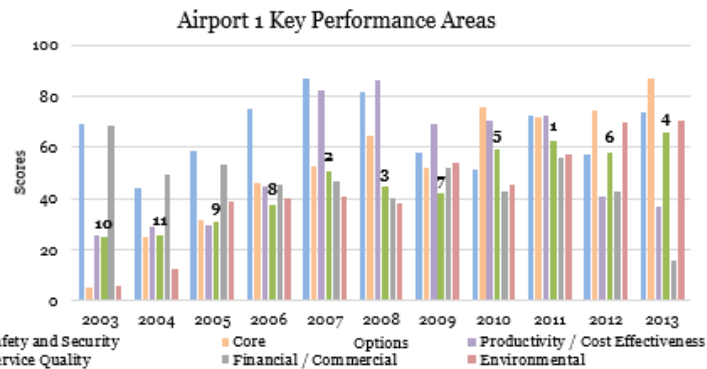


Figure A2. 36 - AIRPORT IN STUDY 2003-2013 Scores
Source: Own Elaboration

A2.5 – PESA-AGB Outputs

A2.5.1 – Value Profile by Key Performance Indicator are depicted in Figures A2.37 – A2.39.

AIRPORT IN STUDY – (1/2)



Figure A2. 37 - AIRPORT IN STUDY Value Profile by Key Performance Indicator for Safety and Security, Core, Productivity/Efficiency, and Service Quality
KPA
Source: Own Elaboration

AIRPORT IN STUDY – (2/2)

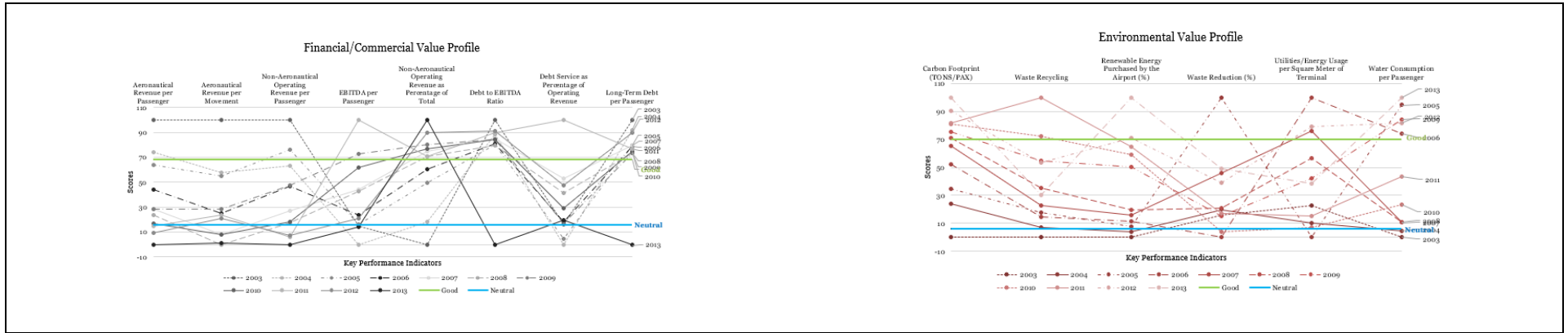


Figure A2. 38 - AIRPORT IN STUDY Value Profile by Key Performance Indicator for Financial/Commercial, and Environmental KPA
Source: Own Elaboration

A2.5.2 – Value Profile by Key Performance Area

AIRPORT IN STUDY

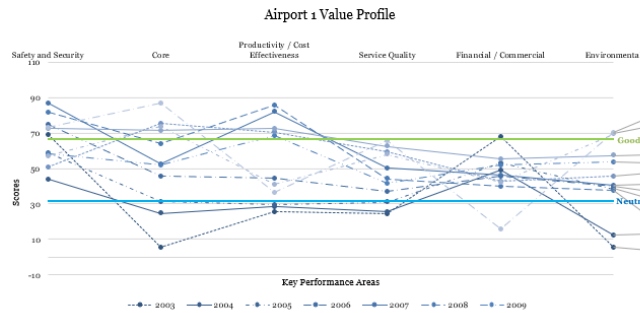


Figure A2. 39 - AIRPORT IN STUDY Value Profile by Key Performance Area
Source: Own Elaboration

A2.5.3 and A2.5.4 – Options Profile and Difference Profile

The airport in study options and difference profiles are depicted in Figures A2.40 – A2.57.

AIRPORT IN STUDY - KPA - Safety and Security

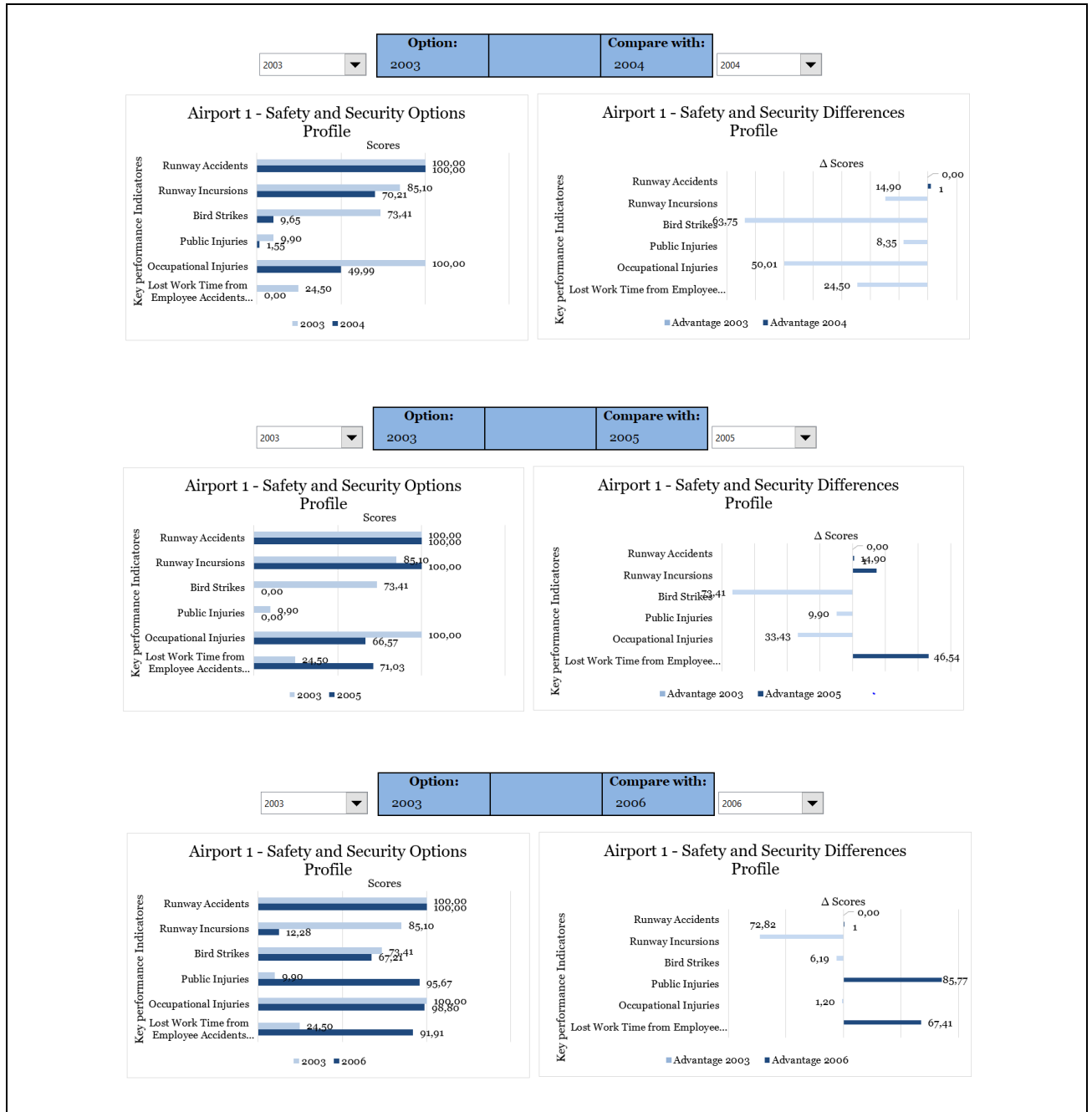


Figure A2. 40 - AIRPORT IN STUDY 2003 to 2004-2006 Safety and Security KPI Options and Difference profiles

Source: Own Elaboration

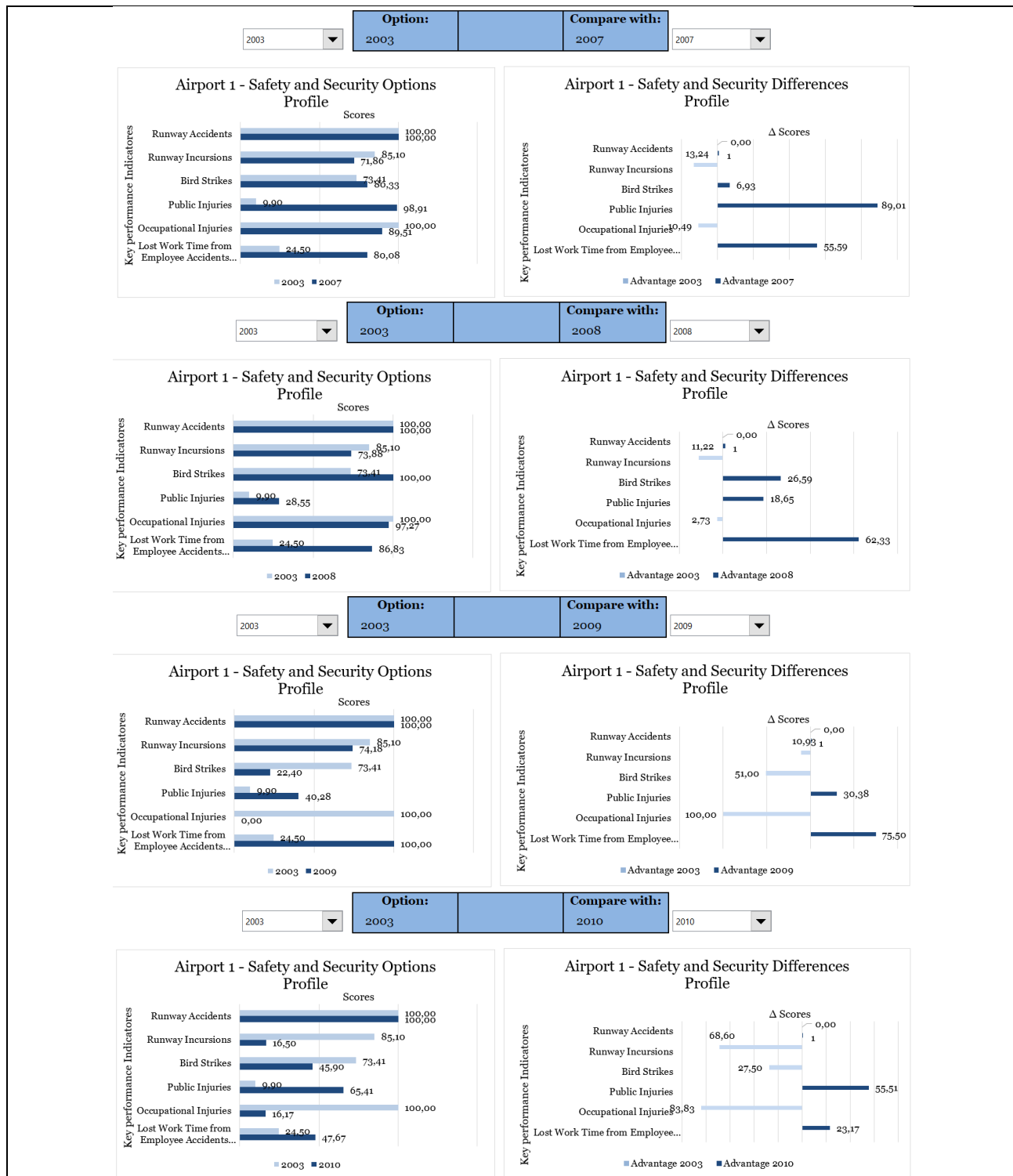


Figure A2. 41 - AIRPORT IN STUDY 2003 to 2007-2010 Safety and Security KPI Options and Difference profiles
Source: Own Elaboration

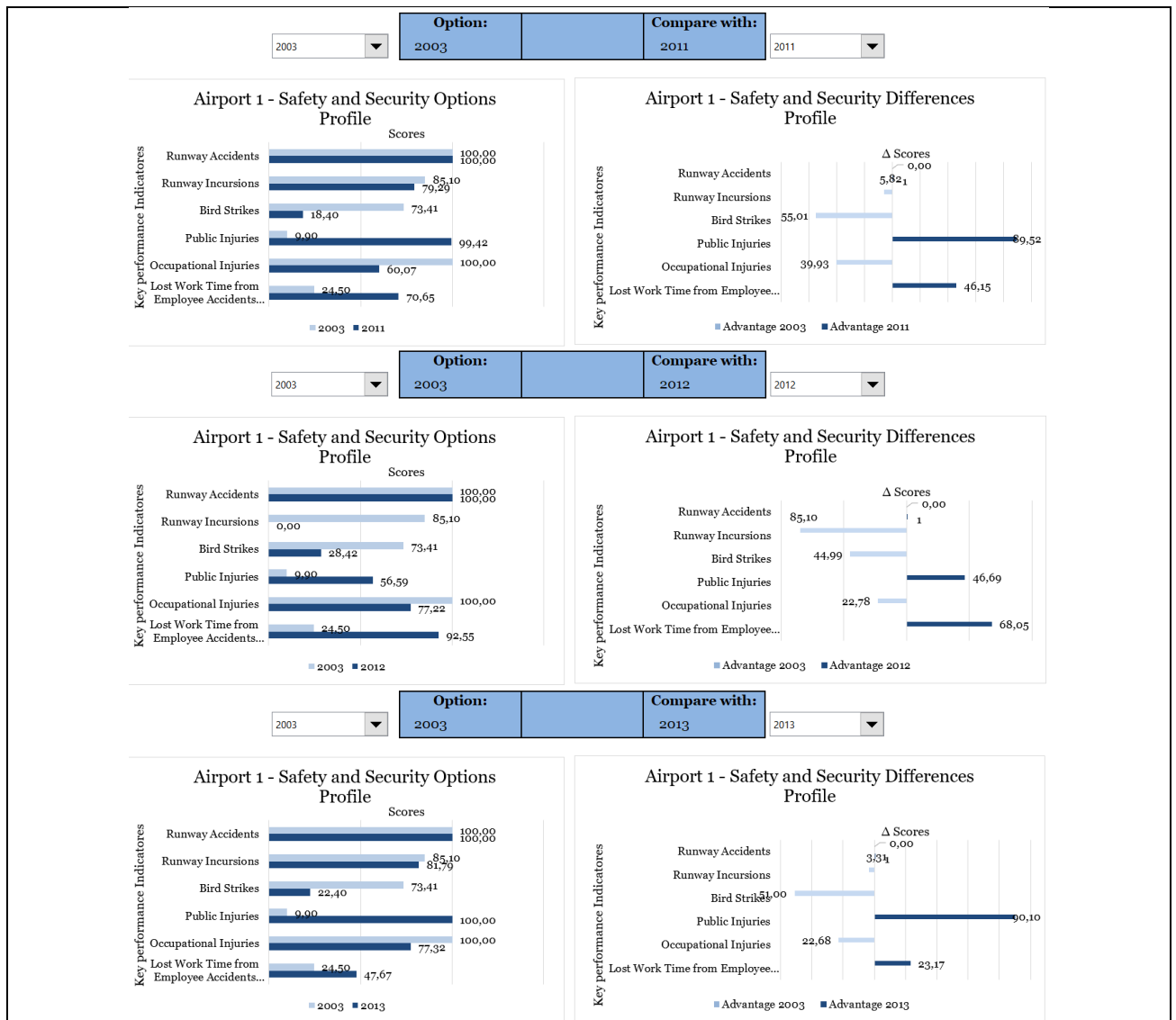


Figure A2. 42 - AIRPORT IN STUDY 2003 to 2011-2013 Safety and Security KPI Options and Difference profiles
 Source: Own Elaboration

AIRPORT IN STUDY – KPA CORE

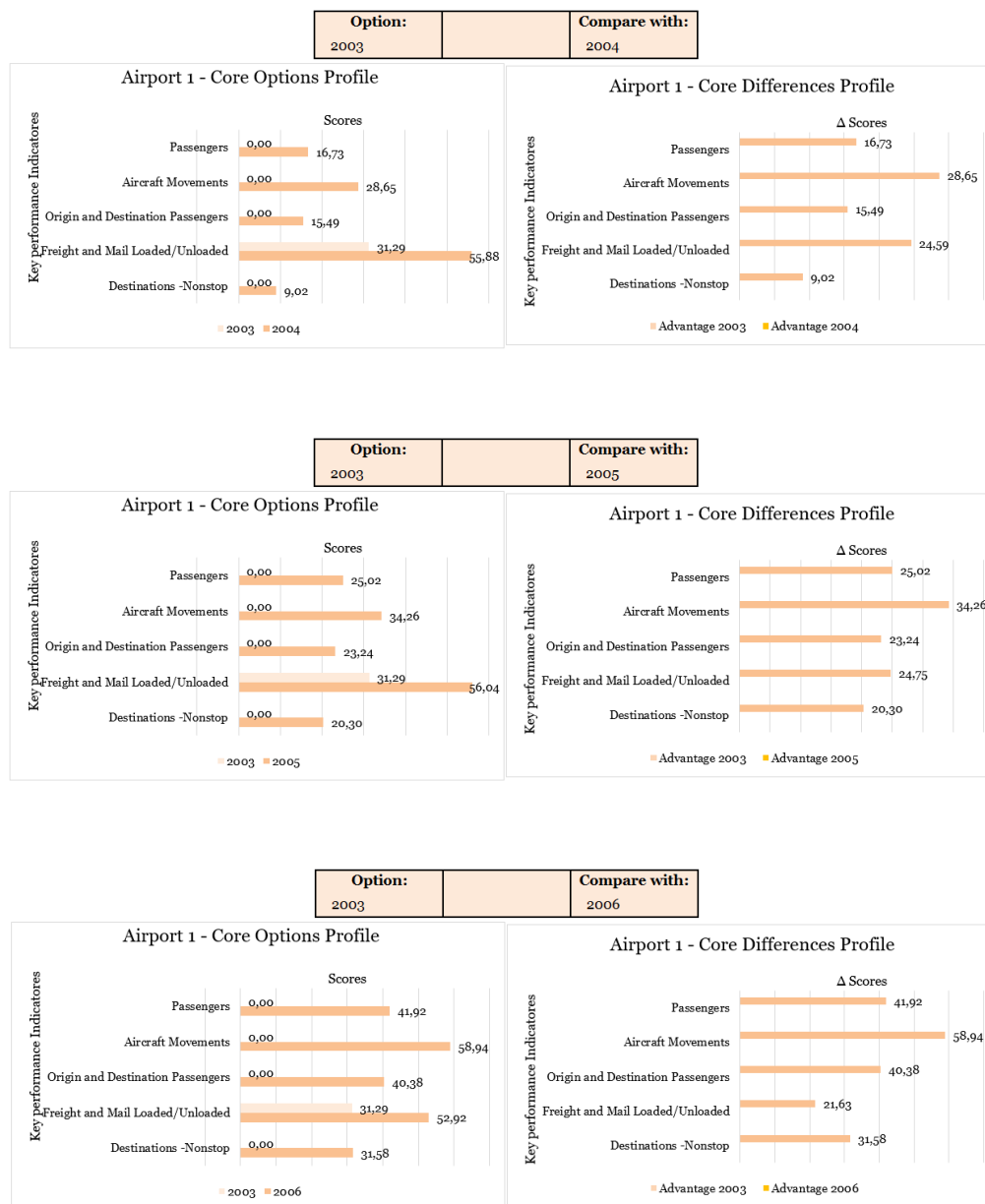


Figure A2. 43 - AIRPORT IN STUDY 2003 to 2004-2006 CORE KPI Options and Difference profiles
Source: Own Elaboration

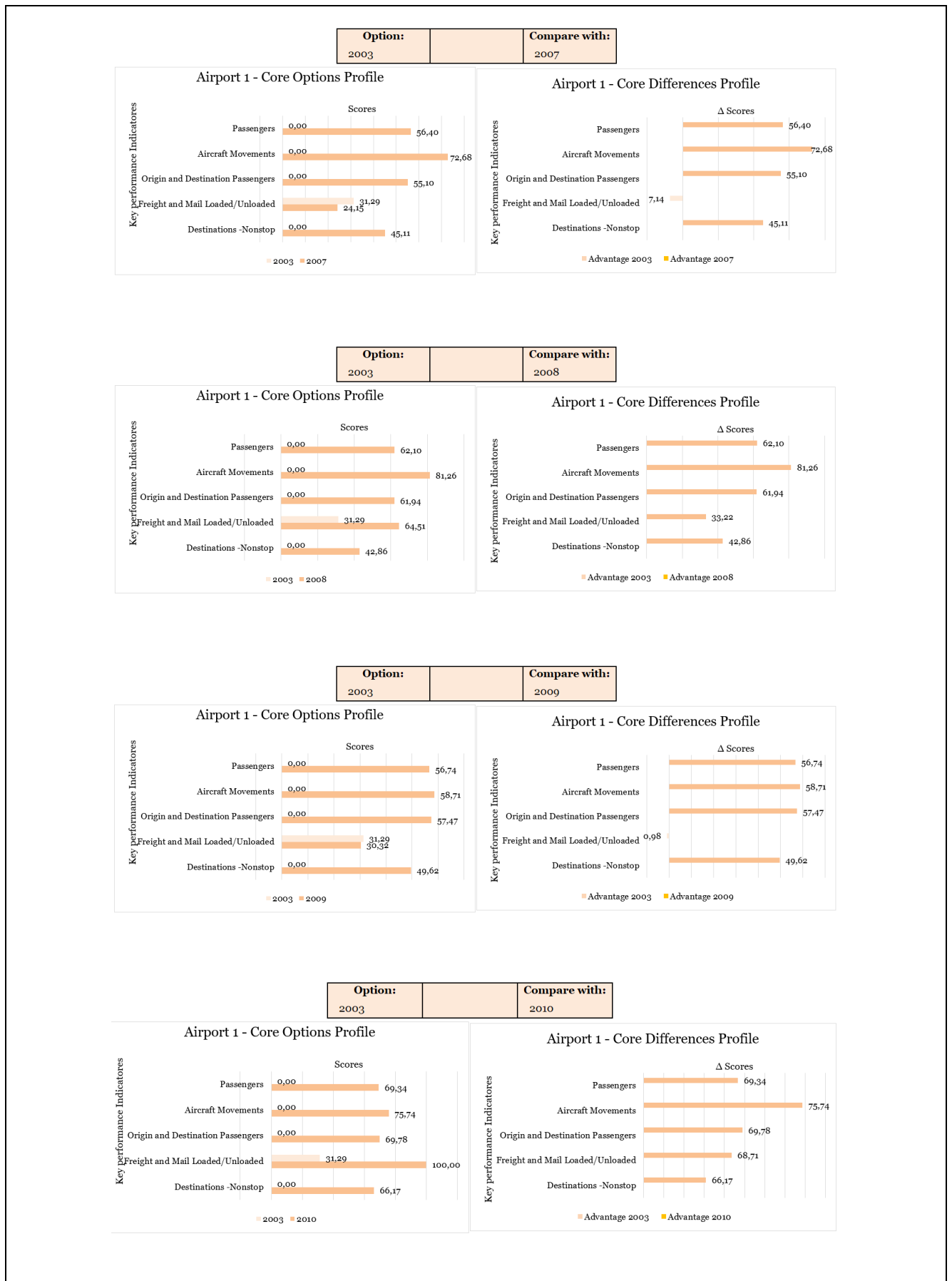


Figure A2. 44 - AIRPORT IN STUDY 2003 to 2007-2010 CORE KPI Options and Difference profiles
Source: Own Elaboration

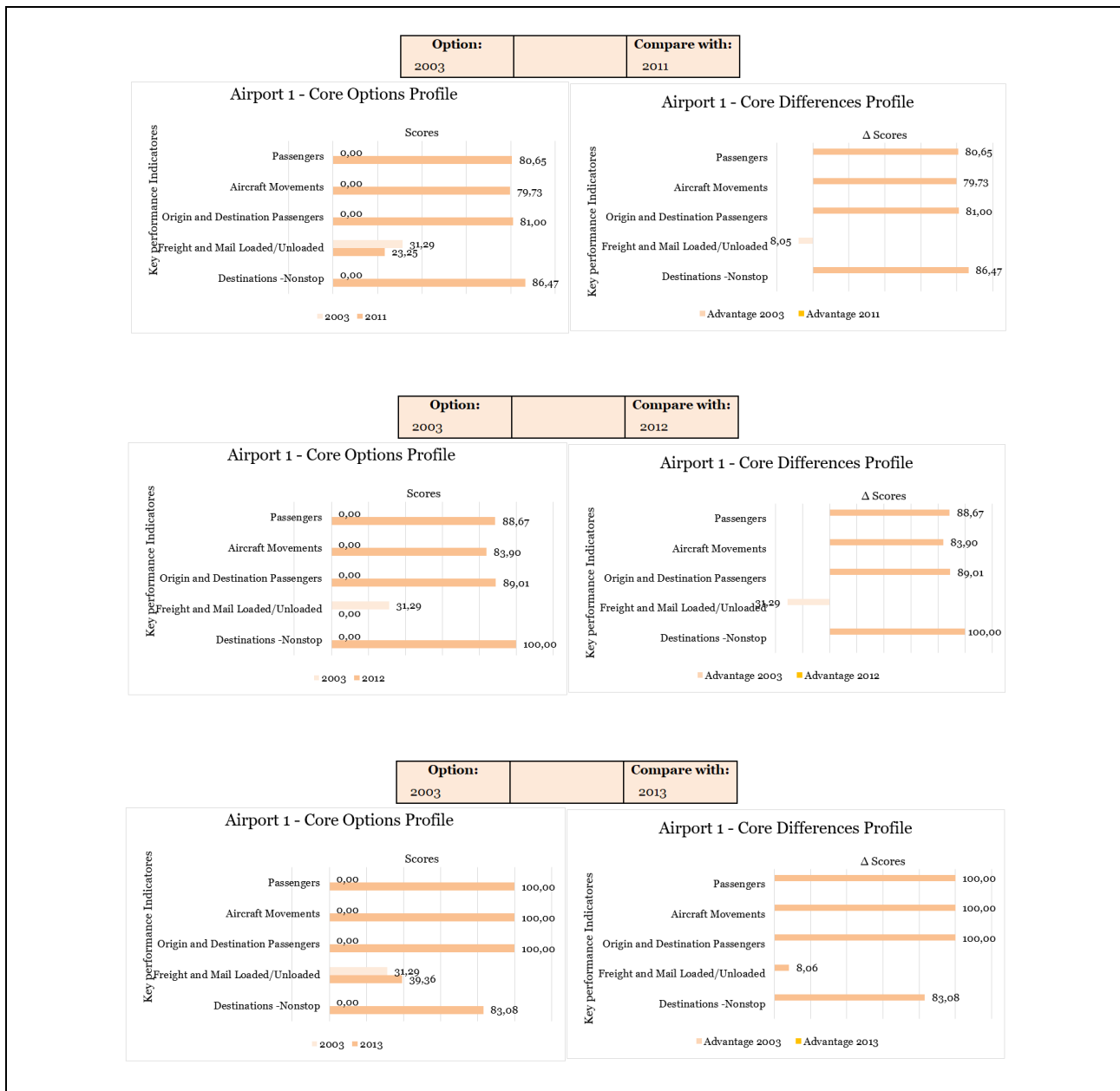


Figure A2. 45 - AIRPORT IN STUDY 2003 to 20011-2013 CORE KPI Options and Difference profiles
Source: Own Elaboration

AIRPORT IN STUDY – KPA Productivity/Cost Effectiveness

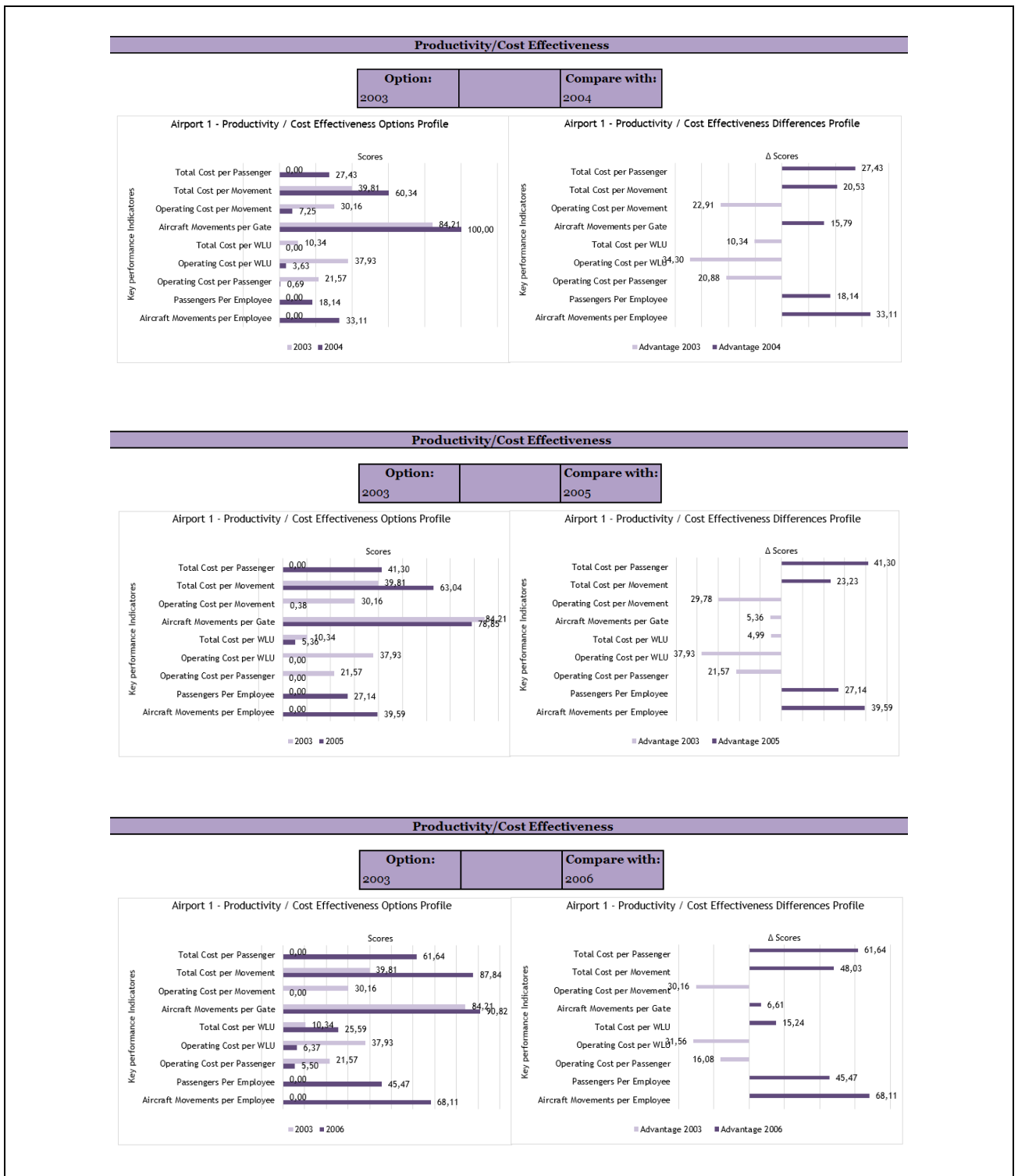
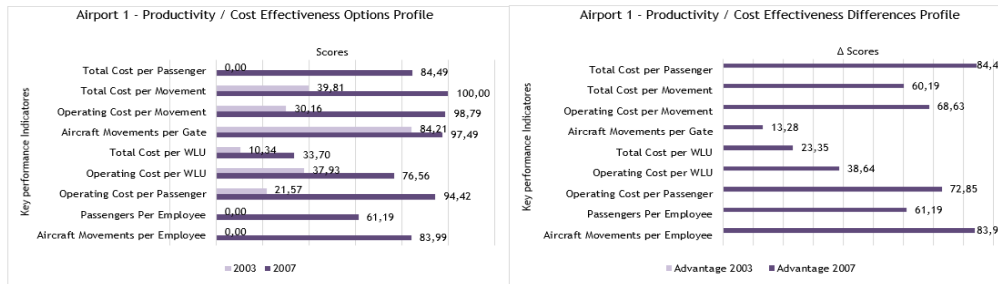


Figure A2. 46 - AIRPORT IN STUDY 2003 to 2004-2006 Productivity/Cost Effectiveness KPI Options and Difference profiles
Source: Own Elaboration

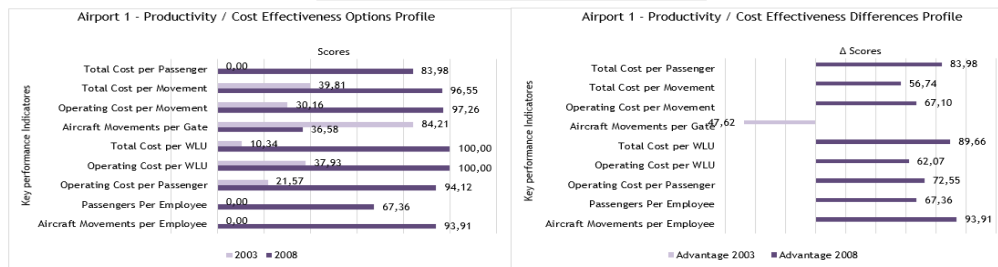
Productivity/Cost Effectiveness

Option: 2003 Compare with: 2007



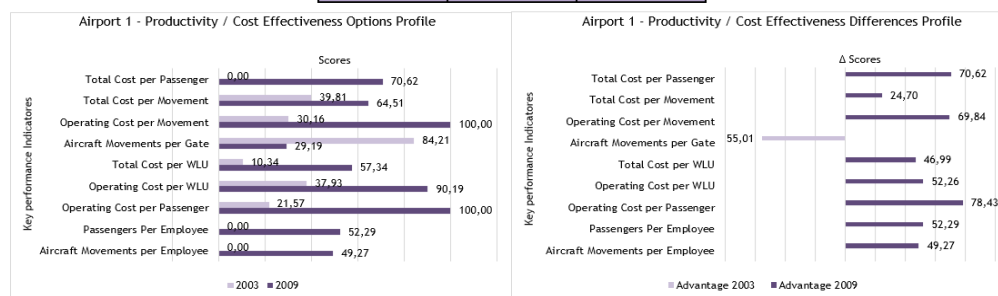
Productivity/Cost Effectiveness

Option: 2003 Compare with: 2008



Productivity/Cost Effectiveness

Option: 2003 Compare with: 2009



Productivity/Cost Effectiveness

Option: 2003 Compare with: 2010



Figure A2. 47 - AIRPORT IN STUDY 2003 to 2007-2010 Productivity/Cost Effectiveness KPI Options and Difference profiles

Source: Own Elaboration

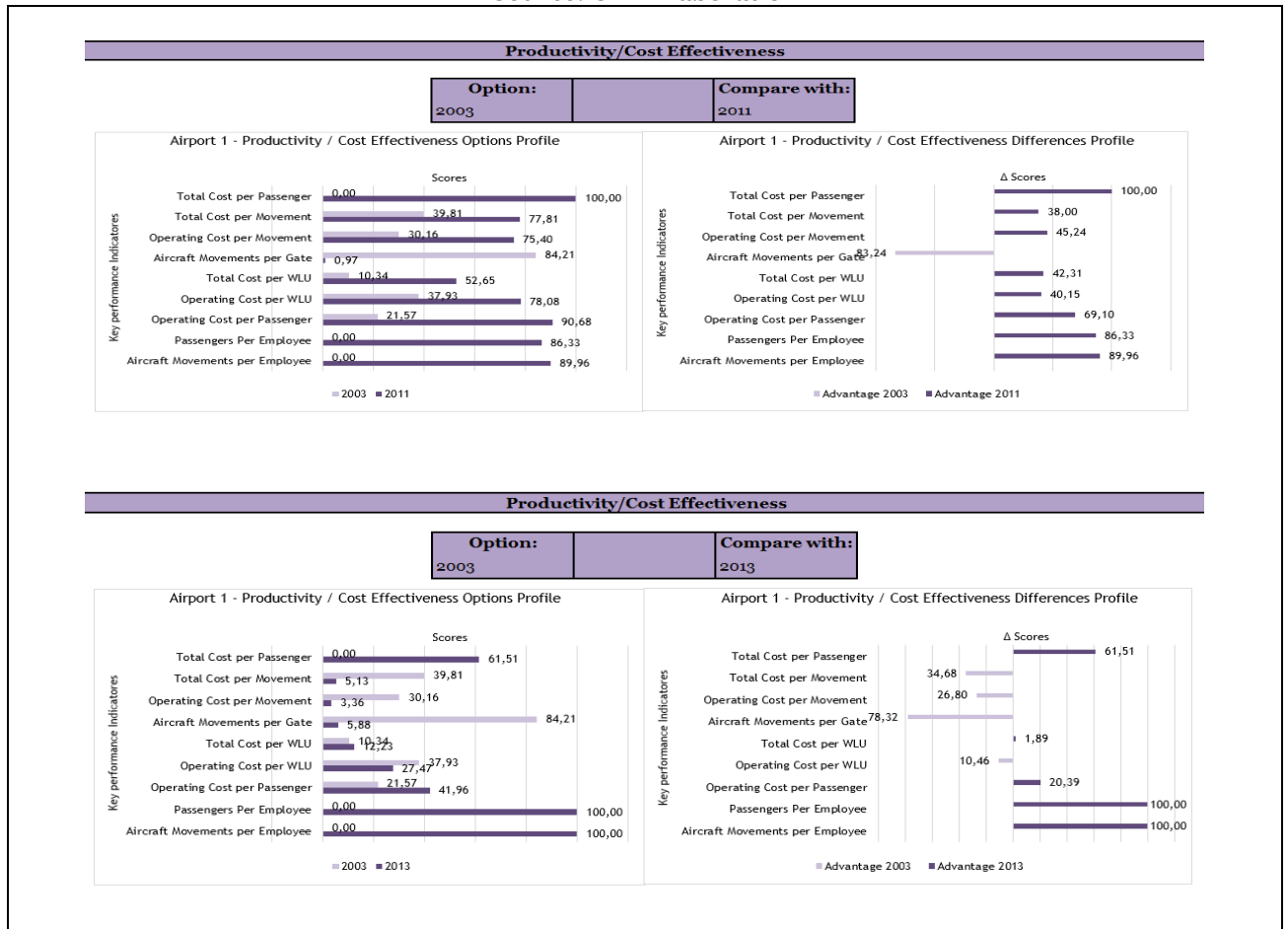
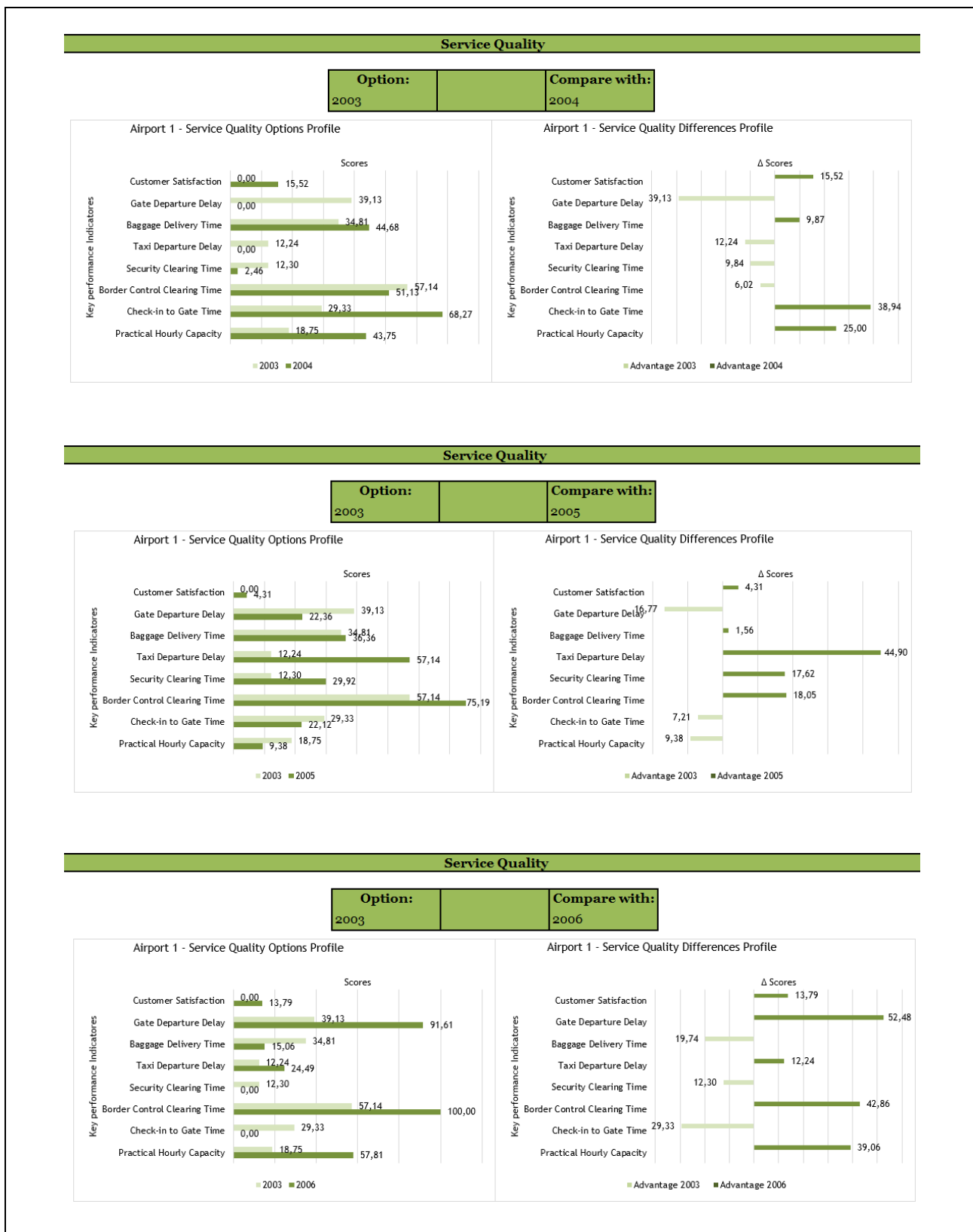


Figure A2. 48 - AIRPORT IN STUDY 2003 to 2011-2013 Productivity/Cost Effectiveness KPI Options and Difference profiles
Source: Own Elaboration

AIRPORT IN STUDY – KPA Service Quality



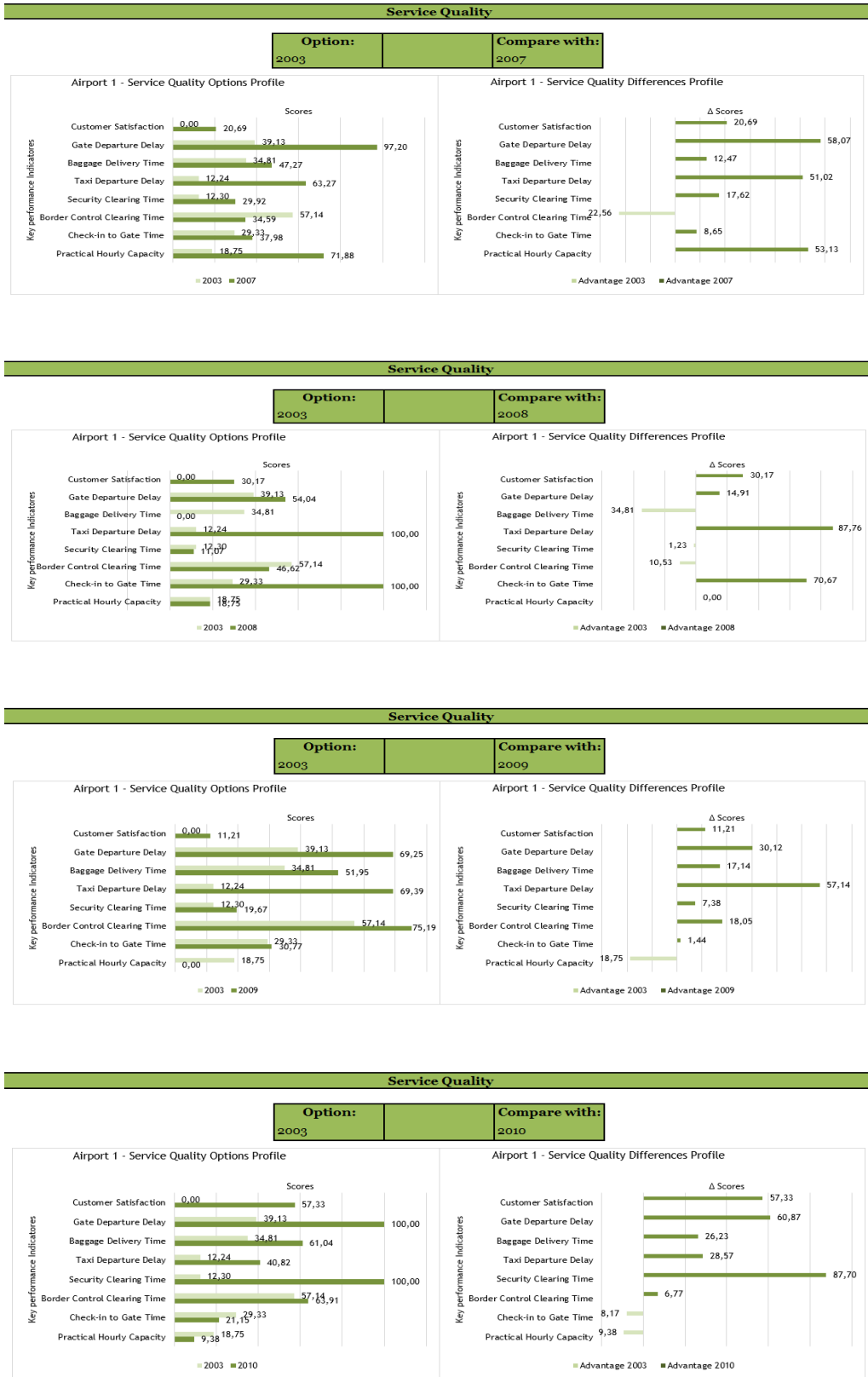


Figure A2. 50 - AIRPORT IN STUDY 2003 to 2007-2010 Service Quality KPI Options and Difference profiles
Source: Own Elaboration

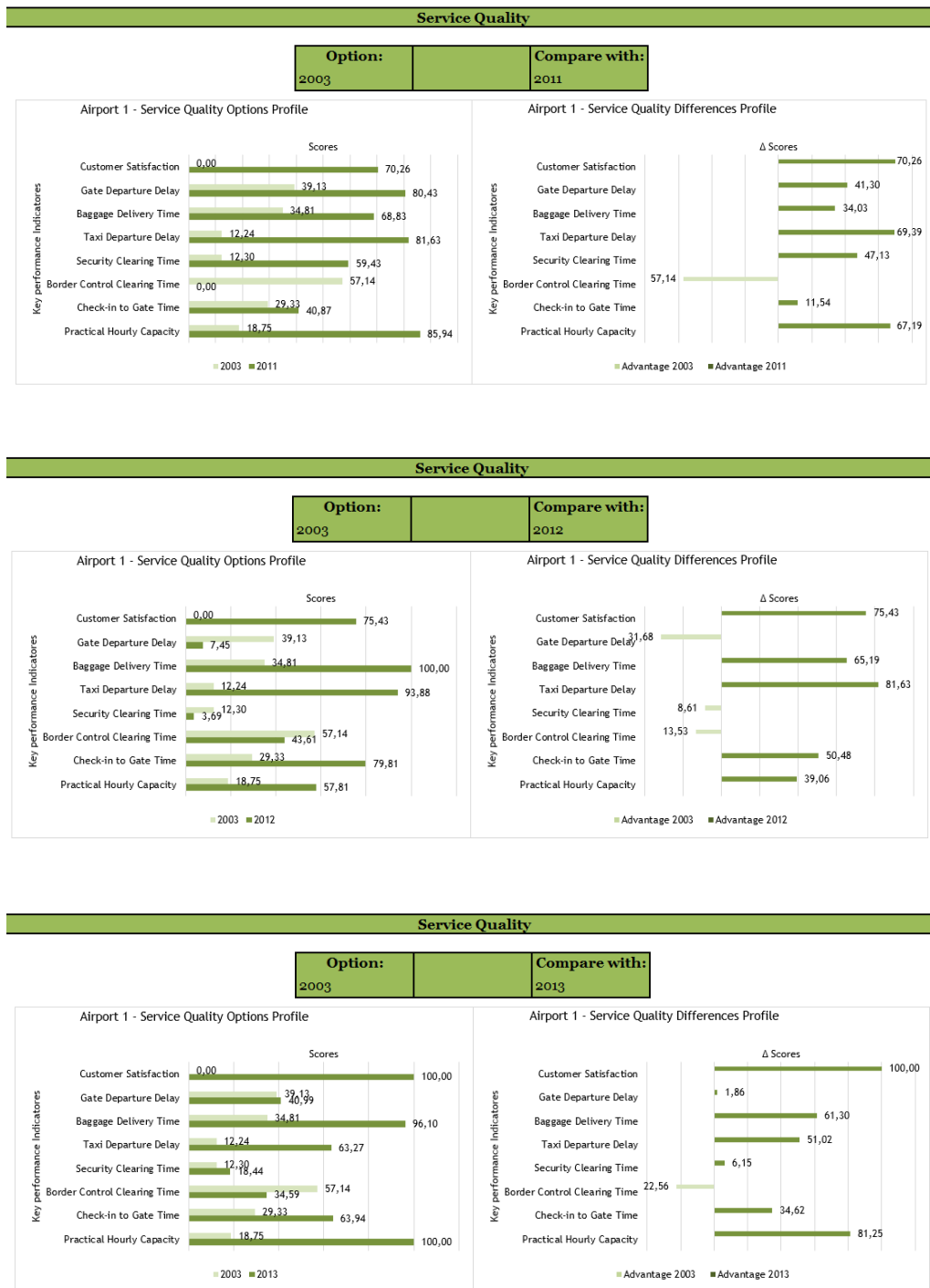


Figure A2. 51 - AIRPORT IN STUDY 2003 to 2011-2013 Service Quality KPI Options and Difference profiles
Source: Own Elaboration

AIRPORT IN STUDY – KPA Financial/Commercial

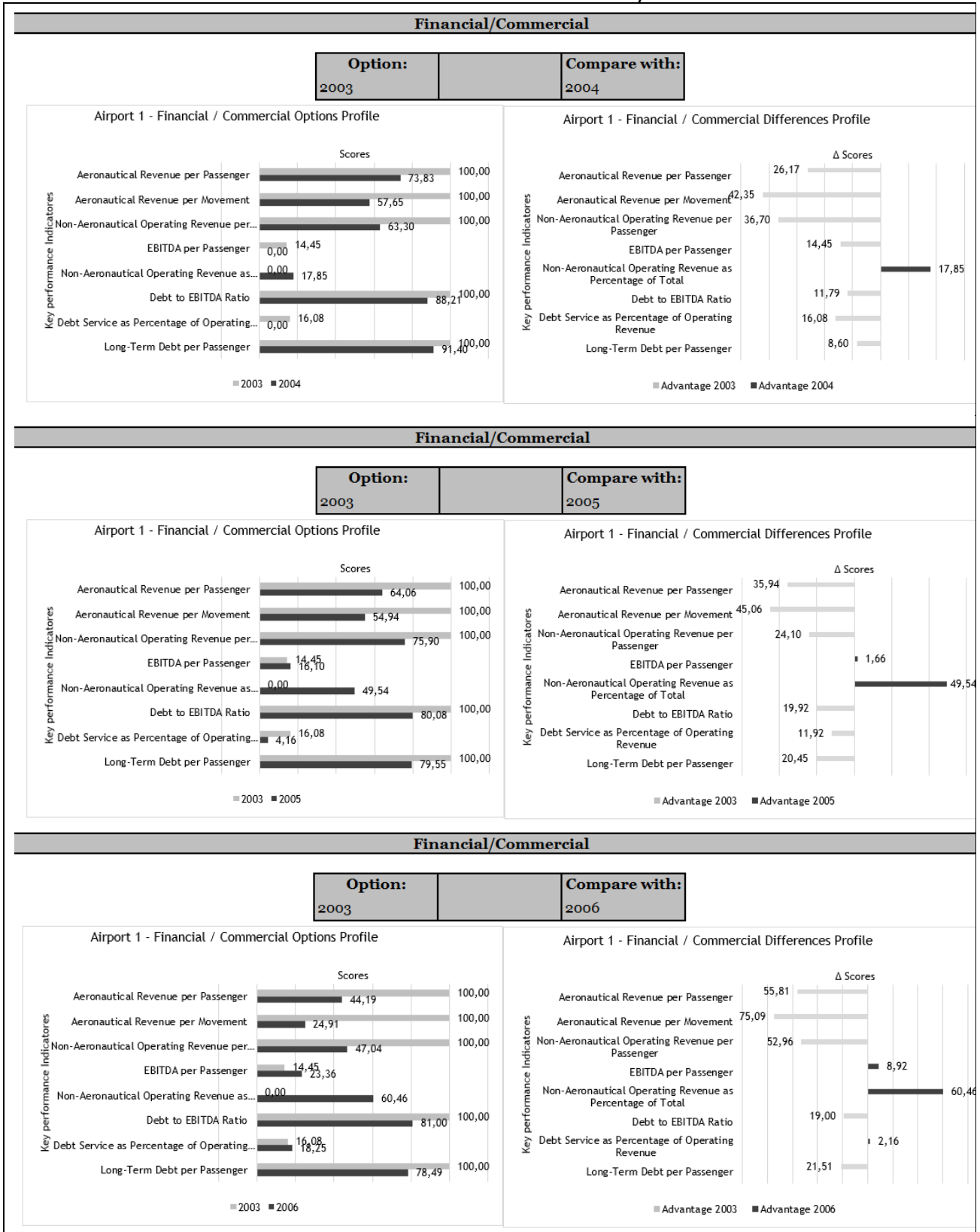


Figure A2. 52 - AIRPORT IN STUDY 2003 to 2004-2006 Financial/Commercial KPI Options and Difference profiles
 Source: Own Elaboration

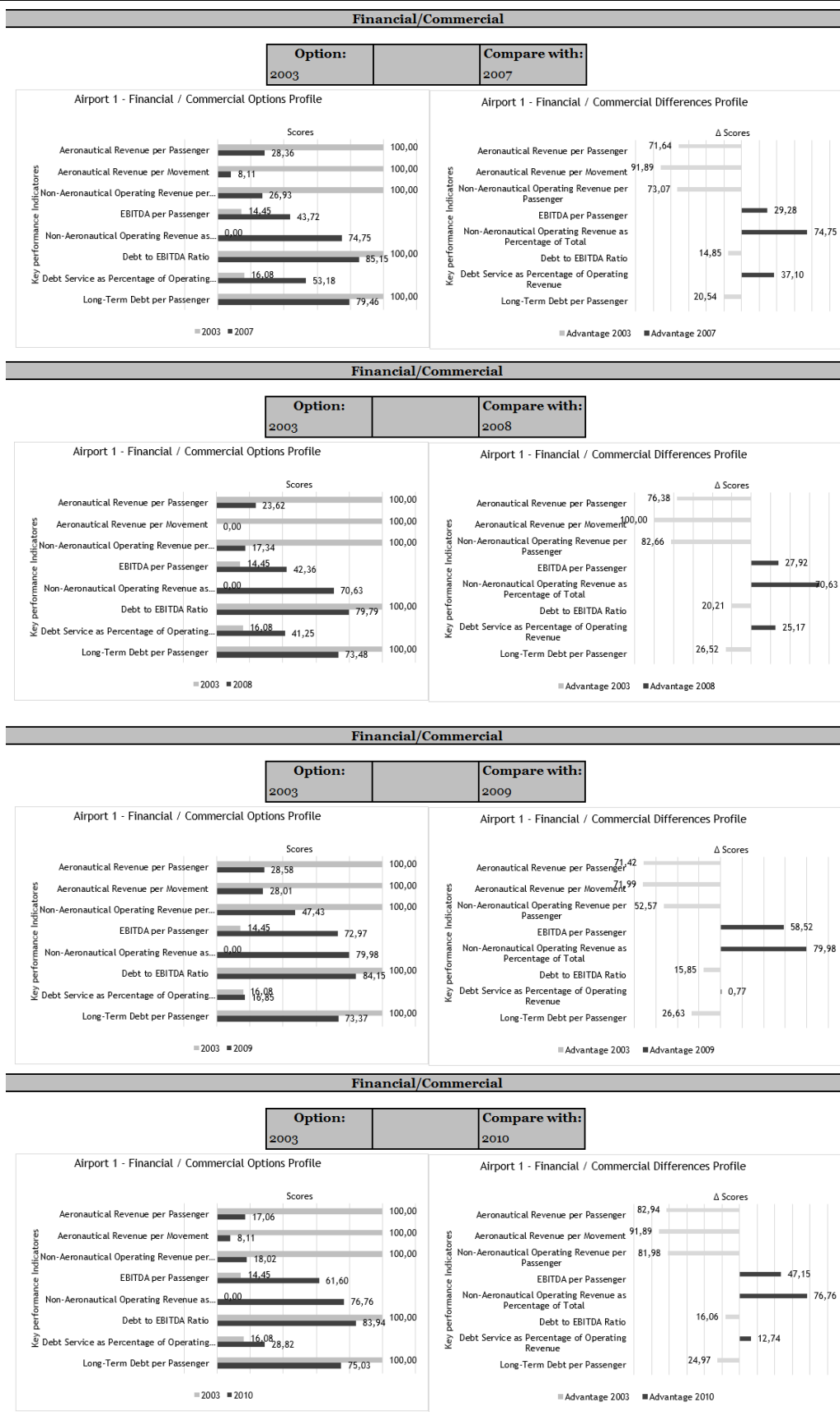


Figure A2. 53 - AIRPORT IN STUDY 2003 to 2007-2010 Financial/Commercial KPI Options and Difference profiles
Source: Own Elaboration

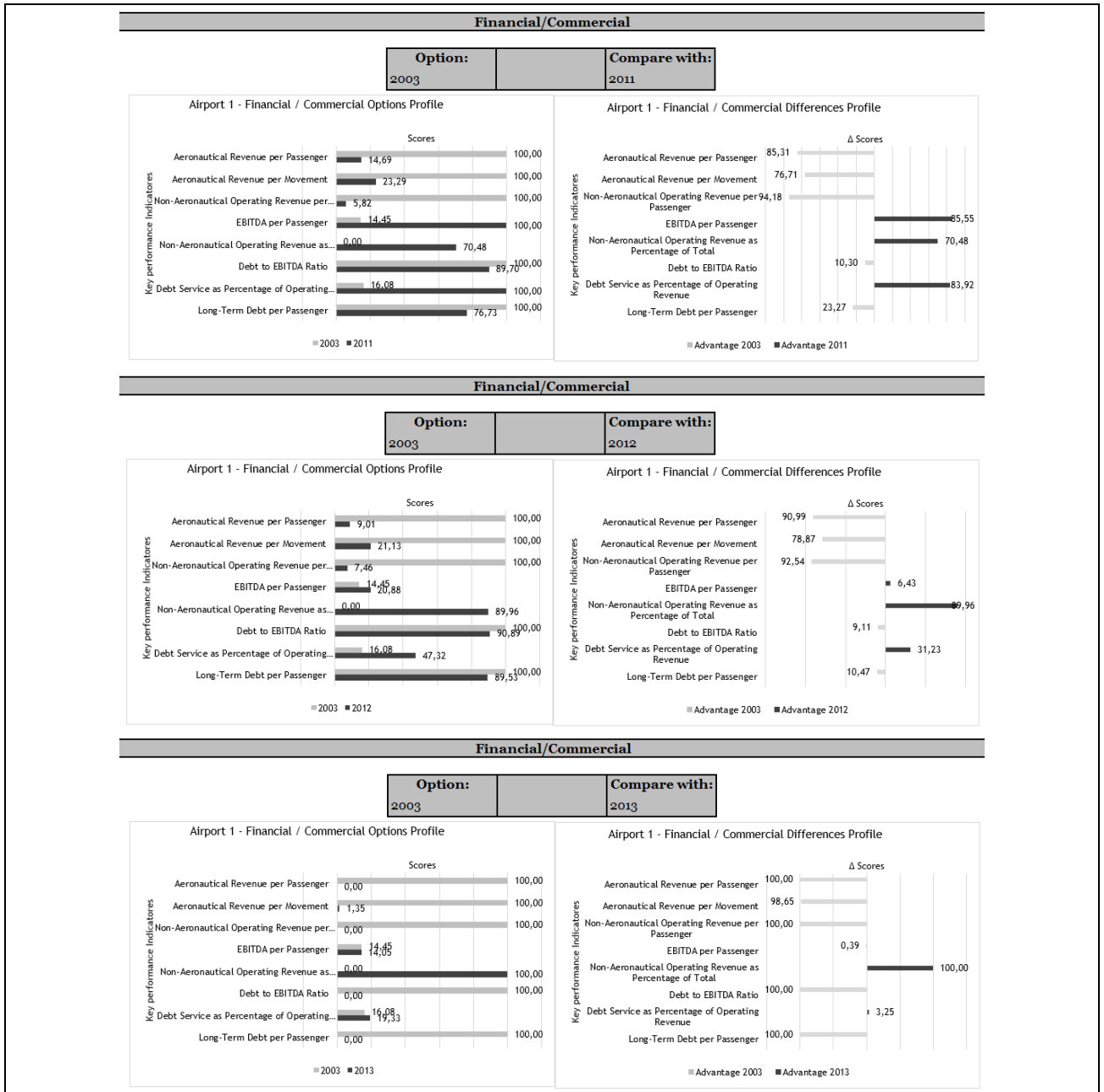


Figure A2. 54 - AIRPORT IN STUDY 2003 to 2011-2013 Financial/Commercial KPI Options and Difference profiles
 Source: Own Elaboration

AIRPORT IN STUDY – KPA Environmental

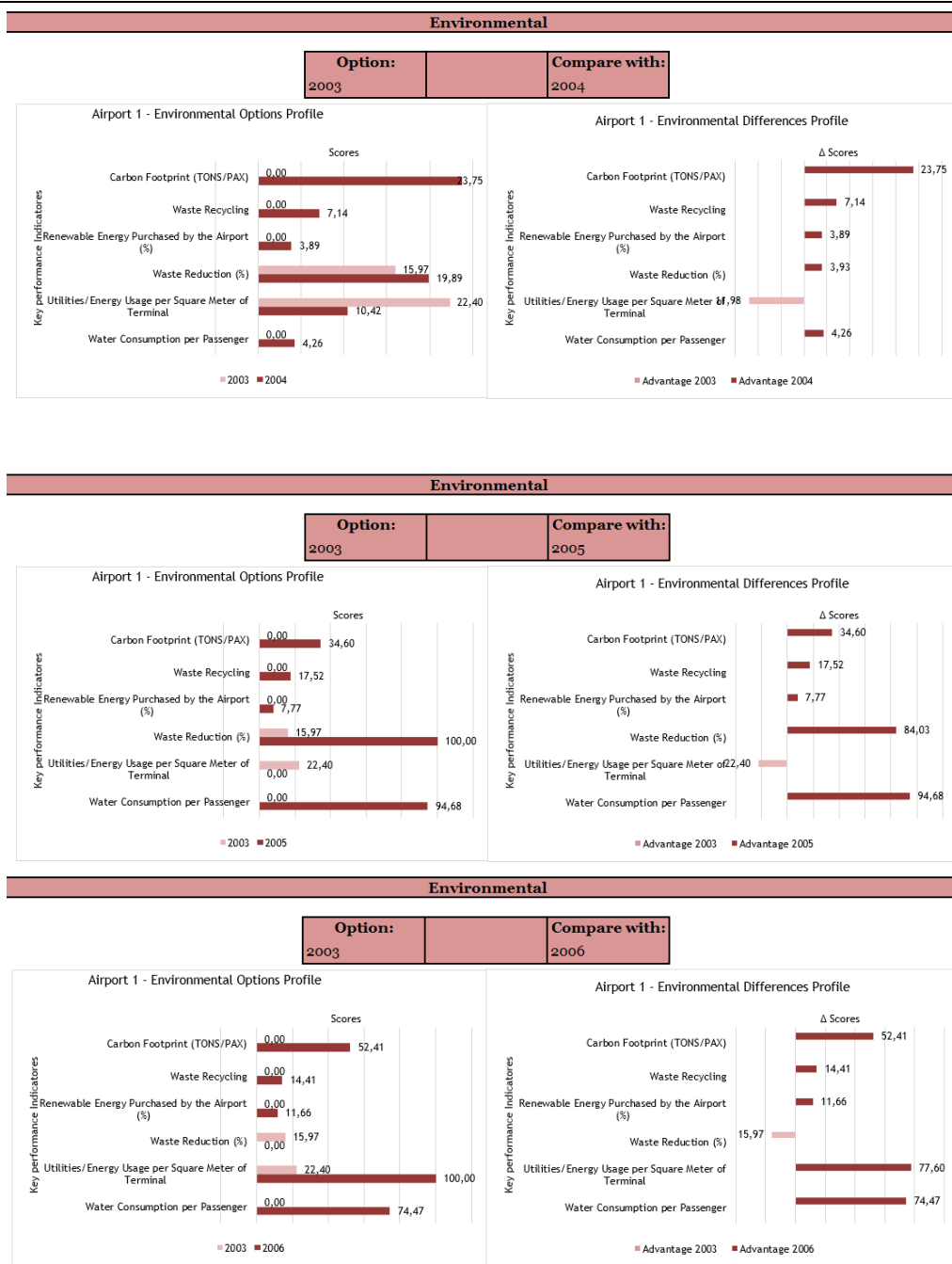


Figure A2. 55 - AIRPORT IN STUDY 2003 to 2004-2006 Environmental KPI Options and Difference profiles
 Source: Own Elaboration

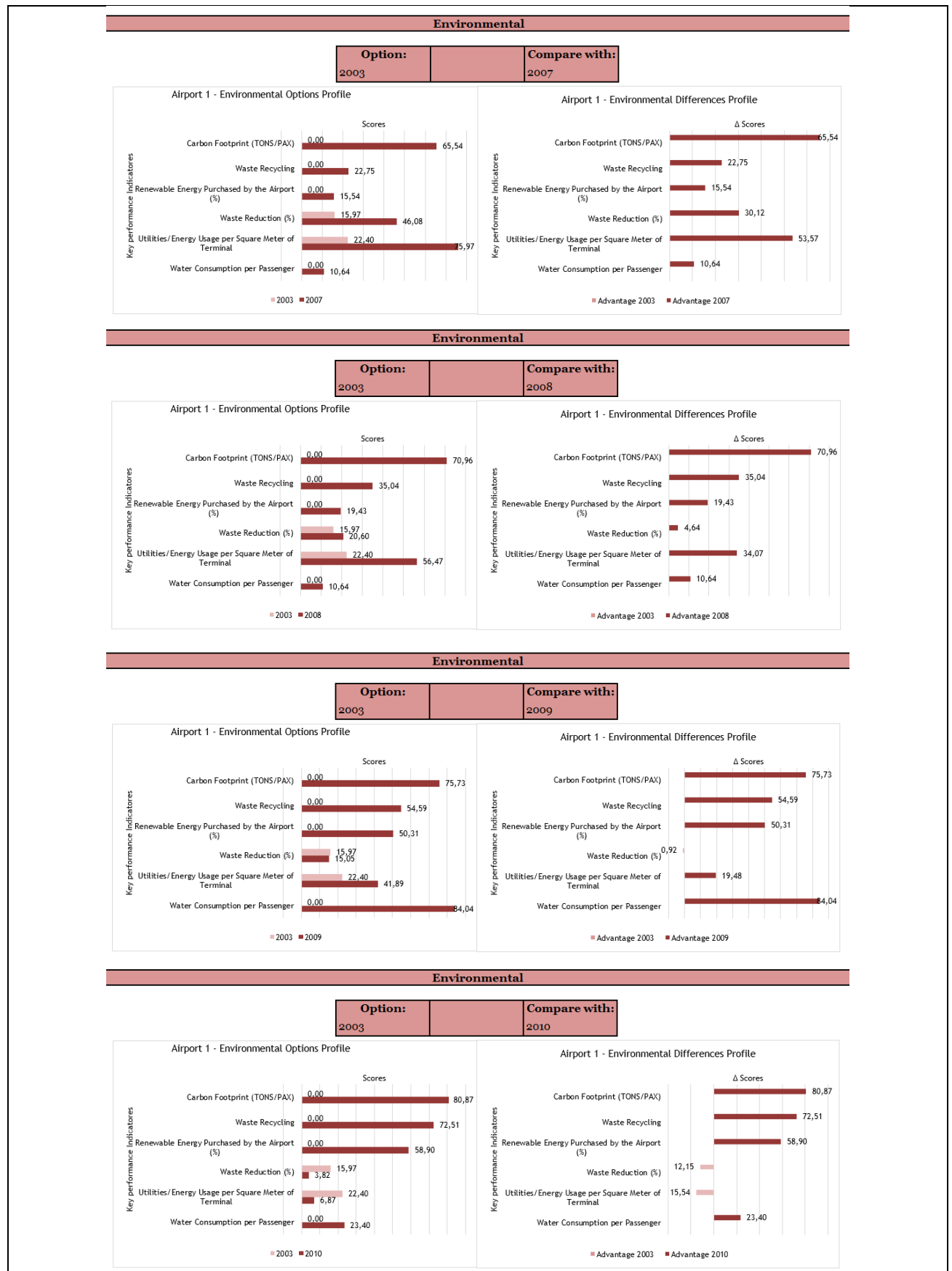


Figure A2. 56 - AIRPORT IN STUDY 2003 to 2007-2010 Environmental KPI Options and Difference profiles
 Source: Own Elaboration

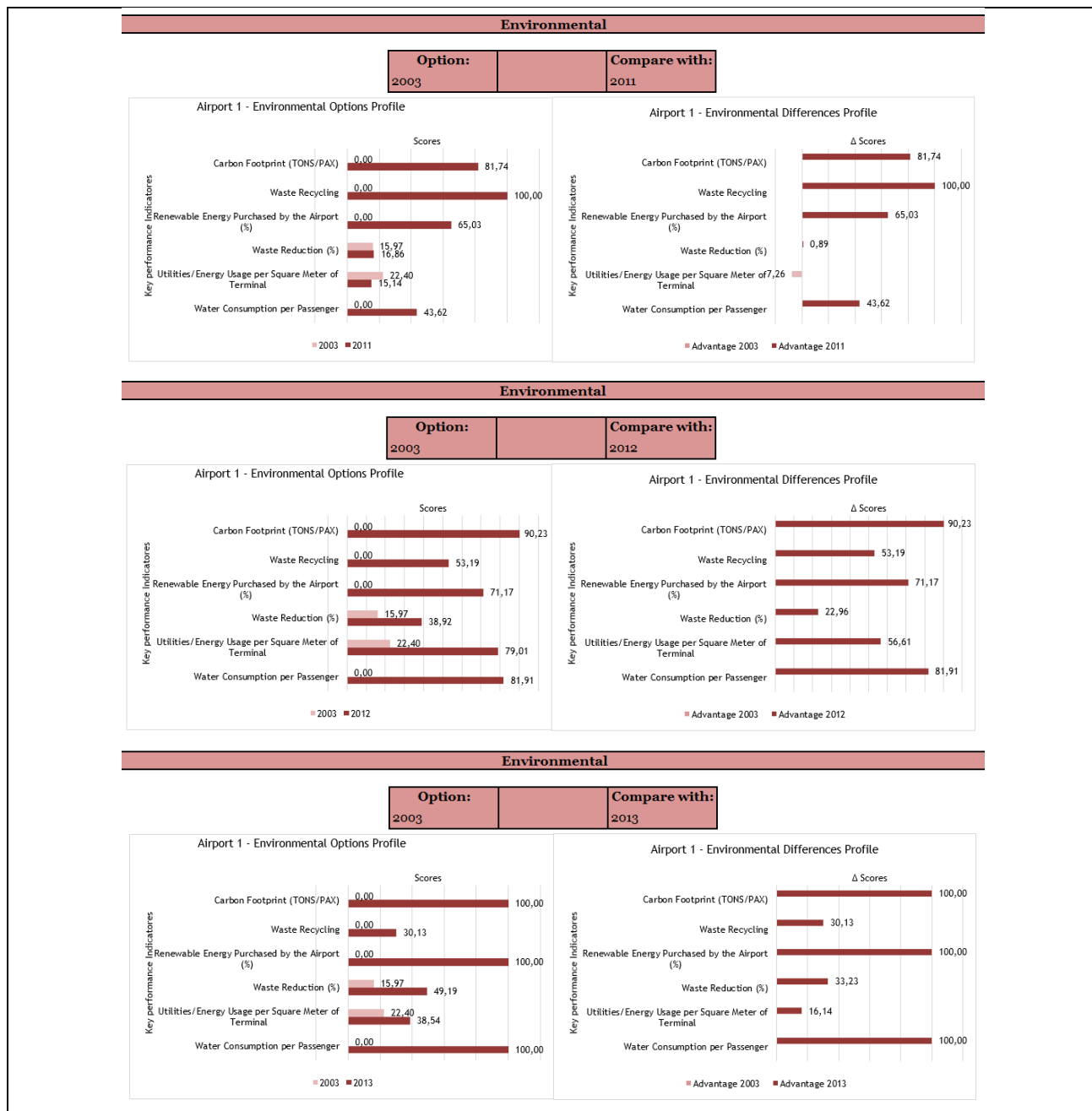


Figure A2. 57 - AIRPORT IN STUDY 2003 to 2011-2013 Environmental KPI Options and Difference profiles
Source: Own Elaboration

Appendix 3 – GDA PESA-AGB Survey

A3 - GDA Model Survey

A3.1 - Introduction

The online survey proposes to obtain the evaluation performance profile to attain by the experts' judgments. The online survey was sent to more than five hundred experts in 2015 [129], and a total of 90 answers were obtained (Table A3. 1) from North and South America (22%), Europe (73%), Asia (3%) and Australia (1%). Note that the PESA-AGB model does not rely on the number of answers but the quality and relevance of the answers to each KPA under study. The percentage summary of the sample by profession/expertise is depicted in Table A3. 2.

Table A3. 1 – Survey Answers.
Source: Own elaboration

KPA	Survey Answers
Core	22
Safety and Security	19
Service Quality	18
Productivity/Cost Effectiveness	13
Financial/Commercial	10
Environmental	8
TOTAL	90

Table A3. 2 - Summary of the sample.
Source: Own elaboration.

Profession/Expertise:	Answers %
Aeronautical Engineer	40%
Airport Specialist	10%
Professor	7%
Airport Safety	7%
PhD Student in Airport Development	5%
Airport Infrastructure Specialist	4%
Airport Manager	4%
Civil Aviation Regulation Specialist	4%
Air and Space Law Specialist	2%
Air Transport Advisor	1%
Airport IT consultant	1%
ATC Safety Analysis	1%
Chemical engineer	1%
Civil Aviation Senior Advisor	1%
Fleet Manager	1%
Civil Regulator - ANAC	1%
Operational ANS Performance Expert / Airport Performance	1%
PhD Transport Systems	1%
Post-Doc researcher - Mechanical Eng.	1%

Profession/Expertise:	Answers %
Technical Director	1%
Transport economics	1%
Transport Systems Planning	1%
Transportation analyst, architect, town planner	1%

A3.2 - Survey table to rank KPAs in order of relevance

PESA-AGB model lead to the creation of six evaluation criteria called KPAs is presented to the experts in an introductory text of the survey. After the initial welcome stating the objective of the survey, the evaluation model is described. The text asks the experts what the more relevant ones are by ranking the areas from very weak to extreme regarding their relevance. Each area must have only one rank, but the same rank can be attributed to several areas (Figure A3. 1).

Please rank the following areas in order of relevance: *
 You may give the same rank to different areas, being 1 the least relevant and 6 the most relevant.

	Very Weak (1)	Weak (2)	Moderate (3)	Strong (4)	Very Strong (5)	Extreme (6)
Core	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Safety and Security	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Service Quality	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Productivity/Cost Effectiveness	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Financial/Commercial	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Environmental	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>

Figure A3. 1 - Survey table to rank KPAs in order of relevance
 Source: Own elaboration

A3.3 - Survey table to rank KPIs in order of relevance

The next step in the survey is the possibility of choosing an area of expertise among the six proposed KPAs, Figure A3. 2. Every KPA can be chosen but are answered one at a time.

Your area of expertise is: *
 (select one)

▼

- Core
- Safety and Security
- Service Quality
- Productivity/Cost Effectiveness
- Financial/Commercial
- Environmental

Com tecnologia
 Google Forms

Figure A3. 2 - Survey choosing an area of expertise among the six proposed KPAs
 Source: Own elaboration

Following KPA choice, a KPA objective explanation and the KPIs of this KPA are presented, Figure A3. 3.

Service Quality

Service quality indicators focus both on how passengers perceive the level of service provided by the airport, and on objective measures of service delivery.

This area include the following Indicators:

- 1- Practical Hourly Capacity
- 2- Gate Departure Delay
- 3- Taxi Departure Delay
- 4- Customer Satisfaction
- 5- Baggage Delivery Time
- 6- Security Clearing Time
- 7- Border Control Clearing Time
- 8- Check-in to Gate Time

Figure A3. 3 - Survey Objective and KPIs of Service Quality KPA
Source: Own elaboration

In the next step, it is asked to rank in order of relevance the KPIs of the chosen KPA (Figure A3. 4).

Please rank the following indicators in order of relevance: *

You may give the same rank to different indicators, being 1 the least relevant and 6 the most relevant.

	Very Weak (1)	Weak (2)	Moderate (3)	Strong (4)	Very Strong (5)	Extreme (6)
Practical Hourly Capacity	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Gate Departure Delay	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Taxi Departure Delay	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Customer Satisfaction	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Baggage Delivery Time	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Security Clearing Time	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Border Control Clearing Time	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Check-in to Gate Time	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>

Figure A3. 4 - Survey table to rank KPIs in order of relevance
Source: Own elaboration

A3.4 - Survey KPI (Criteria) Judgment Matrix

After the rank in order relevance, a step by step demonstration on how to fill out the judgement matrix for all KPIs of the selected KPA is done. It is essential to guide the experts' answers to avoid inconsistent judgements, as depicted in Figure A3. 5.

Practical Hourly Capacity

Maximum aircraft movements per hour assuming average delay of no more than four minutes, or such other number of delay minutes as the airport may set.

	A	B	C	D
A	No	AB	AC	AD
B		No	BC	BD
C			No	CD
D				No

THE BIGGEST DIFFERENCE (points to AD)
THE INTERMEDIATE DIFFERENCE (points to BC)
THE SMALLEST DIFFERENCE (points to CD)

A refers to the maximum Practical Hourly Capacity over the course of 10 years;
 D refers to the minimum Practical Hourly Capacity over the course of 10 years;
 B and C are intermediate values equally distributed between A e D.

- AD - A is more attractive than D. The difference is? (Question 1)
- AC - A is more attractive than C. The difference is? (Question 2)
- BD - B is more attractive than D. The difference is? (Question 3)
- AB - A is more attractive than B. The difference is? (Question 4)
- BC - B is more attractive than C. The difference is? (Question 5)
- CD - C is more attractive than D. The difference is? (Question 6)

Figure A3. 5 - Survey explanation on how to fill out the judgement matrix for all KPIs
Source: Own elaboration

For each KPI judgment matrix, six questions were asked. Thus, A refers to KPI best option, D refers to KPI worst option, B and C were intermediate values equally distributed between A and D. It was proposed to answer these questions six semantic attractiveness difference categories: “very weak,” “weak,” “moderate,” “strong,” “very strong” or “extreme,” to fill all KPI’s judgment matrix Table A3. 3. It is obtained using a weighted arithmetic mean of each KPI's answer and using Table A3. 4 to the correspondent category.

Table A3. 3 - Screening questions for the difference of attractiveness for passengers KPI of Core KPA.
Source: Own elaboration.

Passengers						
RANK	AD	AC	BD	AB	BC	CD
No Difference (wheight: 0)	1	1	1	1	1	1
Very Weak (wheight: 1)	0	0	0	0	1	1
Weak (wheight: 2)	0	0	0	4	2	5
Moderate (wheight: 3)	0	3	2	9	12	7
Strong (wheight: 4)	2	11	13	6	5	4
Very Strong (wheight: 5)	13	7	5	2	0	3
Extreme (wheight: 6)	6	0	1	0	1	1
Weighted Arithmetic Mean	4,955	4,000	4,045	3,136	3,045	3,136
Difference of Attractiveness	Strong-Very Strong	Strong	Strong	Moderate	Moderate	Moderate

Weighted Arithmetic Mean (WAM) Equation (A7. 1), of the survey answers using rank distribution, is calculated by multiplying the weight of the rank by the number of answers and dividing the result by the total number of answers:

$$WAM = \frac{[(Rank = 1) \times n^{\circ} \text{ very weak answers}] + \dots + [(Rank = 6) \times n^{\circ} \text{ extreme answers}]}{(n^{\circ} \text{ total answers})}$$

Equation (A7. 1)

Table A3. 4 - The difference between attractiveness categories.
Source: Own elaboration.

Difference of Attractiveness	Weighted Arithmetic Mean
Extreme	6.000
Very Strong-Extreme	[5.5, 6[
Very Strong	[5, 5.5]
Strong - Very Strong	[4.5, 5]
Strong	[4, 4.5]
Strong - Moderate	[3.5, 4]
Moderate	[3, 3.5]
Weak - Moderate	[2.5, 3[
Weak	[2, 2.5[
Weak - Very Weak	[1.5, 2[
Very Weak	[1, 1.5[
No - Very Weak	[0.5, 1[
No	]0, 0.5[

Table A3. 5 shows an example of the difference in attractiveness of the airport's criteria in study passengers per employee KPI. The model produces this output for all KPI and remains unaltered for all the airports in the study.

Table A3. 5 - Judgement matrix passenger per employee KPI example.
Source: Own elaboration based on online survey results.

Descriptor value	Level	L3	L2	L1
Max over 11 years	L4	Moderate	Strong	Strong-Very Strong
1/3 below Max over 11 years	L3		Moderate	Strong
2/3 below Max over 11 years	L2			Moderate
Min over 11 years	L1			Null

A complete report with all KPIs judgement matrix for all KPAs can be found in appendix 2. Within the 90 answers, the distribution of KPA answers is depicted in Figure A3. 6

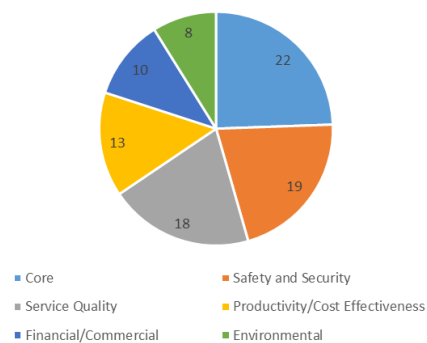


Figure A3. 6 - distribution of KPA answers by the experts
Source: Own elaboration based on online survey results.

Weblink to the survey: <http://goo.gl/forms/UFxeB2M663>

Email sent to experts:

“Dear all,

I am Maria Emilia Baltazar, and I am an Aerospace/Aeronautic PhD student at the University of Beira Interior – Portugal.

I am developing a work related to the development of a global tool to access airport performance and efficiency, based on the ACI classification of Key Performance Areas and Key Performance Indicators, and using a Multicriteria Decision Analysis Support tool; for a good implementation result, I need to obtain answers from specialists in the different fields of the survey, in quantity and especially in quality. Thus it was prepared a questionnaire/survey in which can be found on the link below.

<http://goo.gl/forms/UFxeB2M663>

I ask for your best attention and collaboration on this.

Therefore I am addressing you, and given that I intend to have answers in quantity - but above all in quality, I also ask you to forward this email to people in your professional sphere that you think can help me.

Grateful for your Attention and Availability”

**Annexe 1 - Measuring Attractiveness by a
Categorical Based Evaluation Technique
(MACBETH): mathematical**

Measuring Attractiveness by a Categorical Based Evaluation Technique (MACBETH): mathematical model

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

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

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

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

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

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

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

Where P^k In Equation A.2.1 represents the difference of attractiveness, which is stronger as k is bigger for a j criteria [98].

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 can 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 , with equations A.2.2 and A.2.3 in such a way that:

$v(x) = v(y)$ if and only if J judges the elements x and y to be equally attractive. Equation A.2. 2

$v(x) > v(y)$ if and only if J judges x to be more attractive than y . Equation A.2. 3

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 [106], 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 [141].

Performance Descriptors and Value Profiles

Let $h = 1, \dots, m$ designate the KPA, $j_h = 1_h, \dots, n_h$ 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 over all value are given by the simple additive model Equation A.2.4 and the hierarchical additive model Equation A.2.5.

$$v_h(x_{1_h}, \dots, x_{j_h}, \dots, x_{n_h}) = \sum_{j_h} k_{j_h} v_{j_h}(x_{j_h}) \quad \text{with} \quad \begin{cases} v_{j_h}(target_{j_h}) = 100, \\ v_{j_h}(neutral_{j_h}) = 0, \end{cases} \quad \text{Equation A.2. 4}$$

$$v(overall) = \sum_h (k_h \sum_{j_h} k_{j_h} v_{j_h}(x_{j_h})), \quad \text{Equation A.2. 5}$$

were $target_{j_h}$ and $neutral_{j_h}$ 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 [142].

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.

Theoretical aspects

I. Difference of Attractiveness

In the MACBETH method [106], when the decision-maker does his value judgments about the potential actions (alternatives) in each situation, he will do so in terms of his attractiveness for this alternative.

This task is defined [98] 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 the value difference between x and y numerically, 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 [143] "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 the one hand, the MACBETH method introduces a real line-associated interval 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 [144], 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 the difference of attractiveness semantics categories across a range of real numbers numerically.

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

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

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

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

II. Matrix of value judgments

It is necessary to construct matrices of value judgments, to facilitate the expression of the absolute judgments of the difference of attractiveness between the pairs of alternatives. Figure A2.1 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, depicted in Figure A2.1.

	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 A2.1 – Matrix of value judgments for local evaluation of actions.

Source: Adapted from (Bana e Costa & Vansnick, 1994) [98].

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-makers 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 inconsistency.

Cardinal Inconsistency

Cardinal inconsistency occurs when the decision-maker generates a set of semantically consistent judgments but cannot be represented numerically. It is known from the theory [144], [145] that the numerical representation of multiple semi-orders by constant thresholds is not always possible.

The difference in attractiveness between alternatives x and z was indicated by the decision-maker, making it impossible to construct the constant thresholds because the theoretical condition cannot be respected. 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 the two alternatives is, for example, strong, this does not mean that the range of category C_4 is large, but instead 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.

- 1st LPP:

The 1st PPL verifies the existence of cardinal inconsistencies and mathematically is represented by LPP(I) with Equation A.2.6-A.2.10:

Min c

subject to

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

$$r1) s_1 = 0 \tag{Equation A.2. 6}$$

$$r2) v(x_1) = 0, \text{ where for } \forall x \in X, \text{ is } x P x_1 \tag{Equation A.2. 7}$$

LPP (I)

$$r3) k = \{2, \dots, 6\}: s_k - s_{k-1} \geq 1000 \tag{Equation A.2. 8}$$

$$r4) k = \{1, \dots, 6\}, (x, y) \in C_k : v(x) - v(y) \geq s_k + 1 - c \tag{Equation A.2. 9}$$

$$r5) k = \{1, \dots, 5\}, (x, y) \in C_k : v(x) - v(y) \leq s_{k+1} - 1 + c \tag{Equation A.2. 10}$$

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

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

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

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

- 2nd LPP

The 2nd PPL is responsible for constructing the Cardinal value that represents the set of judgments of the decision-maker. It is represented by the LPP (II) with Equation A.2.11-A.2.18:

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

$$r0) s_1, \dots, s_6 \geq 0; v(x) \geq 0 \forall x \in X; c \geq 0 \quad \text{Equation A.2. 11}$$

$$r1) s_1 = 0 \quad \text{Equation A.2. 12}$$

$$r2) v(x_1) = 0, \text{ where for } \forall x \in X, \text{ is } x P x_1 \quad \text{Equation A.2. 13}$$

$$r3) k = \{2, \dots, 6\}: s_k - s_{k-1} \geq 1000 \quad \text{Equation A.2. 14}$$

LPP (II)

$$r4) k = \{1, \dots, 6\}, (x, y) \in C_k : v(x) - v(y) \geq s_k + 1 \quad \text{Equation A.2. 15}$$

$$r5) k = \{1, \dots, 5\}, (x, y) \in C_k : v(x) - v(y) \leq s_{k+1} - 1 \quad \text{Equation A.2. 16}$$

$$r6) k = \{1, \dots, 5\}, (x, y) \in C_k : v(x) - v(y) = 0.5(s_k + s_{k+1}) + \varepsilon(x, y) - \eta(x, y) \quad \text{Equation A.2. 17}$$

$$r7) (x, y) \in C_6 : v(x) - v(y) = s_6 + 1 - \alpha(x, y) + \delta(x, y) \quad \text{Equation A.2. 18}$$

The numerical representation of semi-orders by constant thresholds, when constructed per the MACBETH method, admits infinite solutions. The criterion adopted by [98], [143] 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 criterion C_6 the minimization of the absolute deviation between the

alternatives value difference and $s_6 + 1$ point was chosen. Therefore, the objective function of (II) is 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 central category value of the difference of attractiveness to which they belong, plus an absolute deviation. This constraint is applied to all the parallel pairs belonging to C_k with $k = 1, \dots, 5$. For pairs with 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. It seeks to make the difference in value between pairs of alternatives belonging to the C_6 category as close as possible to the lower threshold of this category.

- 3th and 4th LPPs

When PPL (I) c is nonzero, there are inconsistencies in the value judgments of the decision-maker. The most appropriate procedure is reviewing the initial judgments, arguing with possible modifications to overcome inconsistency problems. LPPs (III) and (IV) show the possible causes of inconsistency) with Equations A.2.19- A.2.32. They present the same objective function, giving only the restrictions.

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

$$r_0) s_1, \dots, s_6 \geq 0; v(x) \geq 0 \forall x \in X; c \geq 0 \quad \text{Equation A.2. 19}$$

$$r_1) s_1 = 0 \quad \text{Equation A.2. 20}$$

$$r_2) v(x_1) = 0, \text{ where for } \forall x \in X, \text{ is } x P x_1 \quad \text{Equation A.2. 21}$$

$$r_3) k = \{2, \dots, 6\}: s_k - s_{k-1} \geq 1000 \quad \text{Equation A.2. 22}$$

LPP (III)

$$r_4) k = \{1, \dots, 6\}, (x, y) \in C_k : v(x) - v(y) \geq s_k + 1 \quad \text{Equation A.2. 23}$$

$$r_5) k = \{1, \dots, 5\}, (x, y) \in C_k : v(x) - v(y) \leq s_{k+1} - 1 \quad \text{Equation A.2. 24}$$

$$r_6) k = \{1, \dots, 6\}, (x, y) \in C_k : v(x) - v(y) = s_k + 1 - \alpha(x, y) + \delta(x, y) \quad \text{Equation A.2. 25}$$

$$r_7) k = \{1, \dots, 5\}, (x, y) \in C_k : v(x) - v(y) = s_{k+1} - 1 + \beta(x, y) - \gamma(x, y) \quad \text{Equation A.2. 26}$$

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

$$r_0) s_1, \dots, s_6 \geq 0; v(x) \geq 0 \forall x \in X; c \geq 0 \quad \text{Equation A.2. 27}$$

$$r_1) s_1 = 0 \quad \text{Equation A.2. 28}$$

$$r2) v(x_1) = 0, \text{ where for } \forall x \in X, \text{ is } x P x_1 \quad \text{Equation A.2. 29}$$

LPP (IV)

$$r3) k = \{2, \dots, 6\}: s_k - s_{k-1} \geq 1000 \quad \text{Equation A.2. 30}$$

$$r6) k = \{1, \dots, 6\}, (x, y) \in C_k : v(x) - v(y) = s_k + 1 - \alpha(x, y) + \delta(x, y) \quad \text{Equation A.2. 31}$$

$$r7) k = \{1, \dots, 5\}, (x, y) \in C_k : v(x) - v(y) = s_{k+1} - 1 + \beta(x, y) - \gamma(x, y) \quad \text{Equation A.2. 32}$$

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 introduces inconsistency problems. 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 $\beta(x, y)$ it is not exceeding the value of c by introducing $r4$ 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 with the best possible evaluation in this criterion and the worst in the other criteria.