UNIVERSIDADE
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Congress Proceedings

October 9-11, 2019

RIDITA 2019

VII Iberoamerican Air Transportation

Research Society International Congress

Air Transportation Sustainability Strategies: Technological, Operational, Economic, Social and Environmental.

FEUBI - Faculty of Engineering of the University of Beira Interior

RIDITA - Iberoamerican Air Transportation Research Society

October 2019 | Covilhã | Portugal

RIDITA2019

VII Iberoamerican Air Transportation Research Society International Congress

"Air Transportation Sustainability Strategies: Technological, Operational, Economic, Social and Environmental."

VII Congresso Internacional da Sociedade Ibero-americana de Pesquisa em Transporte Aéreo

"Sustentabilidade do Transporte Aéreo: Estratégias Tecnológicas, Operacionais, Económicas, Sociais e Ambientais"

VII Congreso Internacional de la Red Iberoamericana de Investigación en Transporte Aéreo.

"Sostenibilidad del transporte aéreo: estrategias tecnológicas, operativas, económicas, sociales y ambientales"

Covilhã (Portugal), October 9-11, 2019

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UNIVERSIDADE DA BEIRA INTERIOR
FACULDADE DE ENGENHARIA DA UNIVERSIDADE DA BEIRA INTERIOR
CALÇADA DA FONTE DO LAMEIRO
6200-358 COVILHÃ | PORTUGAL

Tel: +351 275 242 051
E-mail: ridita2019@ubi.pt
http://www.ridita2019.ubi.pt

¬ RIDITA2019

VII Iberoamerican Air Transportation Research Society International Congress - "Air Transportation Sustainability Strategies: Technological, Operational, Economic, Social and Environmental."

¬ Organized by

Faculty of Engineering of University of Beira Interior
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¬ Institutional Support

¬ Conference Chairman

Jorge Miguel dos Reis Silva

¬ Editors

Jorge Miguel dos Reis Silva
Maria Emília da Silva Baltazar

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¬ PREAMBULE

Escribir un pequeño prólogo para el libro de actas del VII RIDITA es muy agradable y satisfactorio, por la culminación de este ciclo en el que nuestra Red Iberoamericana de Investigación en Transporte Aéreo llega a su doceavo aniversario con una gran vitalidad y pertinencia.

Los trabajos que integran este séptimo volumen de nuestras memorias bienales han sido creados por investigadores iberoamericanos que provienen de Argentina, Colombia, México, España, y ahora en especial de Brasil y Portugal. La seriedad y profesionalismo con la que los Comités Organizador y Científico han realizado la revisión de los artículos, bajo el sistema doble ciego, garantiza una vez más su alta calidad.

Como es natural en los congresos de la RIDITA, gracias a la diversidad disciplinaria de sus socios, la variedad y riqueza de los temas tratados es muy amplia, incluyendo investigaciones en los campos de las ciencias económico – administrativas y la geografía, por supuesto la ingeniería aeronáutica y cada vez más destacadamente en los campos de la optimización matemática y otras técnicas de modelación.

La vitalidad de la investigación del transporte aéreo que se realiza en la región iberoamericana refuerza la pertinencia existencial de la RIDITA. Es verdad que la ciencia y la tecnología están más globalizadas que nunca; pero también es cierto que la cultura iberoamericana sigue siendo rica y singular, además de ser intensamente compartida por los casi setecientos millones de personas que habitan los veintidós países que integran la región. Nuestras naciones, cultura, geografía e historia demandan el conocimiento y tecnología creados por sus propios individuos y universidades, y con ello los espacios adecuados para su construcción, discusión y difusión. Esa es la misión de la RIDITA en el campo del transporte aéreo.

Ingrato sería no destacar el gran trabajo desarrollado por el Comité Organizador del VII RIDITA, encabezado por el Dr. Jorge dos Reis Silva, del Departamento de Ciencias Aeroespaciales de la Facultad de Ingeniería de la Universidad de Beira Interior. Para ellos nuestro eterno agradecimiento por hacer de este congreso un gran hito en la historia de nuestra red.

En estos doce años nos han acompañado grandes y generosos amigos, algunos ya nos han dejado, como nuestra inolvidable Cristina Barbot, a quien hemos dedicado este congreso, pero otros muchos han venido a sumarse y a tomar nuestras banderas como propias. Los tiempos, siempre son tiempos de renovación, el cambio es permanente. Yo tengo una gran confianza en las nuevas generaciones que construirán el futuro de nuestros países y tomarán nuestras organizaciones en sus manos, en su mente y en su corazón.

A todos nuestros socios y amigos les envío un gran abrazo con todo mi afecto.

Oscar Rico Galeana

Presidente de la RIDITA 2017 - 2019

The Faculty of Engineering of the University of Beira Interior, Covilhã (Portugal), received an honourable invitation from the Iberoamerican Air Transportation Research Society (RIDITA) to organise in 2019 the seventh edition of its international congress, the VII RIDITA.

It was with pleasure that the challenge was accepted, not only for the prestige of the Iberoamerican Air Transportation Research Society itself, but also for the opportunity to bring together this group of academics, researchers, and other stakeholders of the aviation sector, to one of the youngest Portuguese universities, located in the inner part of the country and in a low density territory, but pioneer in the creation in Portugal of Aeronautical Engineering degrees (bachelor, master and doctorate).

Among all modes, air transportation has developed the most in recent decades thus contributing to what is called Globalization. The world is now a Global Village because air transportation has greatly contributed to that.

The VII RIDITA - International Congress of the Iberoamerican Air Transportation Research Society, takes place at the University of Beira Interior, Covilhã, from October 9-11, 2019, precisely under the theme Air Transportation Sustainability: Technological, Operational, Economic, Social and Environmental. Strategies.

Welcome to Portugal, to Covilhã, and the Faculty of Engineering of the University of Beira Interior, and... enjoy the experience!

Covilhã and UBI, September 9, 2019

Jorge Miguel dos Reis Silva

Maria Emília da Silva Baltazar

¬ INTRODUCTION

The event aims to promote and disseminate air transport research in the Ibero-American region, in its scientific, academic, technological, applied, and informative aspects, as well as foster relations among members through scientific sessions, electronic media, and similar events. It pays particular attention to the cultural promotion of air transport research and the teaching of this subject, serving as a center of information and dissemination among stakeholders.

¬ CONGRESS TOPICS

A. Technological Strategies
A.1 Air Transport and Airports
A.2 Air Traffic Management
A.3 Aircraft
A.4 Other
B. Operational Strategies
B.1 Airports
B.2 ATFM
B.3 Aircraft
B.4 Air Transport System Analysis
B.5 Other
C. Economic Strategies

C.1 Economic Evaluation
C.2 Economic Regulation
C.3 Planning and Policy
C.4 Decision-making Processes
C.5 Air Transport Pricing
C.6 Other
D. Social and Environmental Strategies
D.1 Air Transport Sustainable Development
D.2 Air Transport Carbon Footprint Reduction
D.3 Air Transport Externalities
D.4 Health Impacts of Air Transport
D.5 Cultural and Social Issues
D.6 Other

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Junta Directiva: 2017 – 2019

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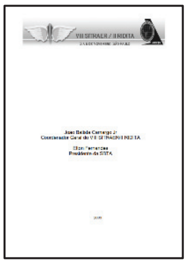
¬ Previous RIDITA Congresses

This event comes in the sequence of the successful of past congress and it is considered an Iberoamerican reference organization in the field of air transportation.




¬RIDITA2019 Statistics

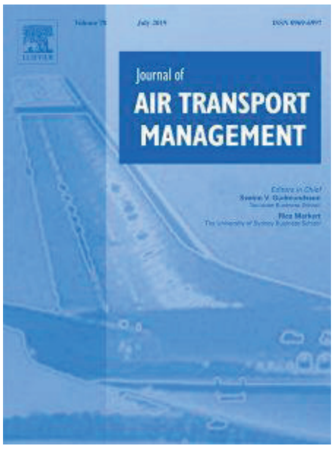
Total of 45 papers and 5 Invited Lectures presented on RIDITA2019.

7810 Visitors in RIDITA2019 Website

¬ SPONSORS

¬ SCIENTIFIC JOURNALS

Journal of Air Transport Management (JATM)



The **Journal of Air Transport Management (JATM)** sets out to address, through high-quality research articles and authoritative commentary, the major economic, management and policy issues facing the air transport industry today. It offers practitioners and academics an international and dynamic forum for analysis and discussion of these issues, linking research and practice and stimulating interaction between the two. The refereed papers in the journal cover all the major sectors of the industry (airlines, airports, air traffic management) as well as related areas such as tourism management and logistics. Papers are blind reviewed, normally by two referees, chosen for their specialist knowledge. The journal provides independent, original and rigorous analysis in the areas of Policy, regulation, and law, Strategy, Operations, Marketing, Economics and finance, and sustainability. Papers are welcomed covering key industry developments and trends, such as changes in government thinking towards air transport; evolving competitive environments and new industry structures; emerging and maturing markets and changing customer needs; sustainability and security challenges; and industry innovation and technological developments.

Case Studies on Transport Policy (CSTP)

Case Studies on Transport Policy covers this gap by providing a repository of relevant material to support teaching and transferability of experiences. Observation of field experience highlighting the details and drawbacks of implementation is invaluable to show how Transport Policy can be applied in the operational field, maintaining consistency with strategic options. Teaching with case studies introduces students to challenges they may face in the real world, and provides a very rich learning method for executive training at every institutional level. For practitioners, and specially governments, case studies are a powerful tool to show the potential benefits from policy measures and packages.

Journal of Airline and Airport Management (JAIRM)

Journal of Airline and Airport Management (2011) is an open access scientific journal. The aim of JAIRM is to publish theoretical and empirical articles that are aimed to contrast and extend existing theories, and build new theories that contribute to advance our understanding of phenomena related with air transport, from the perspectives of three main areas: Air Transport and globalization, Airlines, and Airports.

Focus and Scope

The aim of Journal of Airline and Airport Management is to publish theoretical and empirical articles that are aimed to contrast and extend existing theories, and build new theories that contribute to advance our understanding of phenomena related with air transport, from the perspectives of three main areas:

Air Transport and globalization. Future scenarios. The air transport roles in countries and regions economy, is proved as synergy engine in economic activity, both regarding globalization as well as in their cyclical and punctual dynamics, with special interest in the immediate scenes, foreseen for commercial aviation: Flows, supply and demand, promotional policy, and new environmental development opportunities. The impact in tourism of the current paradigm of air transport is also of interest, specially in those regions in which tourism is very valuable as well as those issues concerning air transport and information society and environmental policies.

Airlines. Regarding any business aspects, specially those involving low cost companies, Asian and Middle East growing companies as well as privatization procedures affecting legacy carriers nowadays. Airline marketing is also of interest as the market evolves faster and becomes more linked everyday and Airlines need innovative and specific solutions to maintain their passengers and to attract new ones. Strategic issues concerning positioning and managing the alliance portfolio also covers are also of interest.

Airports. From airport planning to operational analysis of capacity and flow optimization. Areas of interest cover any aspect susceptible of improving Airport operativeness.

The contributions can adopt confirmatory (quantitative) or explanatory (mainly qualitative) methodological approaches. Theoretical essays that enhance the building or extension of theoretical approaches are also welcome.

JAIRM selects the articles to be published with a double bind, peer review system, following the practices of good scholarly journals. JAIRM is published six-monthly exclusively on-line, and following an open access policy. On-line publication allows to reduce publishing costs, and to make more agile the process of reviewing and edition. JAIRM defends that open access publishing fosters the advance of scientific knowledge, making it available to everyone.

¬ CONGRESS PROGRAM

Time	*9 Oct 2019*	*Place*
10.00 H	**Registration (Until 17.30 h)**	**MSc Room**
11.00 – 11.30 H	**OPENING CEREMONY**	**Auditorium 8.1**
11.30 – 13.00 H	**Invited Lectures**	**Auditorium 8.1**
13.00 – 14.00 H	**Lunch**	**Room of Old Electrical Board**
14.00 – 16.00 H	**Air Transport and Airports Technological Strategies**	**Auditorium 8.1**
16.00 – 16.30 H	**Coffee Break**	**Hall of Auditorium 8.1**
16.30 – 19.00 H	**Air Traffic Management Technological Strategies**	**Auditorium 8.1**
20.00 H	**Welcome Reception**	**Malufa Garden**

Time	10 Oct 2019	Place
8.30 H	Registration (Until 17.30 h)	MSc Room
9.00 – 10.30 H	Invited Lectures	Auditorium 8.1
10.30 – 11.00 H	Coffee Break	Hall of Auditorium 8.1
11.00 – 13.00 H	Airports Operational Strategies	Auditorium 8.1
13.00 – 14.00 H	Lunch	Room of Old Electrical Board
14.00 – 16.00 H	Air Transport Operational Strategies	Auditorium 8.1
16.00 – 16.30 H	Coffee Break	Hall of Auditorium 8.1
16.30 – 19.00 H	Planning and Policy Economic Strategies	Auditorium 8.1
20.00 H	Congress Dinner	PuraLã Hotel
Time	11 Oct 2019	Place
8.30 H	Registration (Until 17.30 h)	MSc Room
9.00 – 10.30 H	Invited Lectures	Auditorium 8.1
10.30 – 11.00 H	Coffee Break	Hall of Auditorium 8.1
11.00 – 13.00 H	Decision-making Processes Economic Strategies	Auditorium 8.1
13:00 – 14.00 H	Lunch	Room of Old Electrical Board
14.00 – 16.00 H	Air Transport Sustainable Development Social and Environmental Strategies	Auditorium 8.1
16.00 – 16.30 H	CLOSING CEREMONY	Auditorium 8.1
17.00 – 18.00 H	RIDITA General Assembly	Auditorium 8.1

¬THE CITY

COVILHÃ
A TECER O FUTURO

Covilhã is a welcoming city in the center of Portugal, combining an ancient history with a social dynamism, full of contemporaneity and future. It´s in this sense that this dynamic and academic town, owner of a strong economic and social life, cultural and sports vitality, offers to its visitors a wide range of social cultural and sports equipment, hotel service, health infra structure, in addition to the prestigious and acknowledged human and environmental surrounding.

Located at the base of Serra da Estrela, this county borders are the neighbor municipalities Penamacor, Belmonte, Manteigas, Seia, Oliveira do Hospital e Fundão. Geographically, Covilhã extends along the Serra da Estrela slopes and in green adjacent valleys of Cova da Beira, surrounded by the Zêzere River and its confluents. It's centered location, gives it a prominent position in the development axis, marked by the three major cities of the region: Guarda - Covilhã - Castelo Branco.

In a cultural landscape dominated by Serra da Estrela, the natives of Covilhã cultivate the art of hospitality, where sympathy, quality and excellence, it's a given.

In this stunning city with mild climate, calm, quiet and safe, located at 700 meters, with a 550 thousand hectares area and an estimated population of about 50 thousand people, there are recognized hotels and restaurants responding with excellence to any request; gastronomic sins based on rare ingredients like wild parsnip, shrub, juniper, mountain cheese or edible mushroom; museums that highlight disparate arts like religious art, wool or cheese; beyond the health tourism with a special reference to Unhais da Serra Spa.Also modernity reduced barriers and created needs, but not annihilated traditions and characteristics that make the soul of this region. All this implies the creation of symbolic ties of identification that generate confidence, taste and sense of belonging.

Covilhã, weaving the future. http://www.cm-covilha.pt

¬ UNIVERSITY OF BEIRA INTERIOR

UNIVERSIDADE BEIRA INTERIOR

The first steps towards what is now the University of Beira Interior were given in the 70's, when the Polytechnic Institute of Covilhã first opened, in 1973. The city, once regarded as the "Portuguese Manchester ", for its long tradition of the wool industry and the dynamics and quality of its textile production, had been affected during this decade, by a crisis at the industry level: large and small factories begin to reveal serious weaknesses that led to its closure, with disastrous social and economic consequences for the region.

It was against this backdrop and within the activities of the working group for the Regional Planning of Cova da Beira, which the idea of creating a higher education institution in the region appeared, in order to give its population the chance to continue their studies without migrating to other parts of the country, most often permanently. Thus, following the publication of Decree-Law No. 402/73 of 11 August under the so-called 'Veiga Simão Reformation', which led to the expansion and diversification of higher education, it was created the Polytechnic Institute of Covilhã (IPC), which received its first 143 students in 1975, enrolled in its two first programs of Textile Engineering and Management and Accounting. In July 1979, six years later, the institution becomes the University Institute of Beira Interior, through the publication of Law No. 44/79 of 11 September, which makes it effective.

The conversion of the University Institute in University of Beira Interior happened in 1986, through the publication of Decree-Law 76-B/86, 30 April. The first Rector of the Institution was Professor Dr. Cândido Manuel Passos Morgado, who remained in office between August 21st 1980 and January 19th 1996, when Prof. Dr. Manuel Santos Silva assumed his duties as Rector, remaining in office until June 19th 2009. Now, sworn in as the fourth Rector of the institution, Professor Dr. António Carreto Fidalgo.

Historical note

One of the most interesting physical characteristics of UBI is recovering ancient buildings of high historical, cultural and architectural value. Besides maintaining the city's landmarks, these are revitalized in spaces which are now devoted to teaching and research. The building of the Polytechnic Institute had also begun by restoring the old premises of the headquarters of the Battalion of Hunters 2, installed in the Marquis de Pombal established Royal Textile Factory, of an important architectural value, located in one of the traditional centres of industrial concentration in Covilhã, along the Ribeira da Degoldra. During the works of redevelopment in 1975, it has been discovered buried archaeological structures belonging to the Royal Textile Factory dyeing facilities, a leading manufacturer of woolen goods, built in the eighteenth century by the Marquis of Pombal.

After two campaigns of archaeological intervention and a full investigation, it was created the University of Beira Interior Wool Museum, opened in 1996. Thus, the old factory buildings located in the south entrance of Covilhã became, quite naturally, not only a logical solution and of continuity with regard to the physical expansion of the institution, but an option that resulted in an enormous benefit to the city in terms of urban planning and environmental impact, through the recovery of abandoned buildings or in ruins, which constitute a significant part of the industrial heritage of Covilhã, making the institution a unique case in the Portuguese University.

Among the most iconic properties, you will fi nd the Convent of Santo António, in Campus II, where the Rectory is located; the former palace of family Melo e Castro; the buildings of the Rato Factory; the Carpets Factory; the Factory of Moço; the Paulo Oliveira Factory; the Wool Manufacturing Company; and the Chapel of São Martinho, a Romanesque monument of the late twelfth century, classifed as of public interest that supports the religious service of UBI. It was also acquired the former house of the family Mendes Veiga, which today houses the Central Library of the University, after having completed the restoring project. In Campus I, the urban redevelopment culminated in the completion of the program Polis, an interesting leisure park that serves as a natural extension to the campus and that includes the project of the historic Ribeira da Degoldra. In the 1990s, it was decided to expand the University for the Northern End of town, near Ribeira da Carpinteira, where it was created Campus IV. UBI continues to grow. In 2004, the construction of the Faculty of Health Sciences began at Campus III, which was inaugurated the 30th April 2007 meeting thus the setup of the infrastructure of the medical school. With a physical space that already reaches 134,500 m2, the University welcomes nearly 7,000 students today.

Old factories converted in educational facilities

The university, in terms of education, is divided into faculties, which embrace the areas of knowledge which, by nature, belong to each one of them. So UBI comprises five faculties: Faculty of Science, Faculty of Engineering, Faculty of Social Sciences and Humanities, Faculty of Arts and Letters and Faculty of Health Sciences. You will find below a brief description of the engineering faculty, stating the main programs they offer. The structure of the programs at the University follow a three (years of graduation), two (years of Masters) and three (years of doctorate) scheme, with some exceptions of five years of graduation, including an integrated Masters. UBI has been recognized for excellence in implementing the diploma supplement with the award of the DS Label by the European Commission.

www.ubi.pt

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Air Transport Operational Strategies

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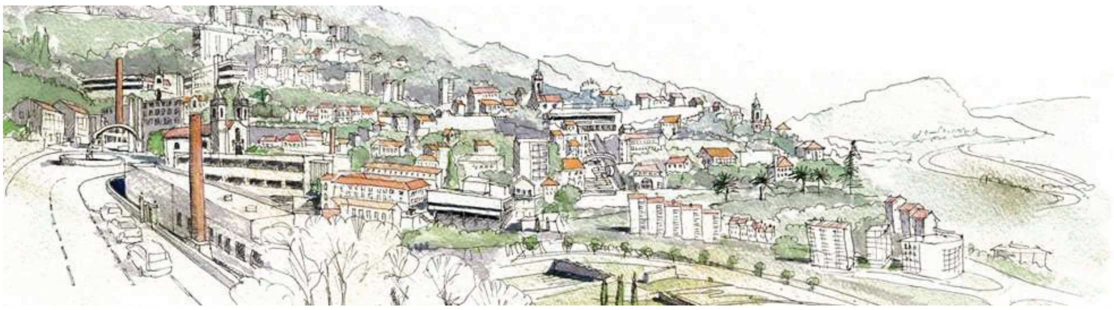
Decision-making Processes Economic Strategies

¬ RIDITA2019 SESSION - 7

Air Transport Sustainable Development Social and Environmental Strategies



Covilhã Aguarela by Jacek Krenz

VII Iberoamerican Air Transportation Research Society International Congress

Air Transportation Sustainability Strategies: Technological, Operational, Economic, Social and Environmental.

Air Transport and Airports Technological Strategies

Identifying the true European ‘low-cost airports’

Edgar Ramiro Jimenez Perez - e.jimenez@cranfield.ac.uk
Cranfield University
Pere Suau-Sanchez - p.suausanchez@cranfield.ac.uk
Cranfield University

Abstract

This paper discusses the long-term effects of low-cost carrier (LCC) presence at European airports and identifies the airports that have benefited the most from LCC consolidation during the current century.

The research uses ‘LCC Market Share’, in terms of seats, to measure the relative importance of LCCs within each airport; and introduces ‘EU LCA Rank’ as a normalised metric of the capacity share of every airport in the European low-cost segment. It evaluates the trends between 2001 and 2018 in a sample of the 300 largest European airports, by total seats in 2018, using OAG supply information (seats by carrier). Results highlight the role that LCCs have played in boosting the growth of airports, both primary and secondary, that were keen to appreciate the development of the low-cost segment earlier. Indeed, despite the fact that LCCs have put many airports on the European map, during the second half of the period of analysis growth has been more significant for major airports.

In that sense, this paper contributes a better understanding of the recent dynamics in European LCCs choice of airports and, in particular, the long-term effects that this disruptive business model have had for airports. Thus adding to previous contributions by [1]–[4].

Keywords

Low cost airport; Low cost carrier; Longitudinal analysis; European airports

Identifying the true European ‘low-cost airports’

1. Introduction and background

Despite the impressive growth of low-cost traffic over the last decades (see Figure 1), the academic literature is not yet conclusive on the long-term impact of Low-Cost Carriers (LCCs) for airports. Moreover, as airline business models converge, the impact extends to all airports and not only those with a greater focus on LCCs. In fact, LCCs in Europe use such a diverse range of airports that the notion of a ‘low cost airport’ (i.e. secondary, remote airports with single-story terminals, no executive lounges and sparse commercial areas) is being increasingly challenged as ‘legacy’ airlines and airports compete in a mature market. This paper discusses the role of LCCs in reshaping the map of LCCs across Europe.

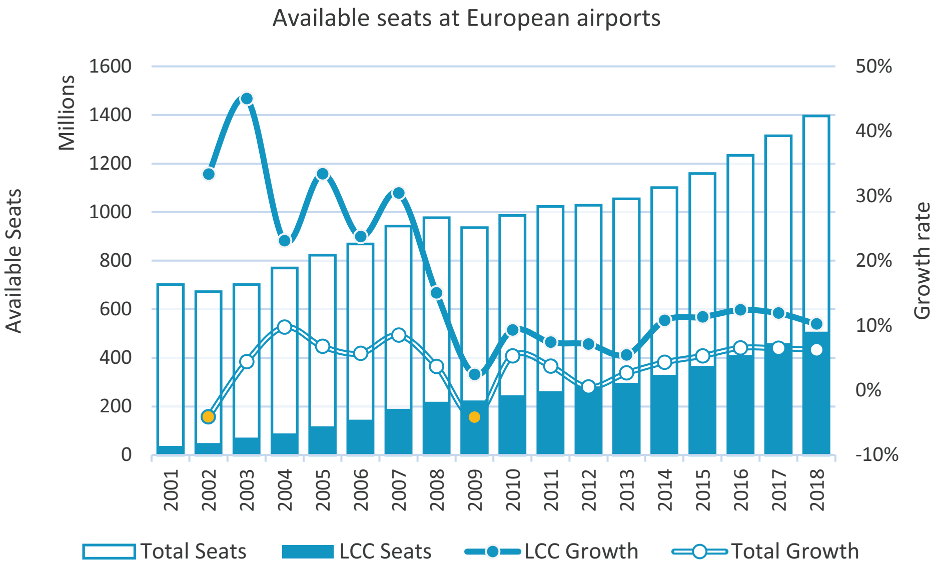


Figure 1. Evolution of LCC and total supply of seats at European airports. Source: [1]

1.1. ‘Low-cost airports’

The continuous growth of LCCs during the last decades motivated a number of research studies on the implications of this trend for airports. However, there is no consensual definition of what a 'low cost airport' may be. De Neufville [2] states “that the ascendency of low-cost airlines entails an increased importance and expansion of low cost airports and airport facilities”, in such a way that LCCs catalyse the development of low-cost airports. Therefore, LCC expansion triggered the emergence of 'low cost airports' and 'low cost facilities', not vice versa. In that sense, this research considers a 'low cost airport' is one that is used by LCCs to a large extent [3].

Kalakou and Macario [4] analysed the business models for different airport categories and found that 'low cost airports' do not follow a unique model. Yet the authors highlighted that in this category “the majority of the airports does not pay attention to the development of retail activities”. They studied Milan Bergamo, Brussels Charleroi, Rome Ciampino, London Luton, Liverpool and London Gatwick as 'low cost airports'. However, airports like Milan Bergamo, Brussels Charleroi and London Gatwick have expanded space for retail stores and food courts in recent years. Overall, the authors concluded that the volume and type of traffic have a strong influence on the airports business model. It would be interesting to analyse whether the opposite interaction also occurs (i.e. whether the business strategy influences traffic types and volumes).

ELFAA [5] also supported the view that LCCs favoured the development of previously loss-making secondary airports into major international airports serving large metropolitan areas. This encouraged other airports to make the transition and compete to offer low cost, efficient facilities to the growing number of LCCs.

Graham [6] reviewed 60 papers on the relationship between airports and LCCs and concluded that “the academic literature is far less clear and conclusive about the overall impacts of LCC operations at airports and the extent to which airports benefit from LCCs, particularly in the long-term.” Moreover, the review argued “that the LCC’s choice of airport is very much determined by its operating model, although through time a wide variation of models have evolved which has complicated the situation.”

Barret [7] identified seven factors for airports to be attractive for LCCs based on an interview with Ryanair's CEO. At the time of the interview (January 2003) Ryanair carried 15.7 million annual passengers using 56 aircraft and only two bases in continental Europe (Charleroi and Hahn). However, in 2018 Ryanair was already the largest European airline flying over 130 million passengers with 400 aircraft based across 86 airports. Thus the current importance of those original factors is debatable, even for an airline that has until recently largely adhered to its original model [8], [9]. Although, more research has attempted to identify “airport choice factors” for LCCs [10]–[13], literature is less focused on actually measuring how LCCs spread through a variety of airports.

Consequently, it is still commonly agreed that LCCs prefer to use 'secondary' airports [2], [3], [14]–[17]. However, Abda et al. [18] found that, in the USA, LCCs were had bigger market shares at primary airports, “contrary to the common perception that LCCs avoid primary airports and direct competition with the FSCs [Full Service Carriers]” [6]. The recent evolution of the aviation market in Europe hints towards similar developments as the business models of European LCCs evolve. Indeed Dobruszkes [15], [16], [19] has analysed the evolution of LCC networks in Europe but lacks details on the impacts for airports. This is covered on more recent research [20] that recognises the need to have more up to date results to account for the trend of some LCCs moving towards primary airports in Europe as well.

1.2. Evolving nature of LCCs

One of the main outcomes of liberalisation in the European aviation market was the emergence and rapid expansion of LCCs [21]. Yet, there is no single approach to the LCC business model, and the differences affect their decisions on the use of airports or airport infrastructure. Considering their individual history, LCCs can be categorised in three groups. First, the *original* LCCs are airlines deliberately organised around the 'low-cost' theme (such as easyJet, Ryanair, Norwegian or Vueling). Second, there are *descendants of charter airlines* that, confronted with decreasing market shares as the “originals” expanded [22], [23], transformed to LCCs and inherited an operational and network structure (such as the now extinct Monarch, Jet2.com or SmartWings). Third, there are *spin-offs* of the traditional, legacy carriers that were set to compete with the *originals* on a similar cost-base (such as GO, Buzz and Clickair in the past, or Germanwings/Eurowings and Iberia Express).

Nevertheless, there are also differences in the models used by airlines within each group. Yet, in general lines, the *originals* chose to capture market at secondary airports (i.e. easyJet at Luton, then Liverpool; Ryanair at Stansted, then Charleroi, and so on). This is different from *FSC spin-offs* and *charter-descendants*, which correspondingly operate from the same bases as their parents or predecessors. More importantly, the groups represent a dynamic evolution:

originals became large and took market from charters and FSCs, who responded by transforming themselves or by creating spin-offs. In the USA these dynamics led to the convergence of costs, fares and business models [18], [24], [25]. In Europe convergence is occurring as well [26], and not only from the transformation of traditional legacy airlines. LCCs – including the *originals* – are also refining their product to attract segments that are less price sensitive because, as they mature, their unit costs (labour in particular) tend to increase. As Christensen et al. [27] explain, across industries "the path to greater revenue is upmarket migration".

As former new entrants go upmarket, the bottom empties enough to encourage disruptive innovations of new entrepreneurs. In the USA this resulted in the emergence of so-called ultra-LCCs like Allegiant and Spirit (both transformed from charters). Arguably, European companies like Ryanair, Wizz Air and Pegasus already applied the ultra-LCC model; hence, there is less room to stimulate new markets with even lower fares. Therefore, they can only do something similar by moving to major airports that were previously not part of their networks.

Irrespective of how airline business models continue to evolve, and airlines group to consolidate, airports should monitor and be ready to accommodate changes. If the expansion of LCCs provides any lesson to airports, it is that their development should be flexible enough to cope with the uncertain future. In this sense, the rest of this paper discusses how LCCs in Europe have impacted both secondary and main airports.

2. Sample and data selection

In order to assess the long-term effects of LCC presence at European airports and identify the airports that have benefited the most from LCC consolidation, this research evaluates the trends of airline supply between 2001 and 2018. Supply information consists of annual available seats by carrier and departure airport according to OAG database [1]. Data comes from a sample of the 300 largest European airports by total seats in 2018. "Europe" includes all countries defined in OAG regions EU1 (Western Europe) and EU2 (Eastern/Central Europe). This denomination includes all of the Russian Federation, Georgia, Azerbaijan, Armenia, Turkey, Cyprus and the Balkans, and it is consistent with IATA's definition of "Europe".

The classification of Low-Cost Carriers follows OAG Mainline/Low Cost categories. This approach capitalises on OAG's knowledge on the industry and avoids a subjective analysis of over 1000 airlines that appear on the database, for which detailed information on unit costs is not available. Similarly, the main variable of interest for the research, 'available seats', include all regular scheduled departures by all carriers from airports in EU1 and EU2 regions towards all regions in the world. This prevents the under-representation of the major European hubs and extends the analysis beyond the intra-European market.

3. Measuring the impact of LCCs on European airports

Measuring the relative importance of LCCs at European airports is not a straightforward task. The largest European LCCs have wide networks with many more than 100 destinations each. At the same time, some airports may be completely dominated by LCCs but relying exclusively on a single airline or not having a significant size. Other airports became *bases* for LCCs (an airport where the carrier permanently positions aircraft and crew who return by the end of the day's rotations and park overnight) as these airlines established a considerable number of bases outside their registration countries and turned into truly pan-European carriers. Bases offer the carriers operational flexibility, and cost savings for routine aircraft maintenance and repair and crew recruitment [28]. They also contribute to the bargaining power of airlines against airports because they provide routes, passenger traffic and other economic benefits for the hinterland [29]. Therefore, an airport that is able to become an airline base may have more of the characteristics that make it attractive to LCCs.

Yet it may not be essential for airports to be a base. Paris Beauvais, for instance, handles nearly 4 million annual passengers without any based aircraft. Similarly, London Luton is the second largest airport for Wizz Air in terms of seats, but the airline only created a permanent base after Brexit became a real threat. Consequently, we propose more indicators to analyse the relative importance of LCCs at the airports under study.

3.1. Ranking airport participation in the low-cost segment

To analyse the level of consolidation of low-cost services, we measured the capacity deployed by LCCs in comparison with the total capacity available at the airport (i.e. the proportion of total annual seats provided by LCCs, out of the total for all the airlines at every airport). This variable, referred as '*LCC Market Share*', reflects the market share of LCCs in every airport market.

In order to analyse how airports compare with each other, we computed the share of every airport in the low-cost segment in Europe. This, the '*EU LCA Share*', corresponds to the proportion of seats offered by LCCs at each airport in relation to the total number of seats offered by LCCs in all European airports. To compare more easily with the previous variable ('*LCC Market Share*'), and to analyse the evolution of LCC influence along the period of analysis, we also created a rank by normalising '*EU LCA Share*' with respect to the airport with the largest number of seats provided by LCCs every year, i.e. the airport with the largest '*EU LCA Share*'. The resulting variable, refered as '*EU LCA Rank*' (see equation (1) for how to compute the variable for airport i in year t considering all airlines k), ranges from 0 to 1, where 1 corresponds to the airport that contributes the most to the European low-cost market. The variables '*LCC Market Share*' and '*EU LCA Rank*' respectively describe the market penetration of LCCs at an airport and the significance of an airport at European level for low-cost services.

$$EU\ LCA\ Rank_{it} = \frac{\frac{\sum_{k \in LCC} Seats_{kit}}{\sum_k Seats_{kt}}}{max_t\left(\frac{\sum_{k \in LCC} Seats_{kit}}{\sum_k Seats_{kt}}\right)} \qquad (1)$$

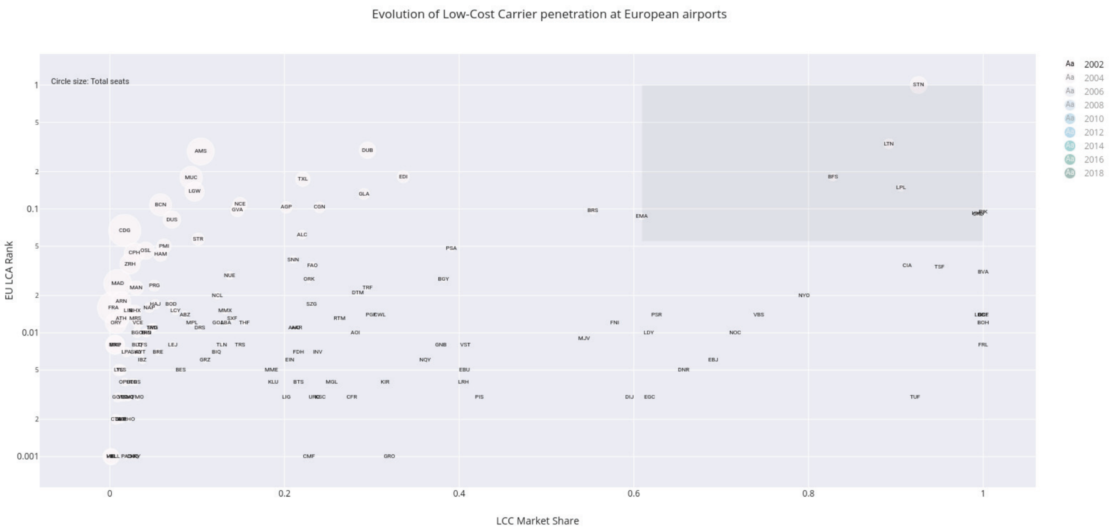


Figure 2. Participation of European airports in the low-cost market, 2002. Source: Authors based on [1]

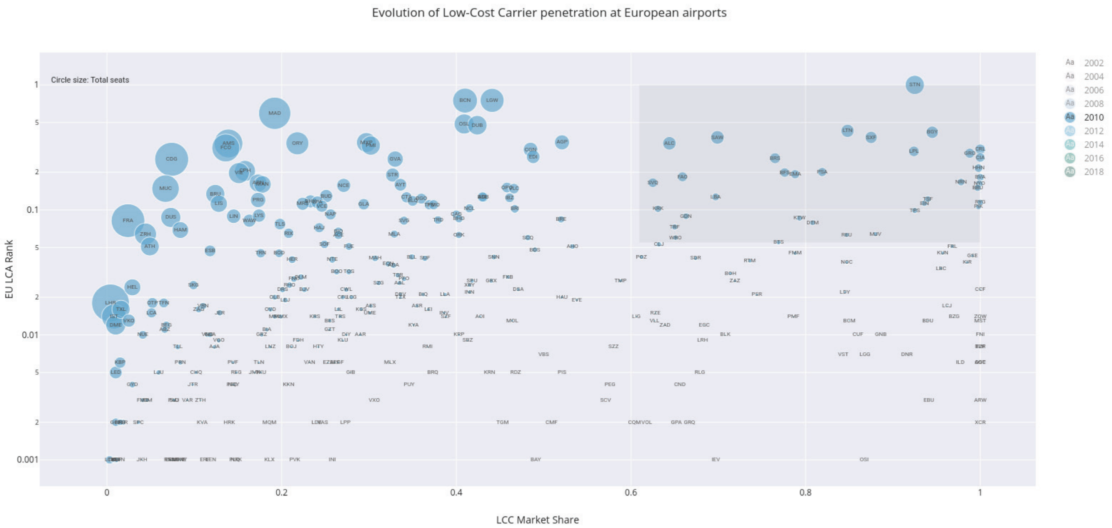


Figure 3. Participation of European airports in the low-cost market, 2010. Source: Authors based on [1]

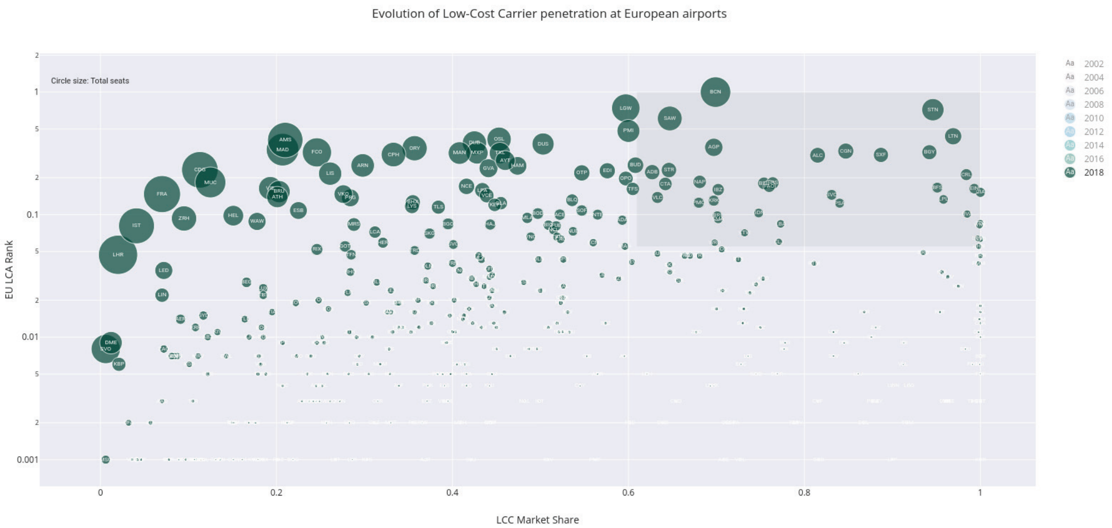


Figure 4. Participation of European airports in the low-cost market, 2018. Source: Authors based on [1]

Figure 2, Figure 3 and Figure 4 show the evolution of European airports according to the two metrics, '*LCC Market Share*' in the horizontal axis and '*EU LCA Rank*' in the vertical axis on a logarithmic scale to facilitate visualisation. The size of the circles in the figures represent the total number of seats provided by all airlines, hence the largest circles correspond to the largest airports in Europe. Two trends are clear from the analysis of these figures. First, LCCs have gained stronger market share in most airports in Europe, as the circles move to the right as time progressed. Second, the bulk of the growth in the low-cost market have remained with main airports and with those that were able to capitalise the initial phase of LCC ascendency, as the larger circles move up as time progressed.

In the end, by 2018 the largest 'low-cost airport' in Europe, i.e. the one providing the largest amount of seats by LCCs, was Barcelona El Prat airport. It provided 21 million seats by LCCs that accounted for 4.1% of the total low-cost market. Along with the main airports that figure prominently on the upper part of Figure 4, some airports traditionally regarded as 'low-cost' have been able to sustain a significant position in the segment, particularly London Stansted, London Luton and Milan Bergamo; as well as Brussels Charleroi, Rome Ciampino and Paris Beauvais, albeit to a lower extent.

4. Embracing LCC growth

Figure 5, Figure 6, Figure 7 and Figure 8 depict the rise of LCC presence at European airports from a geographical perspective. In 2001, few airports were dominated by LCCs. They were pioneers in the segment and, likely because of this, they set what became a standard for the kind of 'secondary' airport that literature often refers as a "requirement" for LCCs: uncongested, simple layout, normally single-story buildings with few amenities [3]; but overall, willing to support the nascent business model of new entrants and converted charters. These airports enjoyed a sort of golden era up to the global financial crisis (2008 - 2009). Indeed, some of them were able to retain a strong position after that, particularly London Stansted, London Luton, Brussels Charleroi and Rome Ciampino. However, the shift of some carriers (especially Ryanair) to main airports and the growth of other types of LCCs proved challenging for several of these pioneering ‘low-cost’ airports. Most notably Hamburg Lubeck that went bankrupt in 2014, Glasgow Prestwick, which went back to government ownership in late 2013, and Frankfurt Hahn.

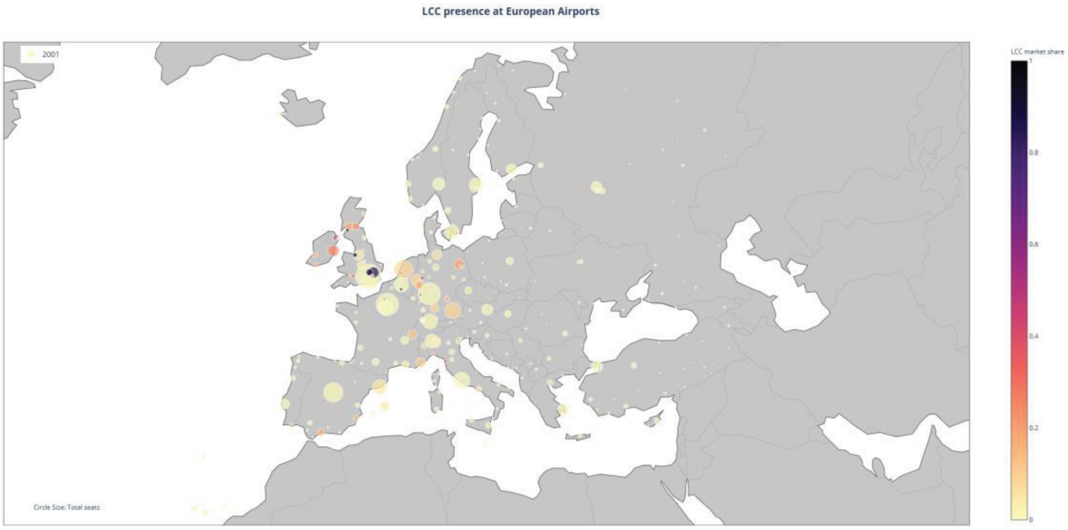


Figure 5. Evolution of LCC market at European airports, 2001. Source: Authors based on [1]

By 2018, several 'main' airports joined Barcelona as leaders in the low-cost market, such as London Gatwick, Dusseldorf, Stuttgart and Palma de Mallorca; along with Bucharest Otopeni and Sofia in Eastern Europe. Remarkably, and despite the role that LCC traffic has had in growing most French airports, only three airports in France are dominated by LCCs (LCC Market Share above 50%): Nantes, Paris Beauvais and Lille. Surprisingly, even though there is a marked dominance of LCCs in the Mediterranean and the Canary Islands, airports in Greece are not markedly dominated by LCCs. Secondary airports remain representative for low-cost traffic for Scandinavia.

On the other hand, airports in Iceland, Finland, Russia, Estonia, Latvia, Belarus, the Czech Republic, most of the Balkans (except Croatia and Macedonia) and Malta show a lesser penetration of LCCs (see Figure 8). That is not to say that LCCs have not grown in these locations, rather incumbent legacy carriers still hold a significant position, or the market is too small in relation to the whole of Europe.

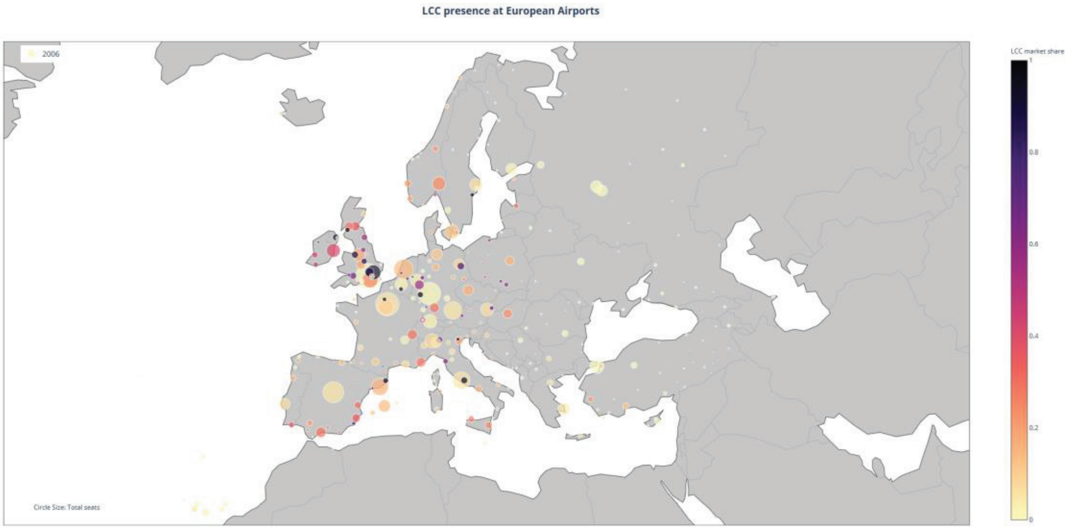


Figure 6. Evolution of LCC market at European airports, 2006. Source: Authors based on [1]

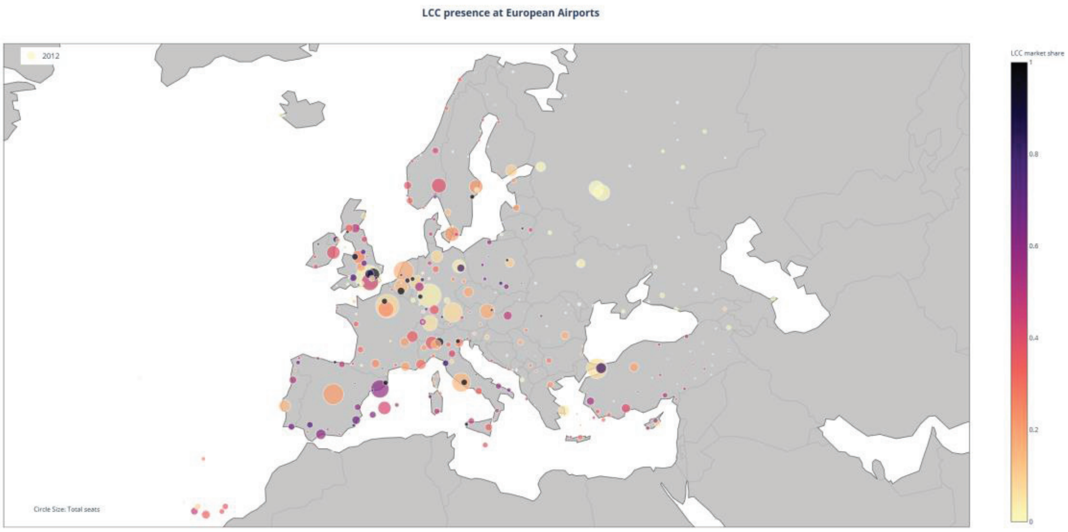


Figure 7. Evolution of LCC market at European airports, 2012. Source: Authors based on [1]

Indeed, by 2018 fewer airports remain with less than 10% LCC market share, such as London Heathrow, Frankfurt, Istanbul, Zurich, Sheremetyevo and Domodedovo in Moscow, Kiev Boryspil, along with "city" airports like London City, Milan Linate, Belfast City and Stockholm Bromma. Interestingly, as mentioned before, Greek airports are not dominated by LCCs either.

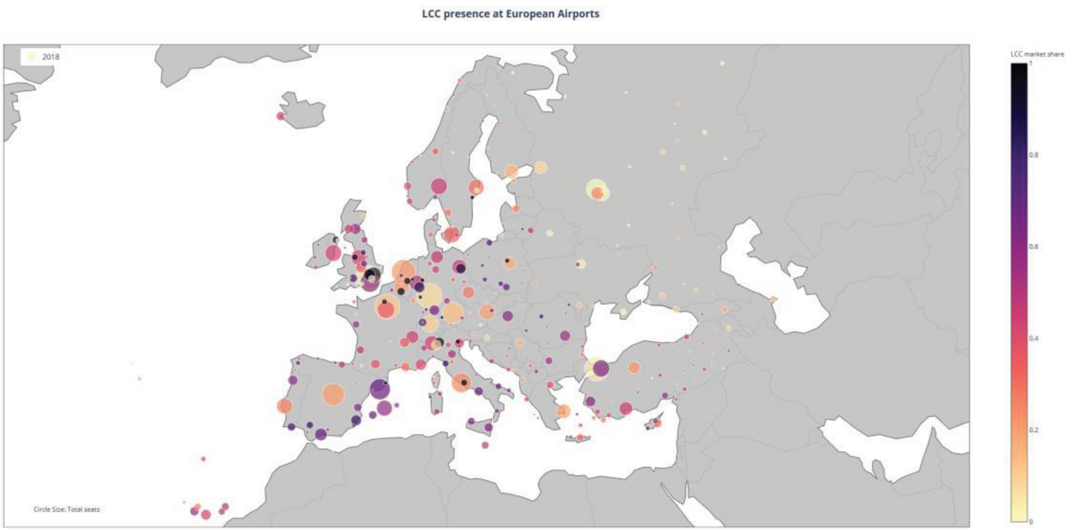


Figure 8. Evolution of LCC market at European airports, 2018. Source: Authors based on [1]

5. Conclusions

Results highlight the role that LCCs have played in boosting the growth of airports, both primary and secondary, that were keen to appreciate the development of the low-cost segment earlier. Indeed, despite the fact that LCCs have put many airports on the European map, during the second half of the period of analysis growth has been more significant for major airports. Hopefully this contributes to debunk the myth that LCCs *require* secondary airports. Instead, it should be considered how LCCs have transformed the entire airline and airport business to become mainstream. This is clear in the hybridisation of both legacy and original LCCs, sharing several operational and commercial practices, particularly in the intra-European market. For instance, as of 2019, no single major European carrier offers hold luggage or food included in the cheapest fare for intra-European flights, proving the acceptability of ‘no-frills’ and ancillary revenues with passengers of all carrier types. Similarly, operational practices such as disembarking using front and rear doors, even when using air bridges, have become increasingly common for legacy carriers.

As the differences between the business models of legacy and LCCs in Europe become increasingly blurred, the interesting question now is what would the next disruptive innovation in airline business be? LCCs transitioning to main airports have exacerbated the capacity crunch at major airports, whilst leaving available capacity at smaller regional airports that, arguably, could support the emergence of new business models.

Moreover, airports across Europe prove able to support different types of airline business models. This entails important insights for airports in other world regions where secondary or regional airports, with good infrastructure to support commercial air transport, are not as readily available as in Europe. Airports in South East Asia appear to be adapting to the impressive growth of LCCs, and long-haul low-cost, in the region. Airports in other regions where LCCs have started more recently, such as Latin America and Africa could be looking at these examples to harmonise the needs of LCCs within existent or planned infrastructure. Overall, managers of airports wishing to embrace the growth of LCCs require the adequate mindset to support strategic development that goes beyond specific infrastructure of a certain type or physical characteristics.

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Impact of the purchase experience at Brazilian airport terminal to improve non-aeronautical revenue

Lenice Mirian da Silva - lenice@ita.br
Aeronautics Institute of Technology - Brazil
Giovanna M R Borille - ronzani@ita.br
Aeronautics Institute of Technology
Michelle C G S P Bandeira - mgalvao20@gmail.com
Aeronautics Institute of Technology

Abstract

Non-aeronautical revenues are related to services characterized by commercial activities at an airport. Commercial facilities provide for airport customer purchase experience. This article discusses practices related to retail stores, food and beverage establishments, and a brief discussion of the value of non-aeronautical revenue.

The research was a case study of the Tancredo Neves/Belo Horizonte Airport (SBCF) in Brazil, with application of a questionnaire for 174 airport users. The study examines passenger profile regarding the purchase experience in the year 2019. The proposed method is based on linear regression. The results obtained are related to the values spent on the types of stores and segments, and travel purpose, in which certain customer profiles appear to be less satisfied with the value and cost-benefit criteria of the products, and the signaling to arrive the store.

An important growth of non-aeronautical revenues in the airport industry is a visible trend in Brazil and worldwide. Thus, the results of this study intend to contribute to the efficiency of airport planning.

Keywords

non-aeronautical revenues; shopping experience; passenger satisfaction; commercial activities

Impact of the purchase experience at Brazilian airport terminal to improve non-aeronautical revenue

Introduction

The revenues generated at the airport are divided into aeronautical and non-aeronautical. Aeronautical revenues include, for example, landing fees, passenger fees, aircraft parking fees, and handling fees, and non-aeronautical revenues refer to commercial facilities such as stores of all types of segments, food and beverages establishments and services [1]. Non-aeronautical revenues are important sources for the commercial performance of an airport and may be classified into categories: (i) duty-free shops, (ii) retail stores, (iii) bars and restaurants, (iv) banks and exchange offices, (v) kiosks and galleries, (vi) parking and rental car, among others [2].

Commercial facilities are directly related to purchases or consumption in commercial establishments of the passenger terminal, and since the customer is already known through satisfaction surveys, it is necessary to inspect their motivations in relation to purchases and consumption. It is observed that the business management of the airport has become a fundamental issue in the improvement of this market, since the airports dramatically increased their non-aeronautical revenues, which represent on average half of total revenues [3].

The non-aeronautical revenues received greater attention from the airports seeking to increase their profitability [4], in which through the study on commercial performance at 75 airports in 30 countries, the authors report that the percentage of passengers travelling to an international destination, airport size, space and the retail mix at the passenger terminal are considered decisive for the airport business. Another decisive variable for non-aeronautical revenues is the waiting time at the airport, where if the boarding time is less than 45 minutes, the profile of the customer who is traveling on business tends to consume more than the travelers on vacation/leisure [5].

Since the airport in its commercial facilities provides services to customers who are traveling, visiting, working or even accompanying passengers, these services need to be of quality. One way to measure this quality of services is through the airport user satisfaction survey.

The quality of the service related to the food and beverage category was studied at Olbia Costa Smeralda Airport (LIEO), Italy [6], in which the authors concluded that the age factor affects the level of satisfaction of passengers, where eldest passengers feel less satisfaction than the rest of the passengers. A study on the satisfaction of passengers in commercial areas at São Paulo/Guarulhos Airport (SBBR), Brazil [7], points out that frequent passengers are more satisfied with the cost-benefit of products and foods (the general perception of passengers was classified as "very dissatisfied"), and in relation to the quality of the products and food, passengers travelling to tourism or are less frequent at that airport had high assessments in the satisfaction analysis.

Table 1 presents the studies discussed here in the literature, where were highlighted the number of airports in the study, quantity and location of airports, the method used in the research and the analyses managed for each of the authors.

Table 1 – Literature review concerning airport commercial facilities. Elaborated by the authors.

RESEARCH-YEAR	#AIRPORT	LOCATION	METHOD	TOPICS
Torres et al. - 2005 [5]	1	Spain	Non-parametric regression	Expenditure, waiting time
Fasone et al. - 2016 [3]	15	Germany	Ridge Regression and partial least squares	Non-aviation revenues Business performance
Chiappa et al. - 2016 [6]	1	Italy	Fuzzy	Service quality
Freitas & Borille - 2017 [7]	1	Brazil	Logistic Regression	User satisfaction, commercial areas
Fuerst & Gross - 2018 [4]	75	Africa, Asia Pacific, Europe, North America, South America	Explanatory variables	Commercial revenues

In the following section, in *Data*, there is a brief discussion on the development of non-aeronautical revenues and the application of the in-situ interview. The *Methodology* section describes the method used to analyze the variables identified in the research. The *Results* section reports the contribution from this research. Finally, the conclusions are presented.

Data

This article has two approaches, the first being an analysis of the non-aeronautical revenues development at the Tancredo Neves/Belo Horizonte Airport (SBCF) from 2015 to 2018; and then an interview application with airport customers at 2019.

For preliminary analysis of the development of commercial revenues were considered the reports of the financial statements, and to verify the profile of customers as the experience of purchasing /consume at the airport an in-situ interview was applied through questionnaires with passengers, with the objective of analyzing the value consumed with variables related to the socio-demographic profile and stores segments, and find customer satisfaction regarding product value, cost benefit and signaling to reach the store. This paper aims to discuss the variables that exert influence on the dependent variables but does not intend to present the model as a prediction of non-aeronautical revenues, at this moment. This analysis will be further explored and presented in future publications.

Non-aeronautical Revenues Development

In this study it was found the distributions of types of stores and food that are offered at Tancredo Neves/Belo Horizonte Airport [8], such as cafeteria, imported items, restaurant, crafts, diner, accessories, ice cream shop, brewery, pharmacy, exchange offices, footwear, perfumery, clothes, relax lounge, sporting goods and bookstore, as shown in Figure 1, all spaces of public and restricted areas are considered. It is observed that most establishments are destined to cafeteria/snacks/sweets/juices segments with 33% of the total establishments of shopping and food stores.

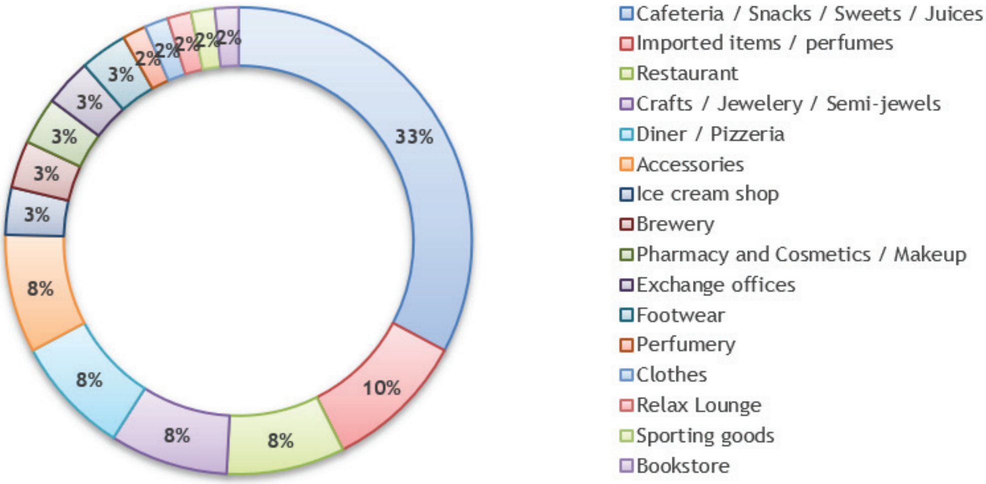

Figure 1 – Distribution of shopping and food stores at Tancredo Neves/Belo Horizonte Airport.
Source: [8] – Elaborated by the authors.

The Tancredo Neves/Belo Horizonte Airport is located in the Southeast region of Brazil, in the state of Minas Gerais, with a TPS area of 132,000 m^2, and has an annual movement (in 2018) of 10,256,169.0 passengers, being granted to the private initiative by auction in November 2013, where the concessionaire initiated the services of expansion, maintenance and exploitation of the airport in May 2014 for a period of 30 years [9]. As a result, it was observed that, in the year 2018, the airport already crowded between the five busiest airports in Brazil, representing 4,86% of the movement of passengers in the national context [10].

To compare non-aeronautical revenues per passenger at Tancredo Neves/Belo Horizonte Airport in the first years of concession and the development of revenues to date [11], the financial reports of the airport were considered, once they are published by the grantor - National Civil Aviation Agency (ANAC), where non-aeronautical revenues for this airport are related to parking revenues, renting spaces, terminal access and support services. It is noteworthy that for the year 2014, the availed revenues were made from August 2014, for this reason will be analyzed here from the next year.

Figure 2 compares the values between non-aeronautical revenues (in Reais, Brazilian currency) by passengers with the movement of passengers for the same period, where the non-aeronautical revenues per passenger were higher in the years 2016 and 2018 (R$8.71 and R$8.92 respectively), already for analysis of the movement of passengers, in 2016 there was a decrease in movement compared to the previous year (2015), and an increase for the following years 2017 and 2018, however for the year 2016 even with less passenger movement, the non-aeronautical revenues by passengers were higher in relation to the previous year, but with a decrease in 2017, and again growth in 2018. Quotation (in Reais) of the dollar are presented in relation to the national currency for information purposes.

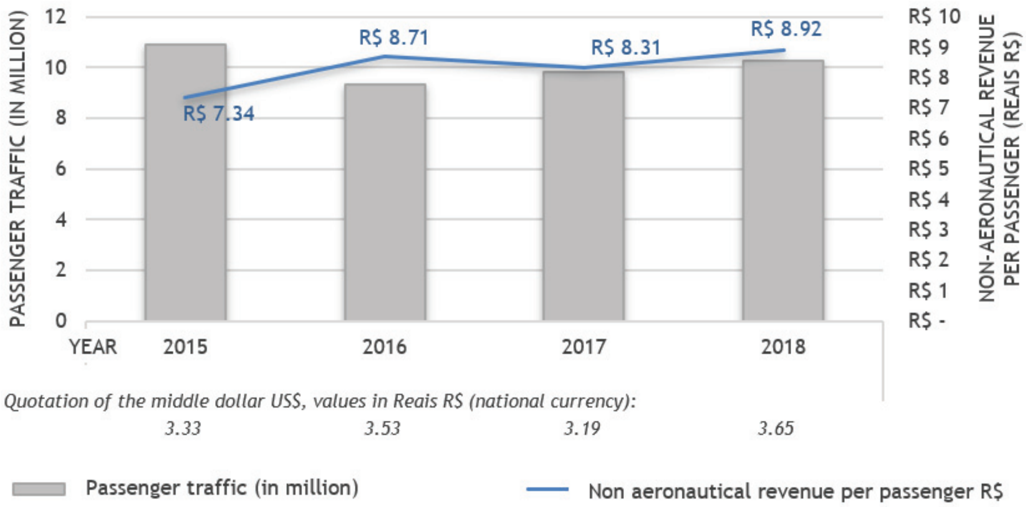

Figure 2 – Passenger traffic and Non-aeronautical revenue per passenger (R$).
Source: Financial Reports [11] and Currencies for BNDES [12]. Elaborated by the authors.

Figure 3 shows the distribution of aeronautical and non-aeronautical revenues, and how this relationship is distributed between the years 2015 to 2018. Among the year 2015 to 2016, non-aeronautical revenues were increasing, and in 2017 and 2018 there was a decrease in these revenues in relation to 2015-2016. It is observed, however, that between 2017 to 2018, the distribution of revenue remained the same, of 30% in relation to the sum of the aeronautical and non-aeronautical revenues.

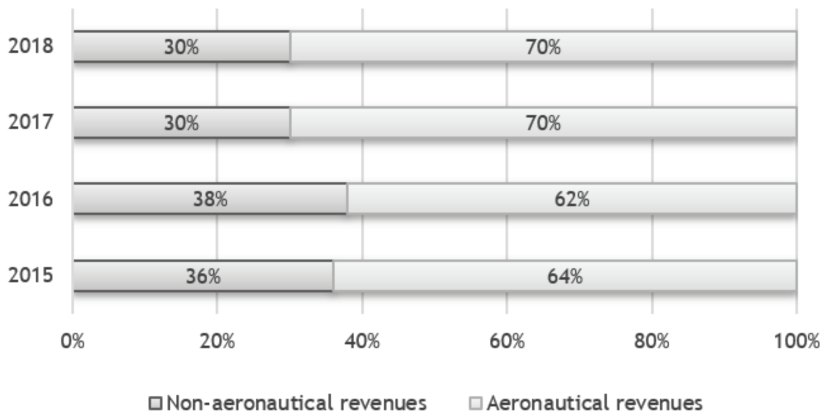

Figure 3 – Revenue distribution.
Source: Financial Reports [11]. Elaborated by the authors.

In-situ interview

The research was conducted in January 17-18, 2019, in public and restricted areas. A limitation of the research was the availability of authorization time by airport management due to operational issues at the airports. Thus, few hours of authorization were obtained for the research in the restricted area, and more time concentrated in the public areas of the terminal.

The interview with airport users was elaborated in a structured questionnaire, with the objective of collecting data about user profile and purchasing behavior. The first stage focused on the socio-demographic characteristics of all interviewees (total sample). In the

next step, for the interviewees who were traveling, they were also interviewed as: (i) which store they bought/consumed, (ii) type of product, and (iii) value spent, in Reais R$. The sample size for the interviews was based on the daily average passenger movement of the Tancredo Neves/Belo Horizonte Airport [10] for the month of January 2019, corresponding to 30.790 passengers paid (boarding and landing). It is considered as the population two days of the daily average, totaling 61.579 passengers, in accordance on the duration of the interview that happened in two days. To represent the portion of this population as the sample to be submitted to the application of the questionnaires, the confidence level of 95% (critical value of 1.96) and a margin of error of 8%, with *p* and *q* of 0.5, was adopted for this study. The *p* is the proportion of the population with the characteristics being analyzed. In the case of an unknown proportion, it is adopted as hypothesis: *p* is equal to 50% or 0.5. The complement, *q* is the proportion of the population that is not being analyzed, that is, 1-*p*, or *q* equals 0. Equation 1 is described below, with a sample of 150 individuals selected in the population of 61.579 passengers.

$$n = \frac{61{,}579 * 0.5 * 0.5 * (1.96)^2}{0.5 * 0.5 * (1.96)^2 + (61{,}579 - 1) * 0.08^2} = 149.7 \rightarrow 150\ samples \qquad \text{(Equation 1)}$$

Thus, 191 interviews were collected in two days, of which 174 were validated (n = 174 for total sample). Of the valid answers, 81 were obtained on the first day of the survey and 93 the next day.

In-situ research was carried out in the presence of a researcher at the airport, in the morning, afternoon and evening periods, in passenger flow locations that were in areas close to the check-in, security inspection, boarding gate to the aircraft, stores, corridors of circulation, food court, exit stairs, landing, access of the airport, and information desk, covering the public areas (area before the security inspection "X-ray") and restricted (area after safety inspection "X-ray"), according to Table 2, grouped in total sample and spending samples.

Table 2 – Profile and Area of the in-situ interview.

Sample	Description	Total (n=174) %	Spending (n=86) %
Profile	Boarding	79	84
	Landing	15	14
	Accompanying Pax	6	2
Area	Public	91	88
	Restricted	9	12

For a sample of customers who consumed or purchased (non-aeronautical revenues) were considered the passengers traveling, being those who were boarding or landing, and the small portion 2% of the sample that consumed but that were not traveling, this were not considered for analysis (Table 2), being the sample equivalent to n = 84 (Table 3), representing a total of 48% of the total sample, to be analyzed regarding the purchasing behavior.

Table 3 presents the socio-demographic profile of the interviewees regarding gender, age group, residents in the state (Minas Gerais) in which the airport is situated, nationality, educational level, and income. Distributions are presented for the total sample size and passengers who were buying/consuming.

Table 3 – Socio-demographic profile of the interviewees.
Source: Elaborated by the authors.

Sample	Type	Total (n=174) %	Spending (n=84) %
Gender	Female	53	57
	Male	47	43
Age	18 - 25	10	7
	26 - 35	30	27
	36 - 45	29	37
	46 - 55	16	15
	56 - 64	10	10
	> 65	5	4
Resident	Minas Gerais	49	35
	Other	51	65
Nationality	Brazilian	97	96
	Foreign	3	4
Educational level	Elementary School	3	4
	High School	13	13
	Graduate	44	37
	Post-Graduation	40	46
Income	0 - 1	8	4
(ranges of minimum wage	1 - 3	19	18
considering 1minimum	3 - 5	20	26
wage equal to R$ 998*)	5 - 10	26	15
	10 - 15	11	20
	15 - 20	5	4
	More than 20	8	9
	Uninformed	3	4

** Minimum wage for the year 2019, in which the quotation of the middle dollar US$, values in Reais R$ (national currency) in 2018 was 3.65 [12].*

Table 4 presents data referring to the airport passenger experience, verifying that the passenger was traveling alone or accompanied, what was the sensation when travelling by aircraft, travel purpose, travel frequency at the Tancredo Neves/Belo Horizonte Airport, if the location of the store disrupted your route at the airport, and if the customer had accessed the platform of the airport website as to the commercial facilities.

Table 4 – Customers Profile that spending.
Source: Elaborated by the authors.

Sample (n=84)	Type	Spending %
Accompanied	Pax alone	48
	Pax accompanied	52
Feelings	Relax	33
	Anxious	27
	Indifferent	36
	Uncomfortable	4
Purpose	Leisure	57
	Business	36
	Others	7
Frequency	<1 (eventually)	8
	First	19
	1 - 4	48
	5 - 12	14
	>12	11
Store Location disrupted	Yes	2
route at airport	No	98
Accessed the airport website as	Yes	8
to commercial establishments	No	92

In relation to the passengers who consumed in retail and food stores, 98% reported that the commercial establishments did not disrupted their route at the airport, and 2%

reported that the store disrupted the route at the airport. Regarding the access on the airport website platform as to the consultation of commercial facilities, a large parcel with 92% reported that they had not accessed the site, and only 8% consulted.

Methodology

To evaluate the research data, two stages were performed: first, the assessment of the perception and experience of the passengers on the products and services consumed at the airport terminal; second, the use of linear regression through the R software (RStudio). During the field research, to obtain the study data, an interview with the passengers was applied. For this purpose, a questionnaire was elaborated with commercial indicators regarding the product and the signaling to reach the stores related to food & beverage and retail, using scale from 0 to 10 (0 being “very bad” and 10 being “very good”) for measures of customer satisfaction.

The study variables were evaluated using linear regression models. The binary variables (dummies) are known as indicator, category, qualitative or binary variables that assume values of 1 or 0, where 1 indicates the presence of the analyzed attribute and 0 indicates its absence [13]. The models obtained to evaluate the variables in the study were described below. For each model, the Y was described as the dependent variable in the model in the Results section: (i) value spent (for all variables to verify significance), (ii) passenger satisfaction with respect to product value, (iii) passenger satisfaction with respect to the cost benefit of the product, and (iv) passenger satisfaction regarding signage to get to the store.

Regression and correlation are techniques used to estimate a relationship that may exist in the population, while the techniques previously studied (central tendency and dispersion measures: average, standard deviation, variance, etc.) are intended to estimate a single population parameter. The analysis of correlation and regression comprises the analysis of sample data to determine whether and how two or more variables are related with each other in a population. The correlation measures the strength, or degree, of relationship between two variables; regression gives the equation that describes the relationship in mathematical terms.

Data for regression analysis and correlation are derived from observations of paired variables. In the regression presupposes some relationship of cause and effect, of explanation of behavior between variables. In a simple regression of two variables results in the equation of a line, a problem of three variables implies a plane, and a problem of k variables implies a hyperplane.

In a multiple regression model, the dependent variable (Y) will be determined by more than one independent variable (X). Generically, a multiple linear regression model with k independent variables and p parameters (p=k+1) is presented in the following form (Equation 2):

$$Y_i = \alpha + \beta_1 X_{1_i} + \beta_2 X_{2_i} + \cdots + \beta_k X_{k_i} + \varepsilon_i \qquad \text{(Equation 2)}$$

Where:

- $\propto$ = is the expected value of Y when all independent variables are null;
- $\boldsymbol{\beta_1}$ = is the expected variation in Y given a unitary increment in $\boldsymbol{X_1}$, keeping constant all other independent variables;
- …

- $\boldsymbol{\beta_k}$ = is the expected variation in Y given a unitary increment in $\boldsymbol{X_k}$, keeping constant all other independent variables;
- $\boldsymbol{k}$ = number of independent variables;
- $\boldsymbol{\varepsilon}$ = is the error not explained by the model.

Results

The results point to models referring to the analyses: (i) value spent, in Reais R$ (for all variables to verify significance) presented in models #1, #2, #3 e #4 (Table 5 and Table 6), (ii) passenger satisfaction with respect to product value, presented model #5, (iii) passenger satisfaction with respect to the cost benefit of the product, presented model #6, and (iv) passenger satisfaction regarding signage to get to the store, presented model #7. For all models, the Confidence Intervals (CI) are presented, based on the statistics of the observed data.

Table 5 – Regression Value Spent to Model #1.
Source: Elaborated by the authors.

	Value Spent (Model #1)		
		Confidence Intervals	
Predictors	*Estimates*	*Lower limit*	*Upper limit*
(Intercept)	53.59	-91.91	199.09
Resident_MG	-15.27	-54.60	24.07
Pax Accompanied	-14.83	-46.47	16.81
Feelings Anxious	-22.98	-61.64	15.67
Feelings Indifferent	2.33	-34.84	39.51
Feelings Uncomfortable	-28.48	-119.95	62.98
Gender Female	10.19	-23.78	44.17
Travel Business	-7.72	-49.23	33.79
Travel Others	69.61 *	6.18	133.04
Age 26-35	-26.34	-91.34	38.67
Age 36-45	-32.24	-97.16	32.67
Age 46-55	-5.55	-77.31	66.22
Age 56-64	-16.50	-88.53	55.53
Age > 65	-29.00	-130.06	72.07
Nationality_BR	-2.35	-85.91	81.21
High School	17.06	-77.52	111.64
Graduate	-10.50	-94.35	73.35
Post-Graduation	13.16	-71.94	98.27
Income 1-3	-10.51	-104.12	83.09
Income 3-5	18.54	-80.40	117.48
Income 5-10	-25.69	-128.22	76.84
Income 10-15	1.80	-98.85	102.45
Income 15-20	-16.69	-151.54	118.17
Income > 20	-21.55	-133.38	90.29
Income Uninformed	-50.01	-168.32	68.31
Frequency < 1	20.56	-43.43	84.55
Frequency 1-4	17.60	-20.42	55.62
Frequency 5-12	14.98	-40.75	70.72
Frequency > 12	27.68	-37.42	92.79
Retail stores	114.46 ***	57.75	171.17
Observations	84		
R^2 / adjusted R^2	0.470 / 0.185		
* $p<0.05$ ** $p<0.01$ *** $p<0.001$			
F-statistic: 1.65 on 29 and 54 DF, p-value: 0.05565			

In linear regression with nominal variables (binary) used here were considered the equations with intercept, considering the differences in relation to the reference base, in which all categories were plotted, and for each category a variable was hidden for 84 observations. In this way, the dependent variable Y = value spent (values in Reais), that is, for all variables to verify significance, and then two more models in individual categories. Table 5 presents a model #1 with the following categories of variable independents: resident in other states, travel alone, fellings relax, age 18-25, elementary school, income until to 1 minimum wage, food & beverage store, frequency first, foreign nationality, gender male, travel leisure. It was observed in model #1 that the R^2 responds by 47% of the model variables, where the p-value of the F-test is significant 5%, that is, the regression model presents a prediction of the significant dependent variable.

Table 6 features the models #2, #3 and #4 with the following categories of independents variables: travel purpose (leisure, business and others), type of stores (retail and food & beverage) and by type segments of stores (cafeteria/snacks/sweets/juices, accessories, crafts, imported item/perfume, footwear, diner/pizzeria, bookstore, restaurant and ice cream shop), respectively. For all models cited, the dependent variable is the value spent, in Reais, with a hidden variable for each category. It was observed in model #2, #3 and #4, that the p-value of the F-test is < 5%, that is, the regression models are significant. The store segment regression model, model #4, 44% of their variables in relation to the value spent, in this way it can be said that the type of store or service of the terminal contribute to improve the non-aeronautical revenue of the airport. In relation to the models #2 and #3, it can be observed that there is a significant statistical relationship, however, the variables may be better explained with a greater number of observations.

Table 6 - Regression Value Spent to Models #2 #3 and #4.
Source: Elaborated by the authors.

	Value Spent (Model #2)			Value Spent (Model #3)			Value Spent (Model #4)		
		Confidence Intervals			*Confidence Intervals*			*Confidence Intervals*	
Predictors	*Estimates*	*Lower*[1]	*Upper*[2]	*Estimates*	*Lower*[1]	*Upper*[2]	*Estimates*	*Lower*[1]	*Upper*[2]
(Intercept)	35.72 ***	18.25	53.18	31.44 ***	18.86	44.01	27.74 ***	12.21	43.27
Travel Business	-3.56	-31.72	24.59						
Travel Others	78.62 **	26.23	131.01						
Retail stores				120.73 ***	73.68	167.79			
Accessories							102.26	1.63	202.89
Crafts							10.26	-90.37	110.89
Imported item/ Perfume							269.76 ***	197.76	341.76
Footwear							72.26	-28.37	172.89
Diner/Pizzeria							5.95	-19.95	31.86
Bookstore							22.26	-78.37	122.89
Restaurant							10.69	-20.96	42.33
Ice cream shop							12.26	-88.37	112.89
Observations	84			84			84		
R^2 / adjusted R^2	0.104 / 0.082			0.236 / 0.226			0.440 / 0.380		
* p<0.05 ** p<0.01 *** p<0.001									
	F-statistic: 4.708 on 2 and 81 DF, p-value: 0.1163E-01			F-statistic: 25.29 on 1 and 82 DF, p-value: 0. 2855E-05			F-statistic: 7.36 on 8 and 75 DF, p-value: 0.3529E-06		

[1] *Lower limit* [2] *Upper limit*

Table 7 presents the models #5, #6 and #7 where the dependent variable is the satisfaction of the passenger in relation to the value of the product (model #5, with categories of independent variables for gender and age group), cost-benefit of the product (model #6, with categories of independent variables for age group and frequency) and signage to the store in the terminal (model #7, with categories of independent variables age group and feelings). For each of the models, independents variables were defined, as shown in the table, with a hidden variable for each category. For all models cited, the p-value of the F-test is < 5%, that is, the regression models are significant.

The regression model on the satisfaction of the product value, model #5, showed that in the category age group when compared with passengers aged 18 to 25 years, passengers aged between 36 and 45 years and above 65 years are less satisfied with the values of the products practiced in the terminal, which can also be seen for the gender category, in which the female gender is less satisfied for this indicator than the male gender. The model #6, on the cost-benefit of the products and/or services showed that these same age classes are also dissatisfied with the cost-benefit of the products and/or services consumed in the terminal, already the most frequent passengers (more than 12 travels) in this Airport are more satisfied as to the cost benefit indicator. Lastly, the model #7 showed that passengers over 65 years old are dissatisfied with the terminal signaling on the way to the store. It was also observed that the indifferent feeling in the passenger presents a significant relationship with the satisfaction of the signaling in the terminal, that is, when compared to the passengers who have shown to be relaxed, the category indifferent feelings presented less satisfaction for this indicator.

Table 7 - Regression for customer satisfaction to Models #5 #6 and #7.
Source: Elaborated by the authors.

SATISFACTION	**Product Value (Model #5)**			**Cost Benefit of the Produt (Model #6)**			**Signage to get to the store (Model #7)**		
Predictors		*Confidence Intervals*			*Confidence Intervals*			*Confidence Intervals*	
	Estimates	*Lower[1]*	*Upper[2]*	*Estimates*	*Lower[1]*	*Upper[2]*	*Estimates*	*Lower[1]*	*Upper[2]*
(Intercept)	7.93 ***	6.08	9.77	7.77 ***	5.83	9.71	5.83 ***	3.05	8.60
Gender Female	-1.19 *	-2.21	-0.16						
Age 26-35	0.09	-1.92	2.10	-1.32	-3.23	0.59	2.05	-0.97	5.08
Age 36-45	-2.98 **	-4.92	-1.04	-1.99 *	-3.83	-0.15	1.98	-0.96	4.93
Age 46-55	-1.17	-3.33	0.99	-0.37	-2.42	1.67	2.68	-0.53	5.89
Age 56-64	-1.86	-4.21	0.49	-1.11	-3.36	1.15	0.22	-3.30	3.75
Age > 65	-4.20 **	-7.27	-1.12	-5.54 ***	-8.43	-2.65	-5.58 *	-10.12	-1.05
Frequency < 1				0.38	-1.49	2.24			
Frequency 1-4				0.32	-0.89	1.53			
Frequency 5-12				0.80	-0.77	2.36			
Frequency > 12				2.00 *	0.29	3.72			
Feelings Anxious							-0.72	-2.55	1.10
Feelings Indifferent							-1.89 *	-3.65	-0.13
Feelings Uncomfortable							0.50	-3.46	4.45
Observations	84			84			84		
R^2 / adjusted R^2	0.285 / 0.229			0.247 / 0.156			0.222 / 0.139		
* p<0.05 ** p<0.01	*** p<0.001								
	F-statistic: 5.112 on 6 and 77 DF, p-value: 0.0001824			F-statistic: 2.702 on 9 and 74 DF, p-value: 0.008913			F-statistic: 2.681 on 8 and 75 DF, p-value: 0.01197		

[1] *Lower limit* [2] *Upper limit*

The R^2 value, 0.47 (Table 5), means that only 47% of the indicator variation explains the amount spent by passengers. It may seem like a low value but as the data analysis represents a cross section in front of the volume of passengers circulating at the terminal daily, the values of R^2 are expected to be low for any models of this study, due to the diversity of units contained in the sample, as well as being research using categorical variables in the analysis of passenger profile in relation to purchasing behavior. Thus, the R^2 value presented in the following regression models (models # 2 to # 7) are even smaller than the main model (model # 1), because diversity increases for a smaller size of observations. However, note that this "low" value of R^2 is statistically significant, since all models presented highly significant F statistics, which validates the mentioned models and brings significant results to the analysis.

Conclusions

Through the availability of shops that are offered by the airport studied, it is evident a greater number of stores destined to category cafeteria/snacks/sweets/juices. As for the development of non-aeronautical revenues per passenger, it is observed that in relation to the last two years studied (2017 and 2018), both for the movement of passengers and non-aeronautical revenues by passengers, in the year 2018 had a growth in relation to the previous year. Considering the distributions of aeronautical and non-aeronautical revenues for the same period, it is noted that non-aeronautical revenues are equivalent to 30%, and aeronautical revenues for this airport represent 70%, at where this proportion has remained for last two years.

The arrangement of the shops (layout) in the airport passenger terminal, most of them, does not fumbled the path of passengers on their route within the terminal. Of the interviewees, it is perceived that a large parcel does not access the airport's website for information about commercial establishments, which can be a point of attention for airport managers, since technological trends are present in Airports, and accesses on digital platforms in the area of non-aeronautical revenues is of fundamental importance.

Regarding the value spent, average values consumed or spent vary according to store type and segment, where lower values are associated with food and beverage stores when compared to retail stores. Travelers who reported as "others" the purpose of the trip, they consumed/spent much higher values than leisure travelers. The product types (store) are strongly related to the value consumed, with higher values spent for the products of the stores of imported items/perfumes and lower values spent for the products of cafeteria/snacks/sweets/juices.

Concerning customer satisfaction, in relation to the value of the product, passengers with more than 65 years and 36 to 45 are more dissatisfied, and female passengers demonstrated to be less satisfied compared to male passengers. For the cost benefit, passengers over 65 years and passengers with 36 to 45 years are more dissatisfied and more frequent passengers (more than 12 trips a year at the airport) are more satisfied. Into the signage to reach the store, passengers over 65 years old are more dissatisfied, and the passengers who reported feeling indifferent are more dissatisfied, when compared to passengers who reported feeling relaxed.

For future studies, it is recommended to apply this research to other Brazilian airports, consider a larger sample for analysis with lower margin of error (including larger number of samples in the restricted area), compare other methods to measure customer satisfaction, and to consider passengers' waiting time.

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Análisis de las nuevas tecnologías y medidas en el sistema de gestión de equipajes

German Alberto Barragan De Los Rios - german.barragan@upb.edu.co
Universidad Pontificia Bolivariana
German Urrea Quiroga - german.urrea@upb.edu.ci
Universidad Pontificia Bolivariana
Andrea Carolina Montes Alis - andrea.montes@upb.edu.co
ISAE Supaero
Jorge Ivan Garcia Sepulveda - jorge.garcia@upb.edu.co
Universidad Pontificia Bolivariana

Abstract

Identificar los principales avances frente al tema de gestión de equipajes debido a su alta relación con el nivel de servicio ofrecido a los pasajeros por parte de las compañías aéreas.

Se realizo una busqueda documental que permitiera identificar las principales tendencias y avances tecnologicos frente a la gestión de equipajes y un posterior analisis sobre la informacion recolectada.

Una identificación de las problemáticas que se presentan actualmente en el sistema de gestión de equipaje de los aeropuertos, presentando las posibles medidas y tecnologías para alcanzar soluciones a estas propuestas tecnológicas y de gestión que mejoran el manejo de equipajes dentro de los aeropuertos y la percepción de nivel de servicio de los usuarios.

Keywords

Gestion de equipajes; Aeropuertos; RFID; EBT

Análisis de las nuevas tecnologías y medidas en el sistema de gestión de equipajes

INTRODUCCIÓN

En virtud de la fuerte expansión de la aviación civil en la última década, los aeropuertos y las aerolíneas han aumentado su dedicación con el fin de ofrecer un mejor servicio a sus pasajeros. Esto abarca desde el momento de la búsqueda y la compra de tiquetes (vía web o en sucursales), hasta el momento de recibir su equipaje en el lugar de destino. No obstante, respecto a la gestión y tratamiento de equipajes, con el fin de evitar daños, demoras y extravíos, aumentar la satisfacción del cliente y evitar costos extras a la compañía, quedan aspectos por mejorar, independientemente de las variables que incidan de manera justificada en este tipo de eventualidades.

Los datos de la Sociedad Internacional de Telecomunicaciones Aeronáuticas (SITA) muestran que el número total de maletas mal gestionadas cayó en 2016 a 21,6 millones, cifra que representa una disminución del 7,2% respecto al total de 23,3 millones de bultos de 2015. Sin embargo, la recuperación y entrega de las maletas perdidas tuvo un coste extra para la industria de 2.100 millones de dólares en 2016, lo que indica que es necesario seguir realizando esfuerzos para garantizar un tratamiento de equipajes más eficiente [1].

Es preciso, entonces, levantar información cualitativa acerca del funcionamiento y los problemas que se presentan actualmente con el sistema de gestión de equipaje de los aeropuertos y estudiar las posibles soluciones (tecnologías y medidas) que han sugerido ejecutar en los próximos años. En consecuencia, se abordan las áreas de la Ingeniería Aeronáutica: infraestructura aeroportuaria, gerencia y costos, y, legislación aérea y regulaciones, ya que se estudia el tema del Sistema de Gestión de Equipajes (BMS) de los aeropuertos.

MÉTODO

La metodología implementada para la realización de esta investigación es completamente teórica, fundamentada en una investigación documental. Fueron abordados tres temas principales teniendo como objetivo es estudiar la forma en que funciona el sistema de gestión de equipaje actual, sus problemáticas y las posibles soluciones a estas.
En la primera parte del trabajo, dedicada a la identificación de leyes, medidas y recomendaciones de las autoridades, organizaciones y reguladores de la aviación civil en el área de gestión de equipajes con el fin de evitar los inconvenientes o ayudar a resolverlos de forma más rápida, se ha realizado un estudio de la legislación, regulaciones y recomendaciones emitidas por las autoridades (nacionales e internacionales) y asociaciones internacionales.

Luego en la parte dedicada al análisis del sistema de gestión de equipaje actual en los aeropuertos, se llevó a cabo la recopilación de información descriptiva de los procesos y sistemas que se aplican en esta área. Además, se realizó lectura, comprensión y extracción de datos estadísticos que evidencian las causas y consecuencias de los inconvenientes que presenta el sistema.

Finalmente, se realizó una consulta bibliográfica detallada fundamentada en artículos y estudios basados en las nuevas tecnologías próximas a aplicar en el sistema de gestión de equipaje, especialmente de la tecnología de identificación por radiofrecuencia (RFID). Con esto, se exponen los detalles del funcionamiento, aplicación y resultados esperados con cada tecnología.

RESULTADOS

Regulaciones y nuevas medidas en el BMS

El área de sistema de gestión de equipaje (BMS) de los aeropuertos está regulada mediante normativas y medidas nacionales e internacionales que tienen como fin común el adecuado manejo del sistema y las condiciones que se deben tener en cuenta para lograr la solución de conflictos que se puedan presentar.

- Convenio de Montreal: es un convenio para la unificación de ciertas reglas para el transporte aéreo internacional [2]. Este convenio regula la responsabilidad civil en el transporte aéreo internacional. Además, reconoce la importancia de asegurar la protección de los intereses de los usuarios y la necesidad de una indemnización equitativa fundada en el principio de restitución.
- Código de Comercio Colombiano y Reglamentos Aeronáuticos de Colombia: ambos tienen como objetivo regular el trasporte aéreo de pasajeros y equipaje a nivel nacional. Están en concordancia y dictan las normas que deben cumplir tanto el transportador como el pasajero.
- Servicios de equipaje IATA: La Asociación Internacional de Transporte Aéreo (IATA) facilita la cooperación entre las aerolíneas con el fin de promover la seguridad, fiabilidad, confianza y rentabilidad en el transporte aéreo. Actualmente, hacen parte de la Asociación alrededor de 275 aerolíneas en más de 117 países [3]. El Grupo de Trabajo de Equipaje (BWG) de IATA fue establecido por el Comité de Servicios Aeroportuarios (ASC) para revisar y desarrollar recomendaciones en una forma que pueda ser adoptada por el ASC y eventualmente por la Conferencia de Servicios al Pasajero (PSC) como Resoluciones (obligatorias) o Prácticas Recomendadas (no obligatorias).
- Resolución 753 de IATA: titulada “seguimiento del equipaje” tiene como objetivo alentar a las aerolíneas a reducir aún más el mal manejo del equipaje mediante la implementación de un seguimiento (rastreo) intersectorial para cada viaje. La resolución 753 entra en vigor el 1 de junio de 2018 [4]. A continuación, mediante la tabla 1 se exponen los propósitos de esta resolución, las obligaciones y requisitos por cumplir por parte de las aerolíneas miembros de IATA [5].

Table 1- Descripción Regulación 753 IATA
Fuente: [3]

Propósito: inventarios precisos de equipaje.	Prevenir y reducir el mal manejo del equipaje determinando su custodia en cada fase del sistema.
	Aumentar la satisfacción de los pasajeros.
	Reducir la posibilidad de fraude.
	Permitir detectar cuando un equipaje es entregado, pero no procesado.
	Acelerar la conciliación y la preparación para vuelos de salida.
	Ayudar a medir el cumplimiento de los Acuerdos de Nivel de Servicio (SLAs).
	Proporcionar evidencia a un proceso de prorrateo de interlínea automático.
Obligaciones de los miembros.	Demostrar entrega de equipaje cuando cambia la custodia.
	Demostrar adquisición de equipaje cuando cambia la custodia.
	Proporcionar un inventario de las maletas a la salida de un vuelo.
	Ser capaz de intercambiar la información con otros miembros o sus agentes según sea necesario.
Requisitos y puntos de seguimiento.	Adquisición del equipaje del pasajero por el miembro o su agente (*check-in*).
	Entrega del equipaje en el avión.
	Entrega y adquisición del equipaje entre los miembros o sus agentes cuando la custodia cambia entre los transportistas.
	Entrega del equipaje al pasajero.

En la figura 1 se puede apreciar los puntos obligatorios donde se debe realizar seguimiento al equipaje, como se mencionó anteriormente.
Para cumplir con la resolución 753, IATA en conjunto con SITA está impulsando el despliegue mundial de la tecnología de identificación por radiofrecuencia (RFID), que puede rastrear con precisión el equipaje de los pasajeros en tiempo real en puntos clave del viaje, y permitirá al sector de transporte aéreo ahorrar más de 3000 millones de dólares en los próximos siete años, además de que podría reducir hasta un 25% el número de maletas mal gestionadas hasta 2022. Algunas grandes aerolíneas y aeropuertos ya han introducido la tecnología RFID, combinada con el hecho de que es compatible con la tecnología existente de código de barras. El coste medio de utilización de esta tecnología es de 0,1 dólar por pasajero, mientras genera ahorros esperados de más de 0,2 dólares por pasajero, según IATA [1].

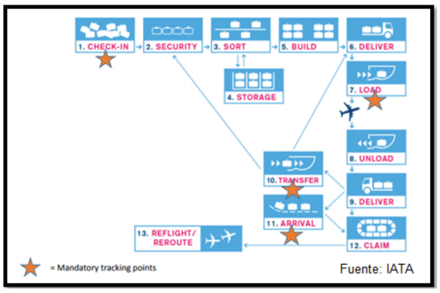

Figure 1 – Puntos Obligatorios De Seguimiento De Equipaje
Source: [5]

Programas y nuevas medidas: en el BWG existen actualmente siete grupos de trabajo, que abarcan los siguientes temas: XML de equipaje, implementación de seguimiento de equipaje, etiqueta electrónica de equipaje (EBT), prorrateos, mapa de artículos perdidos y encontrados, revisión y simplificación del RP1745 y RFID [6]. Actualmente se desarrollan dos programas dentro del área de servicios de equipaje, como se muestra en la tabla 2:

Table 2 - Descripción Regulación 753 IATA
Fuente: [3]

Programa eBC	Proyectos de Equipaje StB
Capacidades mejoradas de equipaje (*enhanced Baggage Capabilities*). Trabajo en conjunto entre las aerolíneas para abordar el mal manejo y las operaciones irregulares. Sus áreas de enfoque son: • Seguimiento del equipaje • Mensajería de equipaje XML • Procesos automatizados de *back office* • Intercambio de datos • Identificación del equipaje	Simplificando el negocio (*Simplifying the Business*). En proceso están dos proyectos: • Proyecto actual-Equipaje XML: El objetivo es centrarse en la estandarización de los datos y las interfaces, aprovechando la tecnología XML y redefiniendo la arquitectura global de intercambio de información. • Nueva idea-Equipaje: el objetivo es reinventar el proceso de equipaje al proporcionar seguimiento y rastreo en tiempo real y una identificación robusta.

El plan para la transformación incluye siete ideas de medidas a aplicar en los años futuros con el fin de mejorar los inconvenientes que se presentan, a continuación, se relacionan en la tabla 3. Con el fin de revolucionar el sistema de gestión de equipaje, se propone rediseñar tres componentes, estos van relacionados con el punto de salida (A) y de destino (B). Se busca optimizar la mejor ruta posible, mejorar la satisfacción del cliente y minimizar el costo, como se aprecia en la figura 2.

¿Qué son A y B?: actualmente, A y B siembre son aeropuertos. Pero estos puntos de entrega y retiro podrían ser cualquier cosa: casa, hotel, oficina o un depósito. ¿Podrían las aerolíneas aprovechar infraestructuras de distribución de paquetería?, ¿Podrían los hoteles tener la capacidad de almacenar equipaje durante varios días antes de la llegada de un huésped? Sin duda, la entrega y recepción del equipaje puede darse en ubicaciones diferentes a las actuales.

Table 3 - Nuevas Medidas En El Sistema De Gestión De Equipajes
Fuente: [4]

Nueva medida	Descripción
Identificación robusta.	Es necesario que haya un mecanismo sólido para identificar por completo la identificación del equipaje, que se compone de tres partes: bolsa, pasajero y viaje. El esquema XML, aprobado por las Normas de Intercambio de Datos de Pasajeros y Aeropuertos de la IATA (PADIS) permitirá a las aerolíneas comenzar la transición a este XML en 2017. Esto asegurará que haya datos de respaldo detrás del número de etiqueta de la bolsa de diez dígitos. Sin embargo, se debe llevar esto más allá y asegurarse de que todo el nuevo equipaje producido tenga la capacidad de contener electrónicamente la identificación de la maleta, el pasajero y el viaje. IATA debe incorporar los estándares requeridos para permitir que cada fabricante registre la identificación.
Simplificar la regulación.	La regulación debe ser revisada para garantizar que esté al día con la tecnología y siga siendo relevante y apropiada. Por ejemplo, las etiquetas de bolsas electrónicas generalmente no transmiten mientras un rastreador de equipaje transmite. Según la regulación actual de la Circular de Asesoramiento FAA 91.21-1c, los rastreadores de equipaje deben tener dos mecanismos separados para apagarse automáticamente durante el vuelo. Actualmente no hay forma de verificar que los dispositivos de rastreo de equipaje comercialmente disponibles cumplan con este requisito.
Seguridad.	Los procesos y la regulación deben revisarse si se cambiara el proceso para ofrecer un servicio de equipaje independiente del pasajero.
Cambio de mentalidad: transparencia.	Como industria aeronáutica, deberían compartir información proactivamente con los clientes. Por lo tanto, es necesario crear actualizaciones en tiempo real para que los clientes conozcan el estado del equipaje. Esto continuamente generará confianza en el sistema. Las aerolíneas no pueden continuar operando en un modelo donde deciden si y cuando le dicen al pasajero el estado del equipaje.
Adoptar soluciones independientes.	Actualmente hay una amplia gama de productos en el sector del equipaje que utiliza variaciones de la tecnología IOT- Internet de las Cosas (ya sea a través de tarjetas 3G, Bluetooth o LoRa). Pero estos dispositivos están fuera del ecosistema de la aviación. Se deberían aceptar a los proveedores independientes que proporcionan productos de seguimiento. Se necesita un mecanismo para que formen parte del ecosistema de la aviación, de modo que puedan compartir sus datos con las aerolíneas, y así, que las aerolíneas estén tan informadas como el cliente.
Robótica.	A pesar de que actualmente existe un alto grado de automatización en el proceso de equipaje, se necesita identificar qué roles jugará la tecnología robótica en el futuro.
Drones/Vehículos de conducción autónoma.	Es muy posible que los drones o los vehículos de conducción autónoma se conviertan en una tecnología clave en el proceso de equipaje. Esto será más importante si se comienza a cambiar el punto de recogida para que sea en otro lugar que no sea el aeropuerto, y si las aerolíneas utilizan instalaciones fuera del sitio. La industria debe comenzar a analizar los casos de uso de drones en el equipaje y empezar a desarrollar cualquier regulación específica relacionada con esto.

¿Cómo pasar de A para B?: si una aerolínea tiene la oportunidad de cambiar el punto de partida y el punto final del viaje para el equipaje, y además puede cambiar cuando lo mueve, podría utilizar el método más eficiente y liberar espacio valioso en los aeropuertos.

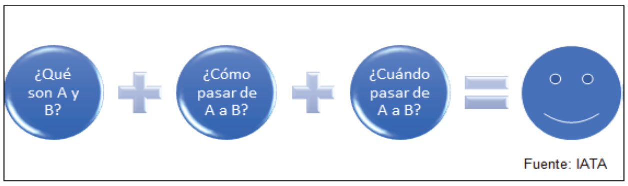

Figure 2 – Componentes por revolucionar
Fuente: [7]

¿Cuándo pasar de A para B?: tradicionalmente, el equipaje ha viajado con el pasajero, sin embargo, con mucha frecuencia este no es lo deseado. Los pasajeros quieren saber que su equipaje estará en su destino cuando o antes de que lleguen. Esto significa que, si se recoge antes de que el pasajero salga, beneficia tanto al pasajero como a la aerolínea. Las pruebas en varios aeropuertos, que permitieron que el pasajero entregara su equipaje la noche anterior a un vuelo, han resultado ser muy populares. Al cambiar el "cuándo", y combinado con el "cómo" las aerolíneas tienen la oportunidad de optimizar la ruta para mover el equipaje de "A" a "B" [7].

Sistema de gestión de equipaje actual

Descripción del sistema: el BMS, se define como un conjunto de sistemas de gestión operativa de los equipajes de los pasajeros que tienen un contrato de trasporte con una aerolínea. El objetivo del BMS es trasportar de un punto A hasta un punto B dicho equipaje de manera segura y en los tiempos pactados.

El sistema de gestión de equipajes es similar en todos los aeropuertos alrededor del mundo y cumplen ciertas características de base para su funcionamiento. A continuación, se describen los elementos del sistema, mostrados en la figura 3.

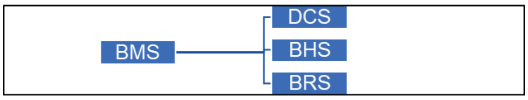

Figure 3 – Componentes por revolucionar
Fuente: Autores

El Sistema de Control de Partidas (DCS) es la columna vertebral operativa de todas las líneas aéreas. Maneja el *check-in*, la aceptación de equipaje facturado, el proceso de embarque, el control de carga y el proceso de inmigración. El sistema verifica si un supuesto pasajero tiene una reserva válida, le asigna un asiento y emite la tarjeta de embarque. Los mostradores de facturación constituyen el espacio físico más importante en el DCS con respecto a la gestión del equipaje, ya que allí se pesa el equipaje de bodega, se verifica que cumpla con las condiciones estipuladas de tamaño y peso (normalmente 23 kg para el peso y 158 cm de dimensión sumando alto, largo y ancho), se verifica el estado físico y se emite la etiqueta de equipaje (facturación del equipaje). Por otra parte, la emisión de la etiqueta (figura 4) es otro punto principal del DCS, ya que esta contiene la información del equipaje: nombre del pasajero, ciudad y fecha de emisión, destino y fecha de vuelo, localizador, número de vuelo, número de control y código de barras (vertical y/o horizontal) del número de la etiqueta. Este documento puede ser emitido por la compañía transportista o por la compañía que presta los servicios de *handling* [8].

Figure 4 – Etiqueta de equipaje facturado
Fuente: Autores

El Sistema de Manejo de Equipaje (BHS) es propiedad del aeropuerto generalmente, se constituye como un conjunto de cintas transportadoras, carruseles, rampas y caídas de equipaje, que permite llevar a cabo el transporte y almacenamiento del equipaje facturado. El sistema garantiza que los equipajes recibidos o en transferencia, sean rastreados, contabilizados, escaneados, inspeccionados y transmitidos a la rampa o cinta transportadora adecuada y así poder llegar hasta el destino deseado, ya sea una aeronave, una bodega o la zona de conciliación. Como se observa en la ilustración 5, el BHS abarca la mayoría de los pasos del BMS: seguridad, clasificación, almacenamiento, preparación, entrega, carga, descarga, entrega, transbordo o llegada, reclamación y revuelo.

El Sistema de Conciliación del Equipaje (BRS) es usualmente es utilizado por el agente *handling*, este sistema ayuda a unir el pasajero con su maleta, vuelo y contenedor. El sistema tiene como objetivo garantizar que el equipaje viaje en el mismo vuelo que el pasajero, o en caso de que el pasajero no haya abordado el vuelo, el equipaje no sea cargado a la bodega (o sea descargado de esta) por razones de seguridad.

También permite disminuir las pérdidas o retrasos de equipaje. Esto cumple con el Anexo 17 de la OACI que establece que "cada estado contratante asegurará que los explotadores del transporte aéreo comercial no transporten el equipaje de pasajeros que no estén a bordo de la aeronave, salvo que ese equipaje esté identificado como equipaje no acompañado y se someta a una inspección adicional". En el envío de mensajes se utiliza un número único de etiqueta de equipaje (LPN), que es un número de diez dígitos. De acuerdo con la resolución 751 de IATA, vigente desde el 1 de junio de 2013, el formato contiene solo números. Por ejemplo: 0-220-208212, donde el primer número es el dígito principal, los tres siguientes son el código de la aerolínea y los otros seis corresponden al número de la maleta.

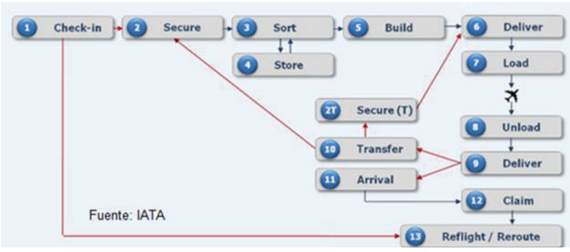

Figure 5 – Etiqueta de equipaje facturado
Fuente: [8]

Causas y consecuencias de las fallas del BMS: un sistema como este puede verse afectado tanto por factores internos como externos, lo que puede resultar en un exceso de equipaje mal gestionado. El término utilizado para estas fallas es: interrupciones del equipaje, y pueden presentarse diferentes casos (causas) con consecuencias como: maletas maltratadas, maletas perdidas, vuelos retrasados o una "montaña de equipajes" acumulado. A continuación, en la tabla 4 se describe los principales casos de interrupciones de equipaje, sus causas y consecuencias [9].

Table 4 - Fallas del BMS
Fuente: [9]

Falla	Causa	Consecuencia
Calidad de impresión de la etiqueta del equipaje.	Mala calidad de impresión de las etiquetas, debido al agotamiento de la tinta, piezas o equipo defectuoso.	Dificultad de lectura de los códigos de barras por parte de los sistemas de gestión y de conciliación. Lo que puede resultar en el retraso del vuelo o maletas extraviadas.
Escáner manual.	Interrupción del escáner individual, falla parcial o total de la red inalámbrica.	Retrasos en el BMS.
BSM	Falta de los BSMs.	El equipaje no será cargado en el sistema de conciliación. Puede provocar desde un retraso en el vuelo y maletas extraviadas hasta la interrupción total del sistema.
BHS	Falla del sistema de energía, del sistema operativo, de la red de seguridad o la red del sistema. Corte causado por uso incorrecto. Falta de redundancia o mantenimiento deficiente.	BHS no operativo.

En cuanto al estudio estadístico con respecto al sistema de gestión de equipajes en el año 2016, en la figura 6 se tienen los siguientes resultados proporcionados por SITA en asociación con *Air Transport World* (ATW).

En la figura 6 se puede observar cómo disminuyó la cantidad de maletas mal gestionadas entre los años 2007 y 2016 (un 54% menos), lo que indica que aeropuertos, aerolíneas y organizaciones relacionadas con el transporte aéreo han realizado esfuerzos para mejorar el BMS y evitar que sucedan interrupciones en el sistema o mitigarlas de forma adecuada en el menor tiempo posible. Las estadísticas de SITA muestran las causas del retraso de los equipajes en 2016.

Figure 6 – Errores en el manejo de equipaje facturado
Fuente: [10]

Se puede destacar que un 47% de las demoras se debe al manejo incorrecto durante el transbordo entre los vuelos de conexión, a lo que le sigue un 16% de maletas que no se cargaron y un 15% con error en la emisión de boleto, cambio de maleta y procesos de seguridad. El 22% restante abarca diversos problemas como: restricciones del aeropuerto, inconvenientes con la aduana, mal clima, problemas de espacio y peso, error al realizar la carga, mal manejo a la llegada y error de etiquetado (como se observa en la figura 7).

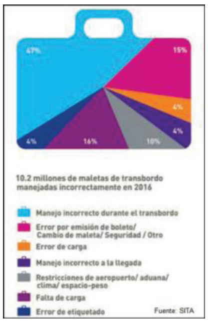

Figure 7 – Causas de la demora del equipaje
Fuente: [10]

En total un 90% de las causas corresponde a interrupciones evitables, cuyos procesos se pueden seguir mejorando con nuevas tecnologías, planes de contingencia o una adecuada mitigación de este una vez suceda para evitar consecuencias negativas tanto para los pasajeros como para la compañía aérea [10].

Nuevas tecnologías en el BMS

Cuando se habla de tecnología en el transporte de equipaje, encontramos que actualmente existen diferentes modelos de maletas inteligentes que pueden ser monitoreadas por el pasajero, a través del celular gracias a la geolocalización; o el uso de la robótica y la inteligencia artificial implementados por algunas aerolíneas. Sin embargo, hace falta que las nuevas tecnologías sean implementadas de forma regular por parte de aerolíneas y aeropuertos, para así garantizar un sistema de gestión de equipajes más eficiente y seguro.

Tecnología EBT: la Etiqueta Electrónica de Equipaje (EBT) se trata de un módulo digital incorporado en la maleta que reemplazaría la etiqueta de equipaje impresa como se hace actualmente (ilustración 8), omitiría la necesidad de realizar filas para obtener la etiqueta y recibir el talón como constancia de esta (ya que se podría programar de forma diferente para cada viaje a realizar).

Figure 7 – EBT RIMOWA
Fuente: [14]

Las EBT funcionarían con una batería de litio (cumpliendo con las normas de la OACI) y visualmente sería parecido a las etiquetas impresas con la ventaja de estar protegida contra la humedad, frío y calor, a salvo de golpes y vibraciones y sin la posibilidad de ser desprendida del equipaje. Los componentes mínimos para garantizar un nivel de funcional estándar de la EBT se muestran en la tabla 5 [11].

Los pasos clave para la implementación son: se requiere actualizar el sistema de control de salida, para que permita reconocer y procesar los equipajes con EBT. La aplicación móvil de la aerolínea debe ser renovada, con el fin de que los pasajeros puedan programar su EBT para un viaje por medio de una interfaz Bluetooth.

Table 5 - Componentes de la EBT
Fuente: [11]

Componente	Propósito	Opcional Obligator
Pantalla	Mostrar el LPN de forma legible por humanos.	Obligatori
Código QR que contiene una URL con el GUID (Identificador Único Global)	Permitir la identificación de la etiqueta a través de un medio óptico. Es un respaldo en caso de que se rompa la pantalla.	Obligatori
RFID	Permitir el seguimiento del equipaje a través de UHF RFID.	Obligatori
BLE (Bluetooth de Baja Energía)	Permitir la interacción de la EBT con un teléfono móvil. Las EBTs deben incluir un interruptor físico que las active en modo escucha, para ser actualizadas.	Obligatori
NFC (Comunicación de Campo Cercano)	Permitir la interacción de la EBT con un teléfono móvil.	Opcional
GSM (Sistema Global para las comunicaciones Móviles)	Para permitir la interacción remota con el dispositivo y el seguimiento global.	Opcional

Se debe realizar una capacitación a los agentes de *handling* sobre el funcionamiento de la EBT para garantizar que se dé un adecuado manejo. Será necesario contar con aprobaciones por parte del gobierno y aduanas en algunas regiones para la implementación de estas etiquetas [11]. Tiene los siguientes beneficios: mejora en los servicios de pasajeros, mejoras en la velocidad de aceptación del equipaje, simplificación del proceso de entrega de equipaje, mejora de la percepción de la aerolínea, mayor oportunidad de recuperación del equipaje en caso de pérdida, procesos de recuperación de equipaje más eficientes.

Tecnología RFID: se define como Identificación por Radiofrecuencia, y sería utilizado en las etiquetas de los equipajes para garantizar el seguimiento durante el viaje, ya sean etiquetas impresas desechables, parecidas a las actuales o las EBTs. La identificación por radio frecuencia es un sistema de almacenamiento y recuperación de datos sin ningún tipo de contacto entre los dispositivos denominados etiquetas, transpondedores o tags RFID y los lectores RFID. El propósito fundamental de la tecnología RFID es transmitir la identidad de un objeto (similar a un número de serie único) mediante ondas de radio. Las tecnologías RFID se agrupan dentro de la tecnología denominada Auto ID (*automatic identification*, o identificación automática). Para esta aplicación se utilizaría una etiqueta RFID de UHF (Ultra Alta Frecuencia) de modo pasivo (alimentadas por señal de radiofrecuencia emitidas por el lector), que tiene un rango de hasta 10 metros y cuya banda de frecuencias va entre 860 a 960 MHz. Las ventajas de este tipo de etiquetas RFID es que son de bajo costo, fáciles de fabricar, con alta velocidad de transmisión de datos, un buen rango de lectura y cumple con los estándares globales (ISO y EPCglobal). La desventaja es que tiene una alta interferencia con líquidos y metales [12].

Los lectores RFID utilizan ondas radiales para activar y capturar los datos almacenados en el chip RFID, así que la placa en la etiqueta de maletas se puede leer incluso cuando está escondida bajo la maleta; eso significa que las maletas no se tienen que manipular individualmente para poder leerlas. Los lectores RFID pueden automatizar el proceso de capturar cada etiqueta en una pila de maletas o en un contenedor en un par de segundos. Esto implica que hay menos maletas que se leen incorrectamente, o incluso que no sean leídas, lo cual resulta en menos maletas que se manejan erróneamente [10]. Las ventajas de la etiqueta con un componente RFID en comparación con la etiqueta actual de papel que contiene un código de barras es que la etiqueta RFID permite tener una mejor legibilidad, ya que no se necesita una línea directa de visión para su detección, como si ocurre con el código de barras; además tendría un menor deterioro, puesto que es resistente a la humedad y temperatura, podría leerse a través de la suciedad y permitiría una mayor capacidad para almacenar datos en ella.

Tecnología XML: los estándares actuales de tecnología de mensajería fueron desarrollados por la industria de la aviación con el fin de automatizar las operaciones y mejorar la comunicación entre las partes. Estas han estado vigentes desde 1985, pero no son compatibles con nuevas aplicaciones, redes, hardware, sistemas operativos ni entornos de desarrollo de aplicaciones. La falla y el rechazo del mensaje están entre las principales causas del mal manejo del equipaje, ya que las prácticas de análisis pueden hacer que los mensajes sean malinterpretados, lo que afecta el servicio al cliente y agrega un costo extra a la industria. Actualmente IATA se encuentra trabajando para lograr un estándar sostenible en el área de mensajería de equipaje en los aeropuertos a través de la tecnología XML que traerá numerosos beneficios, entre ellos: ahorro de costos en el procesamiento de mensajes (mensajería más sencilla, sin necesidad de reinterpretar el mensaje desde cero), reducción del costo de la infraestructura y las comunicaciones, reducción de los costos de soporte y mantenimiento, integración de información a través de las operaciones de la aerolínea, mejora de la calidad de los datos que conduce a menos fallas en la mensajería, intercambio de datos confiable y seguro, ampliación del juego de caracteres, tamaño, estructura del mensaje y tipo de datos, innovación dentro del área de equipaje con nuevas prácticas como etiquetas electrónicas de equipaje (EBT), mejor tiempo para comercializar nuevos productos, mejora de la automatización de procesos y mayor flexibilidad en las operaciones.

XML también está protegido de forma inherente contra la obsolescencia, ya que la estructura permite la extensión periódicamente, cuando las nuevas prácticas requieren que se transmita nueva información. Las reglas que rigen las prácticas y el desarrollo de XML están definidas por el W3C (World Wide Web Consortium), un organismo internacional respetado que no está alineado con ningún proveedor o producto en particular. El Lenguaje de Etiquetado Extensible (XML), del inglés *"eXtensible Markup Language"* es un formato de texto simple, muy flexible derivado de SGML *(Standard Generalized Markup Language)*. Originalmente diseñado para enfrentar los desafíos de la publicación electrónica a gran escala, pero también está desempeñando un papel cada vez más importante en el intercambio de una amplia variedad de datos en la Web y en otros lugares [13].

DISCUSIÓN Y/O ANÁLISIS

Luego de la realización de esta investigación documental sobre las nuevas medidas y tecnologías en el sistema de gestión de equipaje de los aeropuertos se realiza el siguiente análisis y recomendaciones, teniendo en cuenta que el objetivo es alcanzar una mejora en el manejo de los equipajes, reduciendo los vuelos demorados por las fallas en el BMS y las maletas mal gestionadas (extraviadas, dañadas, demoradas). También se pretende aumentar el nivel de satisfacción de los pasajeros y con ello, mantener una buena imagen de la compañía aérea.

Las medidas y tecnologías buscan que las fallas se eviten y en caso de que sucedan, que se puedan solucionar de la forma más eficiente posible, es decir, ahorrando tiempo y recursos. Las recomendaciones con respecto a las medidas y tecnologías se plantean según quien sea el encargado de implementarlas.

Pasajero

El pasajero debe tomar precauciones con su equipaje antes de realizar un viaje para evitar inconvenientes, tales como: informarse sobre los objetos que están permitidos para transportar en el equipaje, instruirse sobre el proceso que debe realizar en caso de inconveniente (equipaje demorado o dañado), marcar la maleta con sus datos personales (para facilitar la conciliación en caso de problema con la etiqueta), verificar los datos de la etiqueta (destino, vuelo), guardar el talón de la etiqueta del equipaje, llegar a tiempo para realizar el proceso de *check-in*, realizar *check-in online* o *autocheck-in*, utilizar la tarjeta de embarque móvil, tomar fotografías del contenido del equipaje, declarar si lleva objetos de

valor y en caso de viajes internacionales, contratar un seguro de viaje internacional que cubra una indemnización en caso de demora o pérdida del equipaje.

Compañías aéreas y aeropuertos

Se recomienda llevar a cabo las prácticas que IATA propone, relacionadas en la tabla 6. Hay que tener en cuenta que la mayoría de estas medidas son propuestas nuevas que están en la fase de estudio, para evaluar la factibilidad, costos, ventajas y desventajas de estas.

Se propone que el sistema de gestión de equipajes de los aeropuertos se enfoque en el aumento del nivel de servicio que ofrece a los pasajeros, es decir, que tenga más en cuenta que estos tienen percepciones sobre el servicio y reaccionan ante estas. Por lo tanto, se pretende que la aerolínea sea capaz de informar al pasajero en tiempo real sobre el estado de su equipaje y en caso de presentar un inconveniente, pueda argumentar las razones que lo ocasionaron, comunicar el estado y la localización del equipaje y el tiempo que tardará en resolverse el problema.
Es importante tener en cuenta que existen tres tipos principales de pasajeros: sensibles al precio, sensibles al tiempo y sensibles al servicio. Por lo cual, la gestión de los equipajes debe estar centrada en cumplir las expectativas de cada tipo de cliente. Es decir, se busca que el sistema sea capaz de brindar un servicio adecuado, a tiempo y sin generar sobrecostos, y la única forma de lograr esto es minimizando los errores del sistema e implementando nuevas tecnologías.

Actualmente, las tecnologías son más accesibles debido a su constante desarrollo, lo que les permite ser de menor tamaño, más sencillas y de precio inferior. Entonces pueden ser aplicadas en el sistema con el fin de aumentar el nivel de servicio, al mismo tiempo que aumenta la seguridad y disminuye el tiempo de operación.

- Nivel de servicio: el transporte aéreo es un servicio y además es un bien no almacenable, por lo cual sólo se tiene una oportunidad para lograr la satisfacción del cliente. De esta forma, propongo que se dé paso a la inmediatez de la información del equipaje, de tal manera que el pasajero tenga una percepción positiva de la aerolínea desde el principio hasta el fin de su viaje. Esto se puede lograr brindando información acertada y a tiempo a través de las aplicaciones móviles, teléfono o correo electrónico.
- Seguridad: la seguridad es fundamental en el sistema de equipajes, ya que debe garantizar que los equipajes cargados en la aeronave sean seguros y no transporten ningún elemento prohibido (estupefacientes, armas, sustancias peligrosas, explosivos, material biológico, etc). Propongo, que se garantice la calidad de los controles de seguridad, dejando a un lado los controles aleatorios y poniendo todos los esfuerzos en la adecuada inspección de cada uno de los equipajes. Para ello se requeriría mayor tiempo, sin embargo, considero que puede ser compensado con tecnologías de inspección automatizadas y también con una llegada anticipada del equipaje al aeropuerto. Además, se puede crear una identidad para cada equipaje y una base de datos que permita analizar los vuelos regulares que éste realiza y así almacenar información sobre los "equipajes conocidos".
- Tiempo: el objetivo de la aviación es poder acortar distancias, es decir, reducir el tiempo de transporte de un lado a otro. Sin embargo, debido a los procesos de control de seguridad del equipaje y de los pasajeros, se debe prever un tiempo de anticipación al vuelo. Propongo que se realice el diseño de rutas óptimas para el equipaje, de tal forma que el tiempo de espera para el pasajero sea menor y de todas formas se garantice la adecuada conciliación equipaje-pasajero. Esto se puede lograr implementando medidas que acorten el recorrido que debe realizar el equipaje antes de ser cargado a la aeronave y en su proceso de descarga. La asistencia en tierra toma su importancia en este aspecto por mejorar en el sistema.

Table 6 - Recomendaciones sobre las nuevas medidas en el BMS

Fuente: Autores

Medida	Recomendaciones
Registro de equipaje en autoservicio	Aumentar los mostradores de registro de equipaje en autoservicio, así como los mostradores c *autocheck-in*. Fomentar el uso del *check-in online*, el *autocheck-in* y los mostradores de entrega rápida de equipaj
Identificación robusta	Proporcionar seguimiento y rastreo en tiempo real mediante la tecnología RFID. Ser más cuidadosos en el proceso de transferencia de equipaje interlínea. Redefinir la arquitectura global de intercambio de información, mediante la mensajería XML. Implementar el uso de equipaje con EBTs.
Simplificación la regulación	Revisar la regulación para garantizar que esté al día con la tecnología y siga siendo relevante apropiada.
Seguridad	Adaptar los procesos de inspección de seguridad de acuerdo con los cambios logísticos y tecnológico Contribuir equipos y recursos para elevar la seguridad en la zona de recogida del equipaje y evitar fraude.
Cambio de mentalidad: transparencia	Comunicación de información de manera proactiva con los clientes. Aumento de la transparencia en los procesos de BMS. Creación de una aplicación para la recepción de actualizaciones sobre el estado y rastreo del equipaj Proporcionar toda la información sobre las tecnologías disponibles y procesos a realizar en caso c inconveniente con el equipaje, antes de realizar el vuelo y de manera fácil (por medio de corre electrónico o mensaje de texto).
Adoptación de soluciones independientes	Permitir a los proveedores independientes que proporcionen productos de seguimiento ligados a IOT.
Robótica	Analizar las potencialidades de aumentar la robótica en el BMS, haciendo el sistema totalment automatizado.
Drones/Vehículos de conducción autónoma	Estudiar la posibilidad de usar drones y vehículos de conducción autónoma para el manejo d equipaje. No sólo dentro del aeropuerto, sino fuera de él en caso de revolucionar el concepto de recepción y entrega del equipaje.
Revolución del concepto de transporte de equipaje	Buscar la optimización de la ruta de equipaje, mejorando la satisfacción del cliente y minimizando costo. Analizar la posibilidad de cambiar el lugar de recepción y entrega del equipaje (no sólo tiene que s el aeropuerto). Evaluar cuál sería el método más adecuado para mover el equipaje en el BSM si cambian los lugar de la recepción y entrega. Estudiar los beneficios que puede traer el anticipar la recepción o entrega del equipaje.

CONCLUSIONES

Mejorar el sistema de gestión de equipajes de los aeropuertos es un reto que incluye no sólo al equipo aeroportuario, sino a las aerolíneas, agentes de *handling*, organizaciones internacionales que rigen la industria aeronáutica e incluso a los pasajeros. Por lo tanto, es necesario el trabajo en conjunto para lograr estos objetivos. Las legislaciones y normas son objetivamente correspondientes a nivel nacional e internacional con respecto a los deberes y derechos de pasajeros y aerolíneas, procesos, tiempos de espera y montos de indemnización en caso de inconveniente con el equipaje. Sin embargo, hace falta una actualización de esta que incluya las medidas y restricciones que se deben tener en cuenta a la hora de utilizar nuevas tecnologías en el sistema.

El BMS se compone de tres sistemas: el Sistema de Control de Partidas (DCS) encargado del *check-in*, la aceptación de equipaje facturado (emisión de la etiqueta), el proceso de embarque, el control de carga y el proceso de inmigración. El Sistema de Manejo de Equipaje (BHS) cuyo objetivo es el transporte, inspección, contabilización, clasificación y almacenamiento del equipaje facturado en el aeropuerto. Y el Sistema de Conciliación del Equipaje (BRS) que ayuda a unir el pasajero con su maleta, vuelo y contenedor mediante la mensajería de equipaje.

Las estadísticas de SITA muestran que las causas del retraso de los equipajes en 2016 son el manejo incorrecto durante el transbordo entre los vuelos de conexión (47%), maletas que no se cargaron (16%), error en la emisión de boleto, cambio de maleta y procesos de seguridad (15%). El 22% restante abarca diversos problemas como: restricciones del aeropuerto, inconvenientes con la aduana, mal clima, problemas de espacio y peso, error al realizar la carga, mal manejo a la llegada y error de etiquetado. Los aspectos por mejorar en el BMS son: asegurar la calidad de impresión de la etiqueta de equipaje, disminuir las interrupciones de los escáneres manuales, evitar la falta de BMSs y evitar las fallas del sistema de energía, del sistema operativo, de la red de seguridad y la red del sistema del BHS.

Por su parte, IATA lleva a cabo programas con el fin de impulsar cambios en la industria y desarrollar nuevos estándares para el BMS y su sistema de mensajería. El BWG de IATA se encarga de revisar y desarrollar recomendaciones en forma de resoluciones (obligatorias) y practicas recomendadas (no obligatorias) para el adecuado manejo del equipaje por parte de las aerolíneas miembros.

Se destaca la Resolución 753 de IATA (vigente a partir de junio de 2018) que busca reducir aún más el mal manejo del equipaje mediante la implementación de un seguimiento intersectorial para cada viaje. Los puntos obligatorios de seguimiento son: check-in, carga en el avión, cambio de custodia interlinea o aeropuerto de llegada y entrega al pasajero.

Se ha desplegado la utilización de la tecnología RFID en las etiquetas para garantizar el seguimiento del equipaje, el costo de ella es de 0,1 dólar por pasajero y genera ahorros de más de 0,2 dólares por pasajero. RFID permitirá al sector de transporte aéreo ahorrar más de 3000 millones de dólares en los próximos siete años, además de que se podría reducir hasta un 25% el número de maletas mal gestionadas hasta 2022. La tecnología EBT también tiene un papel importante en el futuro del BMS, ya que permitiría tener equipajes con etiquetas electrónicas implantadas que se pueden actualizar dependiendo del viaje a realizar y manejar de forma más segura, disminuyendo la perdida y demora del equipaje. En cuanto al sistema de mensajería, se encuentra en estudio la posibilidad de utilizar el lenguaje XML para la transmisión de la información del equipaje, con el fin de ahorrar costos y tener un sistema más fiable, con menos fallas.
Se busca también reinventar el sistema en general, cuestionándose desde/hasta dónde, cómo y cuándo se debe realizar el transporte del equipaje, además de implementar la identificación robusta, la simplificación de la legislación, cambios en el sistema de seguridad, cambios de mentalidad enfatizado en la transparencia entre aerolíneas y pasajeros, la adopción de soluciones tecnológicas independientes, y la utilización de la robótica, drones y vehículos autónomos. El fin de la implementación de nuevas tecnologías y medidas es mantener un alto nivel de servicio en el sistema de gestión de equipaje de los aeropuertos.

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Minimum delay or maximum efficiency? Rising productivity of available capacity at airports: review of current practice and future needs

Sabriye Sera Cavusoglu - seracavusoglu@gmail.com
Instituto Superior Técnico / Transportation Systems
Rosário Macário - rosariomacario@tecnico.ulisboa.pt
Instituto Superior Técnico

Abstract

The purpose of the research is , based on existing slot allocation approaches, providing a critical review of status-quo, literature and current research with demand and congestion management perspectives and to contribute to the ongoing research for improvements. The review contains the analysis of current state of practice and the review of relevant research on capacity and slot allocation modelling with policy and demand management perspectives. Relevant regulatory background and policies such as EU Regulation 95/93 with its amendments and proposals, IATA Worldwide Slot Guidelines; slot allocation procedures and technical assessment reports focusing on market-based mechanisms (e.g. NERA 2004; Mott MacDonald 2006; Steer Davies Gleave 2011) are reviewed.

The review targets identification of existing problems, inefficiencies, gaps and requirements in current practice of slot allocation mechanisms, defining options for change in policies to allocate slots more efficiently, transparent and fair by investigating market-based mechanisms.

The objective of this review paper is to contribute to the ongoing research for improvements to the slot allocation process that can be rationally implemented in practice in order to improve efficiency, fairness and transparency by considering overall social welfare, airline and airport surplus, passenger welfare and explore hypothetical, computational and practical challenges that have arisen from cross-disciplinary methodologies.

Keywords

airport slot allocation; airport demand management; capacity planning

Minimum Delay or Maximum Efficiency? Rising Productivity of Available Capacity at Airports: Review of current practice and future needs

Introduction

The fast evolution of air transport environment and rapidly increasing numbers of traffic developed severe congestion and delay problems at the airports and became a noteworthy transport strategy issue. Around the world airports are increasingly facing capacity constraints, often the runway capacities are restricted by governments and airports are unable to accept additional aircrafts. Recent `Annual World Airport Traffic Report (WATR)`and `Annual World Airport Traffic Forecasts (WATF) 2018-2040` documents of Airports Council International (ACI) show an increase in international passenger traffic with global traffic reaching 22 billion (international and domestic) by 2040 based on a projected growth rate of 4.5% per year [1],[2]. According to Eurocontrol's Report of European Aviation 2040 – Challenges of Growth, there will be around 16 Heathrow-like airports operating in limit capacity by the year 2040 and the delays will be eventually around 20 minutes per flight during peak periods [3].

Besides building new airport, control towers, aprons and runways infrastructure in order to expand capacities, both the US and the EU have been also investing in developing technologies to advance and modernize the air traffic control and surface management in order to reduce the congestion levels at peak hours which are European Single Skies Initiative - SESAR solutions and the American counterpart NextGen. Time Based Separation (TBS) at London-Heathrow Airport has been also started to be used rather than the standard wake-vortex distance separation rules used for landing and departing at runways in order to increase the efficiency of the airport. These solutions will enhance the management of air traffic control and surface traffic by not physically expanding the infrastructure and eventually will create a solution of congestion reduction.

Technological improvements can decrease the necessity of policy limitations in terms of noise and air pollution. Target gains from these mentioned initiatives are considerably less viable in worldwide development, where the capacity challenge is much broader. However, one should also consider that development and full-implementation of these technologies will most likely take a decade for them to take place. Nevertheless, neither these technologies nor expanding infrastructure will not be the ultimate solution for the capacity problem [4]. The capacity that is available, needs to be allocated as efficiently as possible.

This paper presents existing approaches from the literature to the airport capacity(slots) allocation paradigm and policy regulation and a review of the previous work that has been found relevant and fundamental. The progress of the literature highlights the complexity of the problem, its dynamic nature, its fairness, and its requirements. The objective of this paper is to contribute to the ongoing research for improvements to the slot allocation process that can be rationally implemented in practice in order to improve efficiency, fairness and transparency. For that purpose, based on these slot allocation approaches, we provide a critical review of status-quo, literature and current research with demand and congestion management perspectives by considering overall social welfare, airline and airport surplus, passenger welfare and explore hypothetical, computational and practical challenges that have arisen from cross-disciplinary methodologies.

Airport Capacity Allocation

Airport capacity can be allocated in different ways; administrative capacity management with slot allocation and traffic distribution rules; market-based capacity management; a combination of both mechanisms; or no regulation mechanism as applied in the USA with the exceptions of busiest airports EWR, JFK, LAX, ORD and SFO. European airports apply regulations and an administrative mechanism that limit aircraft movements according to the airport's declared runway capacity (number of slots available at each airport per hour). On the contrary, in the United States a first come–first served basis rule applies (except for five airports as previously stated, restricted according to High Density Rules). The trade-off between these two methods is maximising throughput (number of take-offs and landings at a specific period) versus minimising delays that is harmful to both airlines and passengers [4], (Figure 1). Delays in Europe are significantly lower than US [5]. Nevertheless, the US slot allocation system is better at benefitting from existing airport infrastructure while the European slot allocation schemes prevent more efficient use of current infrastructure. The Commission proposed to the European Parliament and the Council to revise the EU Slot Regulation in December 2011 in order to increase the allocation efficiency. Until now, there haven't been a major change in the regime with the legislative proposal.

The traditional way of managing capacity in slot coordinated airports (Level 3 airports) is the slot allocation mechanism all over the world [6]. Most of the time, capacity is expressed in slots at congested airports [7]. An airport slot (or 'slot') is defined as a "permission given by a coordinator for a planned operation to use the full range of airport infrastructure necessary to arrive or depart at a Level 3 airport on a specific date and time." [6].

Two Systematic Regulation Approaches	
Administrative Slot Controls	Market-based Mechanisms
A set of rules European Council Regulation 95/93 [16]: Airports in the European Union are subject to the same regulatory framework and so are the slot allocation schemes. A set of rules that mitigate the congestion problem by limiting the aircraft movements according to the airport's declared runway capacity and an administrative regulatory framework. Canada, Australia, Turkey, South America follow the European approach	A first come- first served basis rule Airports in USA are not slot-coordinated with the exceptions of five major airports; JFK, LaGuardia and Newark in NY Region; Washington, Reagan; and Chicago O'Hare.

*Little is known about regulations from literature regarding Asia-Pacific region.

Figure 1. Slot Allocation Approaches
Source: Authors

Airport slots comprise a strategic instrument for the capacity allocation in the long term. In practice, airport slots are allocated at the strategic level that the planning that starts 5-6 months before operations. Tactical and operational planning occurs a few days to a few hours before operations (Figure 2.)

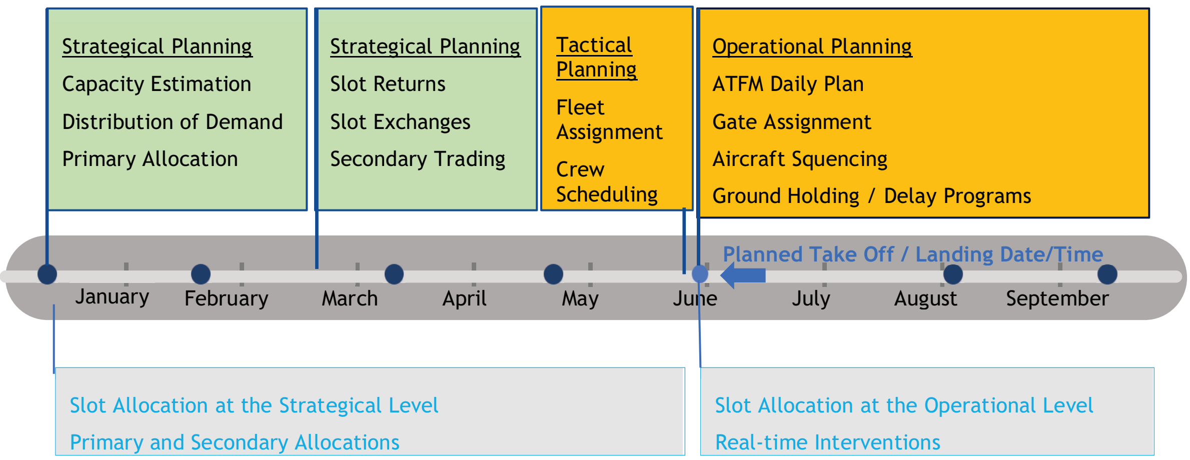

Figure 2. Planning and Slot Allocation Levels
Source: Authors

Capacity Allocation Problem

Transport regulations are mainly concerned with safety, quality and competition. Implementation of these regulations requires political and social workability. From an economic point of view, they need to be cost efficient and produce insignificant minimal transaction costs and account for its own sectoral impact. Economic regulation introduces its own misuse situations and at the end of the day, there is a trade-off to be made between imperfect competition and imperfect regulation [8]. Capacity allocation problem regardless of applied regulatory frameworks has been studied by many scientists and economists in the past, some of whom included a total welfare surplus assumption and some who took consumer surplus into consideration through demand management and congestion management perspectives. They tried to figure out the effects of congestion on allocation efficiency and the effects of policy regulation measures on limitations of congestion and social welfare. The fundamental issue concerning production in welfare economics is whether a market solution will return the socially optimum kind of products (prices, quality, market entry). It is acknowledged that problems can derive from three extensive reasons: distributional equity, externalities and scale economies (market structure) [9]. Overconsumption of airports is denoted as congestion which happens when demand exceeds supply [10]. Scarce capacity means the situation when airport authorithy simply can not answer additional required slots. Thus, scarce capacity and congestion have a substantial relationship.

The congestion-management approaches are separated into two principle classifications: price-based and quantity-based. Under the price-based methods, the airport authority declares a charge per flight that airlines must pay to utilize a congested airport with quantity decisions chosen completely by the carriers. Under the quantity based methods, the airport authority declares a total flight volume that is allocated as fixed number of airport slots with no charge [11]. This regime with an allowed secondary trading between carriers is existent at slot-controlled airports of US. Another quantity-based method is slot auctioning where the airport authority allocates the total volume of slots through an auctioning mechanism.

Limited capacity means less competition for the airlines and this situation may support the incumbent airlines to charge more expensive rates as compared to new entrants which struggle to gain market share. Airlines might prefer using larger aircraft in order to answer the high demand where they can not offer more frequent flights due to limited capacity but using larger aircraft in low range operations would cause unnecessary operational and maintenance costs. In such an environment passengers are left with few choices for selecting airlines where they will also face higher prices with limited flight frequencies [4]. However, with regards to the growing traffic, it is unquestionably appearing socially attractive to allow more passengers to be able to benefit from existing airport capacities through the operation of larger aircraft. According to the analysis conducted in [5], operators on both sides of the Atlantic are adapting to the increase in traffic and limited capacities by switching to larger aircraft. This implies that any negative impact of grandfather rule (the rule under EU's slot allocation regulation which enables airlines being allocated slots on the basis of their previous use of the airport) on the aircraft size is alleviated by the increased traffic volume covered by larger aircraft. Nevertheless, the size of the aircraft is not a complete indicator of slot usage efficiency since airlines have several operations from largest airports serving differing markets by using various aircraft types depending on the traffic and their market strategies.

Current Practice

Declared Capacity, VFR and IFR Procedures and Scheduling

Another factor affecting the level of delays is believed to be the concept of `Declared Capacity`. It is practically the maximum number of movements which can be handled under good weather conditions without exceeding an average delay of 4 minutes [12]. Airports specify a declared capacity and airlines send formal requests for each of their requested slots five months before the start of each season (March and October). US is not using this concept in contrast to practically everywhere else in the world. In Europe, Instrument Flight Rules (IFR) flying procedures apply all the time and declared capacity planning and scheduling are done based on IFR operations. On the contrary, Visual Flight Rules (VFR) procedures at US airports may cause over scheduling of flights in case weather conditions are worse than good that dependency on these rules makes airports' schedules liable to excessive delays [13]. EU airports oversee keeping up the steady level of delays for majority of the time because slot controls protect them from redundant demand and schedule reliability degration. Although the EU regulation rules keep delays at a more acceptable and predictable level, the current regulation is muted to commercial considerations of slot trading and economists agree that the rules effect slot use efficiency negatively.

Current Slot Allocation Scheme in Europe

The slot allocation process in the EU comprises three main stages; primary allocation, slot returns and slot exchanges and transfers as explained in Figure 3. The primary allocation of slots is an administrative process. Airport coordinators are assigned to airports and expected to be neutral and airports are titled as fully coordinated. Airport coordinators either allocate slots to carriers by placing or rescheduling (alternative slot times) slot requests or reject some requests if no possible slot is available in order to meet capacity constraints. At this point, `Grandfather Rights` and `Historical Slots-Time Adjustment` rules are applied by the coordinator which means that the carrier reserves the right of continuing her operation in specific series of slots under the condition that if she operated specific series of her slots (not single slots) at least 80% of the time during a season (use-it-or-lose-it rule). Single slots return back to the slot pool for the upcoming season. However, the use-it-or-lose-it rule has flexibility if the airline can justify the reasons behind low usage of the slots (below 80%). A new entrant at an airport is a carrier having fewer than five slots in total on a particular day or for an intra-EU route holding less than five slots with less than three competitors for the route that day [14]. Finally, the residual slots in the pool are allocated giving priority to yearly commercial air services. If an airline is not using or not planning to use a slot, she is required to return that slot or slots as soon as possible. Late slot returns are considered as unused slots and thus impact the use-it-or-lose it rule. But there hasn't been a penalty application for late returns. European Slot Regulation allows slots to be exchanged or transferred between airlines under specific conditions as explained in Figure 3. The coordinator follows the rules and also considers the effects on airport operations while accepting a transfer or exchange request [14].

Problems Emerging from The Current Mechanism in the EU

The EU Airport Slot Policy remains controversial and suffers from inherent weaknesses although many efforts have been paid to reform it for many years [15]. Council Regulation (EEC) No 95/93 of 18 January 1993 on common rules for the allocation of slots at Community airports [16] has been substantially amended several times. In the EU, airport slots are defined as take-off and landing rights. Carriers have desired to be able to trade in these slots in order to bring in those they need to extend their operations. Nevertheless, although exchange of slots is allowed, absolute sale or purchasing of slots are not, thus slots have no economic value under the regulation. It causes a `grey market` to develop where payments are made for unused, residual so called `graveyard` slots which have literally no economical value. Proof shows that airlines normally ask for a greater number of slots than they truly need and that a noteworthy level of slots are returned too late to be redistributed to another carrier [15]. This perspective importantly affects the effectiveness of the slot allocation system and expands the remaining burden for both coordinators and airline planning teams. The corrupt use of slots is not discouraged adequately within the system. Currently; `fake` or `artificial` slot exchanges are practiced as the main method of buying, selling and leasing of slots to meet the requirements of the regulation since slots have no economic value but is a right [15].Secondary trading occurs at London Heathrow and Gatwick and fake exchanges at Frankfurt, Dusseldorf and Vienna are identified by coordinators [15]. Some of the air carriers involved denied that there had been any payments. Whilst the UK coordinator can provide a list of slot trades taking place at London airports, there is no information on possible contractual constraints in the form of covenants which may dictate to the buyer how such slots can be used. An improved proper mechanism that ensures fair competition between incumbent and newcomer airlines is apparently necessary. Thus, it is also necessary to re-define slots in terms of ownership rights in this context [17].

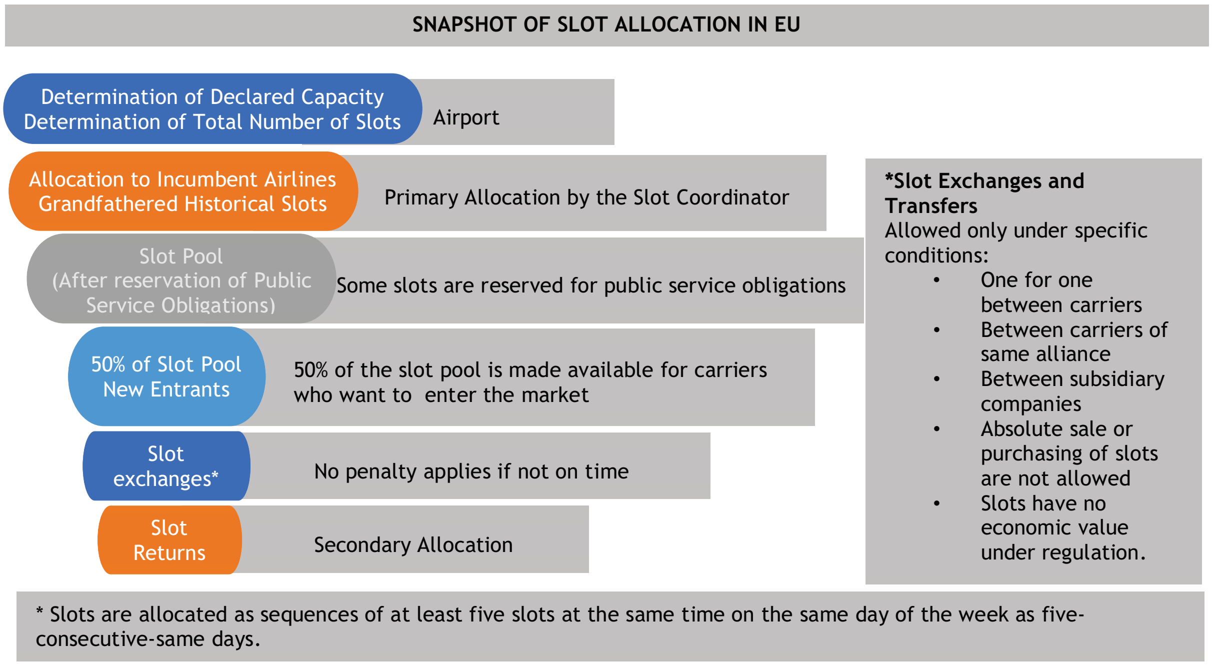

Figure 3. A Simplified Flowchart of the Slot Allocation Mechanism in the EU
Source: Authors

The current system for the allocation of airport capacity firmly depends on administrative rules and highly ignores the benefits of market-based mechanisms [18].

Administrative vs Market-Based Mechanisms

The market-based mechanisms that the most interest has emerged in terms of economic efficiency, equity, distribution, market -access, competition and system's ability to adapt change are Congestion Pricing, Auctions and Secondary Markets. Figure 4. addresses both the alternative IATA based administrative solutions and the market-based mechanisms that have been proposed so far to improve deficiencies of the current system.

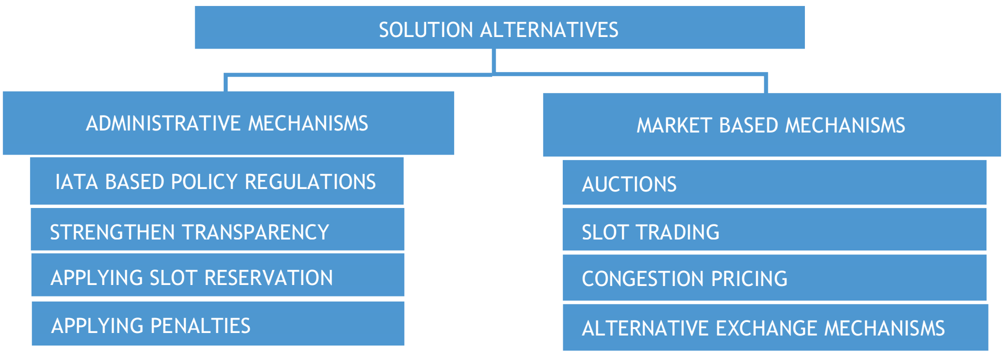

Figure 4. Slot Allocation Solution Alternatives
Source: Authors

Alternate market mechanisms let allocation of airport slots to the ones who value them most and endorse competition between all types of carriers (incumbent airlines and new entrants). In the current administrative system in the EU, the transparency level is not adequate to guarantee optimal slot allocation and so-called grandfather rights at congested airports prevent new entrants from entry into the air transport market [14]. Market mechanisms mainly uncover the economic value of the slots, led the development of an efficient secondary market between airlines, provide use of larger aircraft resulting in carrying more passengers and advance airlines to use slots more efficiently [19]. Carriers feel compromised because of the fact that in the case of market-mechanisms they will have to pay for slots which currently they get for free. They oppose to the idea and feel uncomfortable about the compensation they would receive in such a system. In theory market-mechanisms increase equity but also may raise distributional issues that they have to include appropriate compensation mechanisms. Carriers also expect information confidentiality and most of them don't want the prices they pay to be released. In congestion pricing the fees are evaluated on a flat basis letting the number of the slots determined by the market itself. On the contrary, the number of slots and their lease-period are determined before auctions and only the prices are set by the market. In the case of auctions, it may be more difficult for carriers with low purchasing power to get slots at the busiest airports and that is why the auction mechanism should be well designed with suitable rules that enable new-entrants introduced in the system [20].

Overview of Slot Allocation Research

Supply and demand are the basis for the market and they largely depend on socio-economic factors. When it comes to slot and its value, the rate of supply and demand can give an idea about how the market would be shaped depending on direct and indirect effects of socio-economic factors. Demand and congestion management of airport transportation and the market structure have been subjects of scientific literature in the fields of Transportation Systems, Management Science, Operations Research and Economics due to their relevant objectives. [21],[22],[23],[24],[25],[26],[27] made extensive and leading reviews of the fundamental modelings in these different fields. Various hypothetical, computational and practical challenges rise from possible cross-disciplinary methodologies in order to develop more effective slot allocation mechanisms and policies. Optimization models for the design of airline networks and schedules, scheduling models, airline profit-maximizing behaviour, airline frequency competition, design of demand management policies, under and over scheduling have been the focus of approach and extensively studied in the literature separately and some combined with simple scenarios.

The difficulties of administrative slot control mechanisms have been reported comprehensively within various researches in the United States and Europe [18],[28],[29],[30]. These reports demonstrated the inefficiencies created by the overruling that administrative slot allocation mechanisms caused in an environment where very little space is left for competition and emphasized the barriers that exist for the new entrants.

Beside the main contributors in literature [24],[25],[31],[32],[52],[58],[14];sufficient interest have not been paid by the researchers for policy adjustments through stakeholder engagements in order to enhance airport performance as a part of scarce capacity management. Zografos and Madas defined the problem in the EU as a lack of an overall integrated and operationalized slot allocation strategy that combines the alternative slot allocation strategies and prioritize options to select the best slot allocation strategy for scarce airport capacity in different airport settings by a hierarchical decomposition model – Analytical Hierarchy Process Model (a quantitative model to deal with complex decision making problems) for the assessment of policy compatibility and designed a multi-criteria compatibility assessment per airport cluster is developed [31],[7],[32]. The questions of congestion fee levels, revenue neutrality, safety restrictions, slot coordinators' roles and responsibilities remain unanswered in these studies and has to be further researched to be applied in the proposed strategies.

Demand, Capacity and Congestion Management Instruments

Auctions

Slot auctions alongside with secondary markets (slot trading/slot exchange mechanisms) are proposed by researchers in literature [33],[34],[28],[35],[30],[36],[37],[38],[39]. First models of auctions for primary market, alongside with oral double auctioning for the secondary market were based on uniform-price, sealed-bid auctions. Lab experiments were carried out with hypothetical slot values where also bidders knew the values of the slots. Efficiency and strength of the auction system were objectives of the auction design [33]. Combinatorial sealed-bid package auctions for primary market was first proposed by Rassenti et al, [34]. [28] and [29] consider Market mechanisms' usage, specifically focusing on simultaneous ascending auctioning, in primary slot allocation as a better solution to the inefficiencies of the current situation. But these studies used qualitative methods with statistical results in combined figures and schedule modelling was not considered. Bidders accept the costs of alternative benefits that would generate from the alternative options telling us that slot auctioning in primary allocation and a trading market could result in higher capacity efficiency and lower the fares. Without any experimental results, Ball et al. introduced a framework for slot auctioning mechanism that combines simultaneous multiple round ascending bid auctioning of arrival and/or departure slots (long term lease) at the strategic level adjunct to a secondary market of inter-airline exchange and a real-time market at the operational level and also considered policy criteria and limitations [35]. [35] and [19] developed optimization models in order to investigate the welfare that can be created by the use of slot auctioning mechanisms but the concerns regarding implementation of such mechanisms and the right use of revenues that would be generated have been debated for a long time and remain. A well designed and controlled slot auctioning mechanism can success high efficiency and less delays. [39] is a very good example of an effective approach of introducing slot auction mechanisms in place of administrative mechanisms since it presents evidence of supporting information for this proposed change. His work can be brought further in order to modelling simulating behaviour and conclude with more supportive scientific results to overcome policy barriers of such a change. We see that, the choice for auction mechanism model will be combinatorial auctions due to the nature of the problem but within this mechanism there are many auction types and design options that remain and can be modelled within combinatorial mechanism and investigated.

Primary Allocation Auctions with Agent Based Modelling

The model created [37] applies a scientific approach based on auction engineering and experimental design by using agent-based modelling and simulation tools in a simple scenario where the slot allocation problem is defined as a combinatorial slot allocation problem. This model is the first attempt in literature using agent-based modelling in the slot allocation context and it is improved [38] in a multi-airport scenario. They presented a methodology to study application of combinatorial price-setting auctions at primary allocation/auctioning of all airport capacity in a simple scenario and they identified the slot allocation problem as a combinatorial allocation problem (CAP). The work proposes a methodology of experimental design and it defines particular scenarios that will be used to compare the outcome of auction markets with mathematical optimisation and administrative mechanisms. Primary allocation auctions are compared both with optimisation mechanisms and the current administrative allocation mechanisms in terms of the Key Performance Indicators (KPIs) related to economic efficiency, equity, market competition, resilience, interoperability, capacity and delay defined in the previous project group study. It is obvious that network carriers will pay higher amounts of money to guarantee small amount of shifted flights, while low cost carriers will eventually prefer shifting most of their flights by getting much cheaper slots. It can be interpreted that willingness to pay will determine the capacity allocation. This finding would guide us set rules to an allocation mechanism to avoid monopolisation by carriers having high market power.

Secondary Trading and Slot Sales

Collapse of Sabena and Swiss Air let the sale of their slots to other carriers who then leased some part of them again to other carriers until they'd need to get them back under their own use. British Airways who is the dominant carrier at London Heathrow increased the number of his slots by secondary trading between 2001 and 2006 with a significant amount as well. Evidence from statistics that 499 slots were traded at Heathrow between 2001 and 2006 which have even been traded more than once [30]. During this time, the number of slots allocated from the pool has decreased significantly from 220 to 120 by the end of 2006. Implementation of a formalized secondary trading slot allocation mechanism is believed to result in higher social welfare surplus and efficiency. [40] propose an alternative secondary trading mechanism where secondary trading is formalized through a combinatorial slot allocation management system by modelling it as an integer linear programming problem. En-route airspace capacities have been taken into consideration for the first time in this study as a part of the slot allocation process; the grandfather rights is another critical factor in the study and their influence related to slot allocation on the produced costs are investigated. Their work present quantified results that helps us compare the proposed system with current practice and also helps to verify the qualitative approaches that have been worked previously in literature. There is a significant decrease of costs in the framework they propose compared to current practice and secondary market slot share significantly increases in this framework.

Congestion Pricing and Congestion Internalization

Congestion tax acts as an instrument against congestion but congestion pricing has no role when a monopolist carrier dominates the airport since the congestion is completely internalised. This is a positive finding as opposed to the standard stresses over the loss of welfare by the hub's dominant carrier [41]. Monopoly and Cournot Oligopoly (model of imperfect competition in which the number of firms matters, and it represents one way of thinking about what happens when the world is neither perfectly competitive nor a monopoly) theories are used in Brueckner's model to construct models where carriers have market power. Under the case of oligopoly, a tax abducting the part of the congestion which is not internalized, can enhance allocation. Vagueness of congestion pricing identifies itself with the span of the remaining market power effect against the congestion externality. When a carrier's flight share is large, the congestion tax it will pay is relatively small compared to the congestion tax that a carrier having smaller flight share pays since the carrier having large flight share will internalize most of the congestion created by its additional flight. So; an airline should only pay for the congestion it creates for other operators [42]. Effect of congestion pricing scheme on market shares is also investigated and it is concluded that welfare loss is not significant in an atomistic market and self-internalization does not play an important role [43]. Effects of congestion pricing on business passengers and leisure passengers have been explored in [44]. To protect business passengers from redundant congestion caused by leisure passengers, the tendency is applying bigger airport charges and fares. As an outcome, the optimal welfare airport charge can surpass the level of the externality of marginal congestion costs. This result shows consistency with the study conducted [43]. Slot-sales are found to be efficient only when no congestion is internalized by the airlines and it can replace the congestion tax regime to produce the best optima [11].

The influence of congestion pricing, slot trading and slot auctioning methods when an airport wants to maximize its profit due to budget constraints and when its revenue is important has to be further investigated. Findings from literature support the use of auctions over congestion pricing since a higher total traffic is achieved and higher objective function values are achieved on the margin of airport profit [45].

The reality of unused slots and barriers to new entrants remain in a free slot distribution regime and the number of slots distributed effects the total flight volume Nevertheless, the studies barely can present a solution of which mechanism should be used when making a decision due to the complexity of the problem.

Schedule Enhancements, Allocation Fairness and Efficiency Improvements and Alternate Slot Exchange Mechanisms

An increasingly applicable course of research includes demonstrating the impacts of demand management on airline schedules and airport congestion to enhance practices and policies at congested airports. At US airports, it is recommended by following researches that scheduling interventions could enhance the performance of the congested airports. [46] considered revenue models of airline scheduling and later on developed an approach to airline frequency competition where scheduling decisions of each airline was separated depending on O-D (origin destination) for full day operations [47]. Later on, economic approaches are integrated in order to identify airline strategic behaviour into airline scheduling models by developing a game-theoretic framework and by assuming that the airports were overscheduled and discussing that a capacity reduction may lead less delays and operational costs by the authors [23]. Nonlinear delay dynamics into flight scheduling studies as a measure of on-time performance are integrated by [43] and [48],[49],[50] used queuing models of congestion modelling combined with pricing methods. [51] formulated an integer program of deterministic queue dynamics which combines runway configurations and associated service rates. [52],[53],[54],[55],[25],[56],[57],[58] used optimization techniques for airline schedule modelling as well as optimization models for the design of airline networks and schedules of flights. Theoretical models of demand management with internalization of congestion and congestion pricing strategies have been developed [41],[42],[59],[44]. [60] added the market-power development to these uniform congestion pricing strategies. Nevertheless, no explicit welfare ranking results between these approaches could be achieved. These studies provided critical observation and understanding on the economic perspectives associated to demand management at congested airports. They commonly considered plain operational settings which can not provide realistic snap shots of the nature of the airport operations at the airport and network level.

A proper scheduling mechanism can enhance the system where demand management solutions are preferable due to infrastructure limitations. [56], [61] and [58] indicate that a proper and fair scheduling mechanism can enhance the system where demand management solutions are preferable due to infrastructure limitations. [58] developed an optimization-based, strategic, single-airport model that implemented existing EU and IATA regulations, slot coordination procedures and operational constraints that maximizes the slot allocation efficiency and minimizes the schedule displacement (the difference between the slot times allocated and requested). Similarly, the studies conducted by [54] and [62] confirm the effect of declared capacity on the number of scheduled movements that overprotective limiting of declared capacity settings can cause unnecessary down scheduling.

An alternative market-based slot allocation mechanism solution is proposed [63] for the case of a single constrained airport. The model provides airlines/operators to contribute in the decision-making process by enabling them pay or receive compensations in order to reduce delays. Based on two approaches (en-route regulation and airport-arrival regulation) with computed scenarios and with real data, the model considers Pareto efficiency, individual and combinatorial rationality by providing the participants' confidentiality and demonstrates the preferability of market-based mechanisms in terms of overall delay-related costs to first planned first served slot allocation regulations. Improvements of this model by solving same problem at network level by a mechanism simultaneously allocates slots (consistent with requested schedule) to the airlines was developed by the authors [64]. Thus, the model included a monetary compensation mechanism (including elimination of grandfather rights) in order to amplify fairness and efficiency but only for a given day. A set of slots for a specific period of time such as for a slot scheduling season could be more likely to match real life situations.

Concluding Remarks

Impact of regulation policy on allocation efficiency and its effect on the market structure by ensuring safety, equity and fair competition can not be disregarded. Market monopolisation risk due to dominant carriers must be controlled carefully to ensure policy objectives. Optimization models that have been reviewed show studies of theoretical economic models with hugely formalized operational framework. The airline competitive and profit-maximizing behaviour models with air-fare and aircraft type instruments combined with schedule and planning optimization models where market-based mechanisms framework with defined policy-measures could enhance research synergies for considering a complex decision making challenge such as a global optimization problem solved for objectives and incentives of all actors. Following contributions of [26] and [56] that provide methodologies toward more powerful policies, we see that there is still room for further researching frameworks of integrated models that would combine different administrative and market-based solutions in primary and secondary allocations by using new analysing, modelling and simulation methods.The methodological integration of models of airport capacity, operations and congestion into the design and evaluation of slot allocation measures is critical to quantifying the benefits of new mechanisms. Accomplishing more extensive integration by having all stake-holders participate at the decision-making level could increase the performance of the current system and approaches. Future research is expected to focus on improvements to the slot allocation process that can be rationally implemented in practice in order to improve efficiency, fairness and transparency simultaneously.

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Methodology for analysing Multi-Airport System Capacity: SBPL-MMMX System Case

Miguel Mujica Mota - m.mujica.mota@hva.nl
Amsterdam University of Applied Sciences
Alejandro Di Bernardi - aledibernardi@hotmail.com
National University of La Plata
Paolo Scala - p.m.scala@hva.nl
Amsterdam University of Applied Sciences
Daniel Delahaye - delahaye@recherche.enac.fr
ENAC

Abstract

The following paper presents a simulation-based methodology for analysing the potential operational capacity of a multi-airport system. The case presented is the one of the region of Mexico City composed by Santa Lucia Airport and Mexico City. The study is composed of several modules that compose the multi-airport system: airport(s) and airspace. Together they form an integrated model in which the different elements interact for revealing the capacity potential of the region of Mexico city. Then an experimental design is developed under different time horizons which allow identifying the problems that will arise once the traffic increases in the coming years.

It will allow us to identify the limitations, problems and potential of the region of Mexico city.

This research is original research in which for the first time proposes a methodology for identifying the capacity of a system composed of different airports which have the common objective of serving a geographical region.

Keywords

AICM; simulation; Connectivity; NAICM

Methodology for analysing Multi-Airport System Capacity: SBPL-MMMX System Case

Introduction

Mexico City airport is the main gateway to the country since years ago. However, its growth has been hampered by the saturation of the airport which in most slots of the day it is impossible to accommodate more traffic. The latter can be only achieved by performing three activities: infrastructure expansion, optimization of the current resources or by managing the system under a different paradigm such as the multi-airport system approach.
The previous government in Mexico decided for the first choice by constructing a new infrastructure in an old lake which made the project a risky business with uncertain outcomes. For the previous reasons and other consequences mainly environmental [1] the new government (by late 2018) decided to cancel the project and betted for a less risky approach by expanding an old military facility and changing the approach to a multi-airport system which will be composed by Santa Lucia Airport, Mexico City Airport and eventually Toluca which is also in the vicinity of Mexico City.
The opposition to this solution claim that the multi-airport system approach will not be able to solve the original problem of saturation in Mexico city airport while at the same time maintaining a steady traffic growth and also that the multi-airport system will not be equivalent in capacity to the previous option of a completely new airport.
The present study aims at answering some of the questions raised by the critics to the project, in particular, it will answer the questions of whether this proposal is able to cope with the expected demand in the coming years and if it is also able to solve the congestion problems in the current airport of Mexico city. In addition, this study will provide some light in the expected performance indicators of the new facilities and the limitations that will be faced once the expected traffic becomes a reality.
The present analysis involves the following aircraft fields

- Benito Juárez International Airport of Mexico City (MEX) which is the main airport for Mexico City
- Military Base "General Alfredo Lezama Álvarez" of Santa Lucia (NLU) which is currently a military base, but it will be upgraded to attract commercial traffic.

STATE OF THE ART IN MULTI-AIRPORT SYSTEMS

The topic of Multi-Airport Systems (MAS) has been gaining some attention the last few years as many issues regarding complex airport systems have been studied. The concept of a MAS is defined as one main airport with another or more secondary airports that together serve a metropolitan region and it has diverse issues that require attention, such as capacity, coordination, selection, sustainability and feasibility among others.
Regarding the definition and feasibility, the seminal paper of de Neufville [2] introduced the analysis of the viability of MAS by defining that the air traffic of a metropolitan area should exceed 10 million originating passengers per year so that a MAS could be economically and operationally viable, however this number has increased up to 15 million in some cases.

On the other hand, the paper of Martin and Voltes-Dorta [3] provides some caution for the development and use of MAS. They suggest, considering a financial approach, that some MAS worldwide are operating inefficiently and that the consolidation of air traffic of the whole MAS into one airport could provide a better performance regarding operating costs. However, their conclusions did not consider that, as the utilization of any capacity-constrained resource increases in a stochastic environment, the service levels of the system rapidly deteriorate with a non-linear function [4].

Furthermore, Fasone et al. [5] and Yang et al. [6] suggested that the viability of a MAS is intertwined with the development of other transport infrastructure, such as, railways, roads and bus services, that connects customers and cargo with the various airports in the system so that customers of the MAS could have accessible options to use any of the airports in the system and change their initial preference regarding the principal airport.

As mentioned, de Neufville and Odoni [7] state the viability threshold, which in 2013 they calculated was 15 million passengers per year for originating passengers, discarding the transfer ones.

Regarding the issue of airport selection, the subject of the main factors involved influencing selection among customers has been extensively studied using statistical methods ([8], [9], [10], [11], [12], [13], [14]. These papers found that air fare, access time, flight frequency, the number of airlines and the availability of particular airport–airline combinations were statistically significant factors in customer choice of airport. Interestingly, airport access time was found to be more important for business travellers than for leisure travellers. In contrast, leisure travellers were found to be more sensitive to price changes than business travellers.

The specific issue of multi-airport capacity has only been studied by Ramanujam and Balakrishnan [15]. The study by Ramanujam and Balakrishnan [15] focuses on the definition of capacity envelopes for the MAS of NYC, based on Gilbo [16] proposal. Using quantile regression and historical data, they modelled the relation between arrival and departure rates at singular airports considering the arrival rate as the independent variable, as arrivals are given priority over departures at singular airports. In addition, they also modelled the relation between arrival and departure rates of different airports, because the (airspace) approach and departure paths of different airports in MAS could interfere with each other. They found that the visibility factor is significant for arrivals but not for departures and that the capacity envelope area is increased when using one runway for arrivals and a different runway for departures, instead of a mixed use of runway for arrivals and departures. They also found that airside capacity is more significant for defining airport capacity than airspace as approach path overlap factor was not found to be statistically significant for capacity envelope definition.

Regarding Operational capacity of an airport, there are diverse studies attempting to estimate it for a singular airport resource, such as, runway capacity ([16], [17], [18], [19], [20]), and terminal capacity ([21], [22], [23]). In addition, there are few attempts to model the actual capacity of the whole airside operations of a singular airport, i.e., runways, taxiways and apron operations. Modelling the complete set of capacity-constrained resources of an airport could provide practitioners and researchers with better decision tools for design and management of the complete airside facilities of an airport as the interactions among different serialized queues could create different behaviour patterns than singular resources. In literature, only the work of Mujica et al. [24] present this approach. The paper by Mujica et al. [24] analyses, using Discrete Simulation, the capacity and performance of Lelystad Airport assuming that some traffic will be diverted from the highly utilized Schiphol Airport in Amsterdam. They modelled the capacity of Lelystad Airport considering historic data of wind visibility and airport traffic and considering various operative restrictions, such as, the separation criteria between aircraft operations, weather conditions, mix of aircrafts and type of taxiways. They found that the use of rapid exit taxiways could increase the throughput of a singular airport.

Thus, this literature review shows that regarding airport systems some studies have covered different aspects of single airports and by using some mathematical techniques some aspects of the MAS, but no authors have modelled a Multi-Airport System considering an integral approach (two or three airport operations together with airspace and/or different elements of the airport). This type of study could provide great insight in understanding the consequences and potential problems that might appear once the system of airports is operational. Consequently, the objective of the paper is to address this gap as it will be focused on studying a twin system that will be operational in the near future in Mexico considering the current Mexico City International Airport and the future Santa Lucia Airport.

METHODOLOGY

The study considers the two airports in their current phase and the expected developments for the short, medium and long term horizons.

Figure 1 illustrates the geographical location of NLU and MEX.

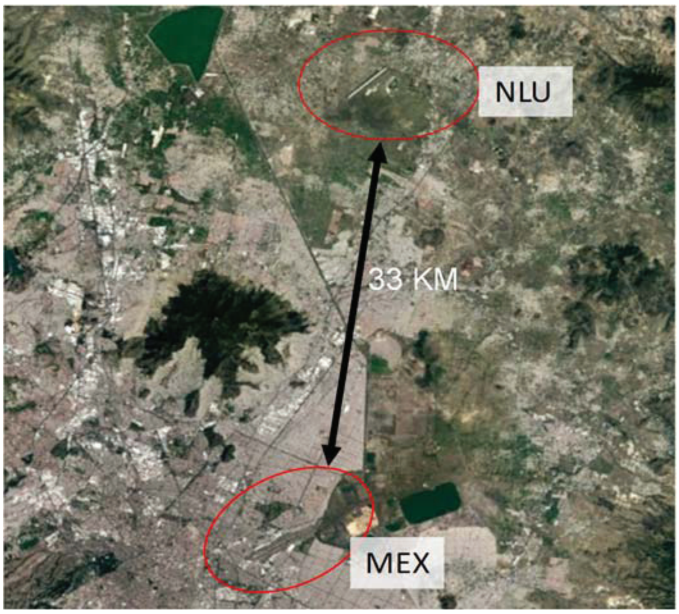

Figure 1. Aerial view of system NLU-MEX

The methodology followed in this work, is the one presented by Mujica et al. [25] for developing a multi model system in which a combination of models are developed in order to create one that minimizes the uncertainty associated with the modelling process (Fig.2).
The developed model considers the following elements:
• Benito Juárez International Airport (IATA Code: MEX). For the modelling of this airport, we used a high-detailed model developed by the authors for diverse studies [26].
• Santa Lucia Airport (IATA Code: NLU). For this airport the airport model considers the characteristics reported in public documents of the Mexican government and the development project of the airport. A macro model of this airport is developed.
• Current aeronautical routes. For the traffic approaching to the two airports, the current aeronautical routes have been considered and once NLU is operational, a modification based on the expertise and experience of the authors, has been proposed.
• Current capacities of MEX runway system regarding runway, taxiways and terminal stands.
• Capacities of NLU airport regarding runway and stands for the macro model.

The analysis is performed by developing different scenarios considering different assumptions and taking the expected demand of traffic as an input for the model together with current restrictions and traffic mix. All the technical restrictions that correspond to airspace and ground operations of the airports under study have been considered.
In the first instance, Scenario 0 is analyzed, This scenario represents the baseline for comparison of the following 6 scenarios that are used for characterizing the capacity of the aeronautical operation. This scenario is the current situation of the airport system of Mexico City.

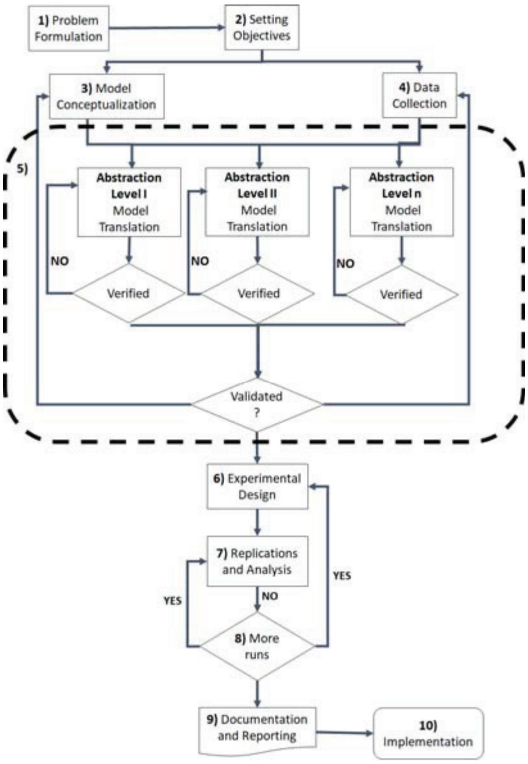

Figure 2. Methodology of the n-model virtual cycle approach for airport capacity
Source: [25]

Boundary Conditions and Analysis Criteria

The analysis is carried out considering the following operational assumptions:
- Current MEX airport layout.
- Sequential configuration of runways, taxiways and platforms for NLU.
- Current traffic mix for MEX airport.
- Current airspace based on Mexico AIP will be considered for the base case scenario.
- A feasible redesign of airspace to allow operation of NLU and MEX together is proposed.

The analysis is also made based on the following general considerations:

- The mix indexes% (C + 3D) of the AICM are maintained.
- 44,320,000 Pax / year is adopted as the current passenger level in Mexico City.
- 414,000 Movements / year is adopted. Starting with 590 arrivals/day.
- 18 hours of operation and 120 Pax / Average aircraft for both airports is assumed
- An annual operation is assumed for both airports
- The slot management model is maintained.
- The parking spaces available at MEX are maintained at 103
- 33 Parking places available in NLU are assumed from scenario 0 to 5a
- The considerations for the aeronautical capacity and associated airspace are conceptual.

All the simulations carried out consisted of simulations of 30 hours of operation and for each scenario 30 replications were made for obtaining the statistical indicators.

SCENARIO ANALYSIS AND RESULTS

The following section presents the different scenarios evaluated for the current study, starting with a base-case scenario and progressively modifying it for evaluating different situations.

Scenario 0

This scenario serves as the base case and represents the current situation of the airport in Mexico City. It makes use of a low-level simulation model, based on MEX's AIP, as well as using current air traffic values to compare the operational results with the subsequent scenarios.

The model includes the following elements:

- MEX Air Space
- Runway system 05R-23L and 05L-23R
- Terminal 1 and Terminal 2 with 103 aircraft parking positions in total
- Taxiway system with speed restrictions
- Flight plan for an average day of operation
- Traffic mix that includes low cost airlines (LCCs) and full service airlines (FSCs) and different aircraft equipment

For modelling the complete system, a simulation model of the current airspace together with the model of MEX were used. Figure 3 illustrates the airspace of the MEX model. The current routes reported in the AIP of Mexico [27] are used.

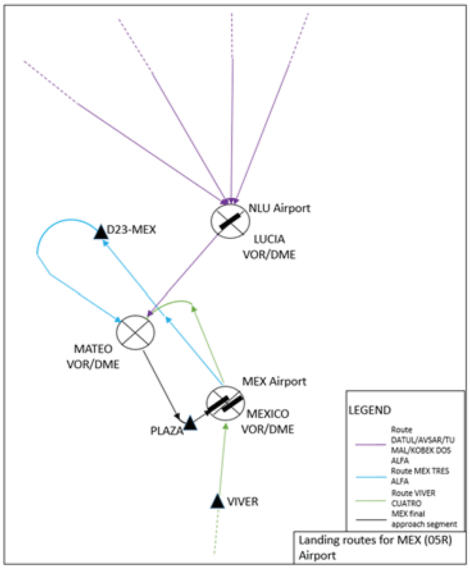

Figure 3. Elements of the airspace model

Figure 4 illustrates the low-level operating model implemented in MEX. With this model, all the emergent dynamics can be identified, as well as conflict situations that limit the capacity of the system like runway occupancy times, runway crossings, delays, congestion among others.

By running experiments with this model, we obtained performance indicators for the system, and we validated them statistically comparing them with historical data. Figure 5 presents the evolution of traffic during the day for the airport where clearly it can be seen that the levels of congestion are reached from 10 am until late at night (such as the real situation).

Regarding the remaining performance indicators for the elements that compose the system, Table 1 present different values obtained with the experiments.

It can be seen that the maximum value of ATM/HR corresponds to the declared limitation of the airport by the government. In addition, it can also be perceived that the remaining elements of the system are not fully congested during the day, only during peak times, revealing the effect of the business models of the companies that operate in the airport. From the analysis, it can also be perceived that the runway is the bottleneck of the system as it has been known for years now in Mexico.

Figure 4. Airside model of Mexico City Airport

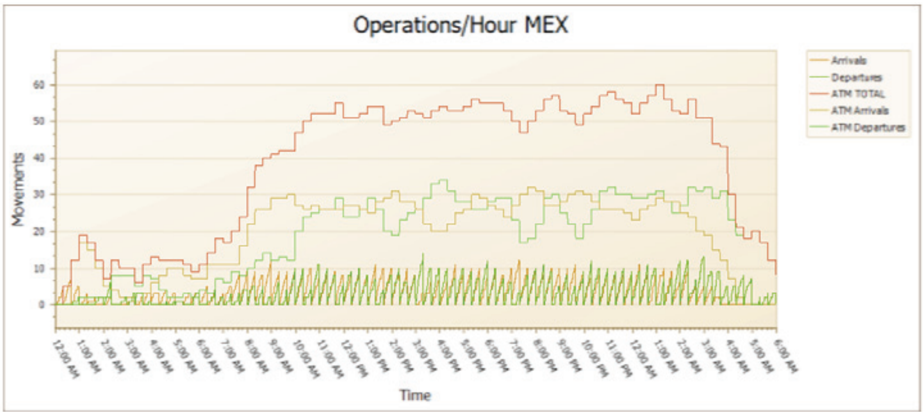

Figure 5. ATM evolution during the day

Table 1. Performance indicators of MEX

	MEX	
	Avg Value	Max Value
ATM/Hr	38.6	62
Gate Occupancy	55%	78%
Aircraft Waiting Runway	6	15
Aircraft Waiting Gate	0	6
Total Annual Passengers	30.4 MILL	48 MILL

Scenario 1

For this scenario, a redesign of the air routes that respect the operational restrictions was made, so that aircraft can fly from north and south to both airports without infringing safety restrictions.
It is assumed that low cost airlines LCCs transfer their operation to NLU and the Hub operation of legacy carriers is kept in MEX. The same airspace design was maintained for later scenarios. Figure 6 illustrates the simulated airspace as well as the location of the two airports under study.

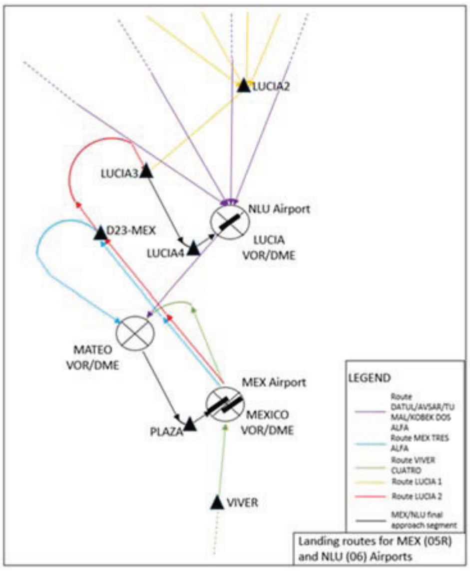

Figure 6. Air routes re-design for the system NLU-MEX

Table 2 shows the values of the air routes used for the study.

Table 2. Description of the landing routes for the MEX and NLU airports

Destination airport	Route	Waypoint	Altitude [ft]	Speed [kts]
MEX	DATUL/AVSAR/TUMAL/KOBEK/ DOS ALFA	LUCIA	12.000	220
		MATEO (IAF)	12.000	220
		PLAZA (FAF)	8.800	130
MEX	MEX TRES ALFA	MEX	FL 240*	250
		D23-MEX	18.000	250
		MATEO (IAF)	12.000	220
		PLAZA (FAF)	8.800	130
MEX	VIVER CUATRO	VIVER	12.000	250
		MEX	12.000	220
		MATEO (IAF)	12.000	220
		PLAZA (FAF)	8.800	130
NLU	Route LUCIA 1	LUCIA2	12.000	220
		LUCIA3	12.000	220
		LUCIA4 (FAF)	8.800	130
NLU	Route LUCIA 2	MEX	FL 240*	250
		D23-MEX	18.000	250
		LUCIA3	12.000	220
		LUCIA4 (FAF)	8.800	130

This scenario would correspond to a stage prior to the construction of the two runways referred in [28]. This scenario would also free up MEX capacity without affecting traffic growth. In addition, the function of the hub of MEX (in which full-service airlines operate) is not affected, and the growing demand of the low-cost airlines that service domestic demand is not hampered by this strategy. This scenario assumes that some LCC companies and charter ones will operate in NLU like the following: Magnicharter, Viva Aerobus, Interjet and Volaris; even some LCCs from the US could operate in this airport like Southwest or JetBlue. The same premise is maintained for subsequent scenarios in which we increase the volume of traffic.
As it can be seen in Table 3, once the airports are operating independently, the saturation of MEX is solved as in the worst situations the number of ATMs are 45 ATM/hr. Under the mentioned assumptions, the demand is shared by the two systems, and the maximum expected traffic with the type of equipment assumed would imply a maximum of 34 million of passengers for MEX and 30.7 million for NLU, making a total of almost 65 million passengers for the combined system.

Table 3. Performance indicators for Scenario 1

	MEX		NLU	
	AVG Value	MAX Value.	AVG Value	MAX Value
Traffic Share	57%		43%	
ATM/Hr	23	44	17	41
Gate Occupancy	47%	59%	48%	100%
Aircraft Waiting Runway	1	6	0	0
Aircraft Waiting Gate	0	0	0	8
Total Annual Passengers	18 MILL	34.7 MILL	13.4 MILL	30.7 MILL

Scenario 2

This scenario would correspond to the time-horizon when two runways have been completed in NLU, and the HUB operation of FSC would move to NLU while the LCCs would move to MEX. In this scenario, a simultaneous operation of landings and takeoffs in NLU will be possible (due to the two runways), and MEX would have enough room to absorb the growth of low-cost airlines as it is seen in the results of the simulations.

In this scenario, MEX remains as an airport for low cost airlines (LCCs); Table 4 shows the main performance indicators, as it can be seen that MEX is totally decongested, since the maximum number of movements would be 37 ATM / Hr or 60% of its capacity. On the other hand, NLU would have two tracks and operate at the time of maximum demand at 47 ATM / hr which suggests that it would not be even close to the current situation of MEX. 67 million passengers could be moved annually between the two airports with very reasonable operational indicators as Table 4 suggests.

Table 4. Performance indicators for Scenario 2

	MEX		NLU	
	AVG Value	MAX Value.	AVG Value	MAX Value
Traffic Share	43%		57%	
ATM/Hr	14	37	25	47
Gate Occupancy	19%	44%	70%	100%
Aircraft Waiting Runway	0	4	0	1
Aircraft Waiting Gate	0	0	5	23
Total Annual Passengers	11 MILL	29 MILL	19.7 MILL	37 MILL

It is important to note that it is perceived that the first bottleneck for NLU will be the aircraft parking spaces, since it is observed that there would be an average value of 5 cases of aircraft that do not have a gate when landing. Furthermore, in times of high demand this number can go up to 23 aircraft.

Scenario 3 and the following ones are designed to determine the growth limits and the elements that would restrict growth due to operational and capacity constraints.

Scenario 3

In this scenario, the same proportion of traffic mix between FSCs and LCCs is maintained, the variation of traffic consists of an increase of 10% in the demand for LCCs and FSC for both MEX and NLU. This scenario would correspond to a mid-term scenario assuming the current traffic growth trend.

In the case of NLU, the number of operations increases to a max of 50 ATM / hr at times of maximum demand, although on the other hand to avoid problems of reactive or induced delays it will be necessary to implement remote stands or add more gates to the infrastructure since the problems of aircraft without gate is evident (Table 5). 70 million passengers could be expected under this scenario(60% more than what MEX alone is currently receiving).

In this situation the problem of lacking gates for NLU is evident as the results illustrate. During peak hour, the problems could be severe (45 Aircraft waiting) which might be translated in delays for the flights at certain moments of the day.

Table 5. Performance indicators for Scenario 3

	MEX		NLU	
	AVG Value	MAX Value.	AVG Value	MAX Value
Traffic Share	43%		57%	
ATM/Hr	15.5	40	27.5	49.6
Gate Occupancy	19%	44%	75.8%	100%
Aircraft Waiting Runway	0	3	0	1
Aircraft Waiting Gate	1	1	14.4	45
Total Annual Passengers	12.2 MILL	31.5 MILL	21.7 MILL	39 MILL

Scenario 4

The increase in air traffic corresponds to 30% of LCCs and 30% of FSCs in MEX and NLU respectively. As previously mentioned, LCCs traffic can grow in MEX and FSC in NLU with a Hub-Spoke business model. This scenario would correspond to a medium-term horizon as well.
It can be realized that MEX does not present major problems, since it would be operating at a daily average of 18 ATM / Hr with peaks of 45 ATM/hr. However, in the case of NLU, it is already clear that in terms of runways there would be no problems, but it would be necessary to find a solution to the lack of Gates as Table 6 illustrates.

Table 6. Performance indicators for Scenario 4

	MEX		NLU	
	AVG Value	MAX Value.	AVG Value	MAX Value
Traffic Share	43%		57%	
ATM/Hr	17.7	45	31	65
Gate Occupancy	25%	49%	83%	100%
Aircraft Waiting Runway	0	3.6	0	2
Aircraft Waiting Gate	0	1	44	119
Total Annual Passengers	14 MILL	35.5 MILL	24.4 MILL	51 MILL

Scenario 5a and 5b

In scenario 5a and 5b air traffic increases by 70% in MEX and NLU respectively. This scenario would correspond to the assumption that traffic would grow as predicted in the next 50 years. This would be a long-term scenario, and would allow to evaluate the operation and limitations to absorb the expected traffic.

Scenario 5a

MEX reveals that under this configuration, it could grow without major problems for the next 50 years, however, NLU would have severe problems in case no gates expansion is performed as Table 7 illustrates.
Under the expected traffic, NLU gate infrastructure would be severely limited, for this reason, an alternative scenario (5b) is proposed which contemplates an expansion of the parking positions for aircraft and terminal building. In 5b, the number of parking spaces is doubled (66 Gates).

Table 7. Performance indicators for Scenario 5a

	MEX		NLU	
	AVG Value	MAX Value.	AVG Value	MAX Value
Traffic Share	43%		57%	
ATM/Hr	24	49.5	36	89
Gate Occupancy	28%	70%	85%	100%
Aircraft Waiting Runway	0.7	8	0	2.8
Aircraft Waiting Gate	0	1	112	256
Total Annual Passengers	19 MILL	39 MILL	28.4 MILL	70 MILL

Scenario 5b

The problem of lack of gates is partially solved but not completely. From Table 8 it can be noticed that there are still some problems during some days, as still some aircraft do not find a gate. The latter suggests that the double of gates is not enough for the operation, instead it is necessary to invest in more than 33 gates.
Table 8 presents the complementary indicators for the long-term scenario. As it can be seen, MEX reveals the limitation of the Runway as some aircraft will be limited by the runway, however, with a proper management of the sequence of the expected traffic mix, this can be minimized. In the case of NLU, the gates are the limiting factor for growth. The complete system would be expected to absorb a maximum of 120 mill of passengers.

Table 8. Performance indicators for Scenario 5b

	MEX		NLU	
	AVG Value	MAX Value.	AVG Value	MAX Value
Traffic Share	43%		57%	
ATM/Hr	24	50	42	105
Gate Occupancy	28%	70%	57%	100%
Aircraft Waiting Runway	0.7	8	0	4
Aircraft Waiting Gate	0	1	8	50
Total Annual Passengers	19 MILL	39.5 MILL	33 MILL	82.7 MILL

DISCUSSION AND CONCLUSION

The study presented for the first time a methodology for performing a simulation-based analysis of a Multi-airport system. We presented the case of Santa Lucia and Mexico City Airport which has become a key development for the country. The study consisted in different scenarios based on public information and governmental plans using three models: one for Mexico City airport, another for Santa Lucia and another one for the airspace that connects both airports. The experiments with the different scenarios gave light to some important issues regarding the development of the facilities such as the capacities of the system and the limitations that will appear when the growth in traffic takes place in the airport system. Some important results about the scenarios are discussed.
Regarding Scenario 0, we could identify that the main bottleneck is the runway, which coincides with what has been discussed publicly in the media. Depending on the time of the day, the effect of the runway is more or less severe. In addition, we could also identify that the limit of the capacity of 61ATM/hr can be reached sometimes. Assuming these operating levels, it can be estimated that this airport could absorb a capacity of 48 million passengers assuming the average aircraft type with an occupancy of 120 passengers, maintaining continuously 61 ATM / Hr, which is currently unfeasible.
Scenario 1 gives light on the operational levels of the system NLU-MEX system with one runway in NLU. Under the assumptions presented, NLU can operate with values of 41 ATM / Hr without major problem (using only one runway). In the case of MEX, it can be seen that the congestion problem is solved as it operates with an average of 40 ATM / hr, or what is the same at 65% of its current capacity. With the release of capacity, it would be expected that the problems of flight delays would be drastically reduced, and in addition to that, it would also be expected that the Mexican national airport network would operate without major setbacks with the consequence of deactivating the Ground Delay Program (GDP) which is currently active due to congestion [28] (Mujica and Romero, 2018).
With the following scenario where the traffic is increased (Scenario 3 to 5) they reveal that NLU will suffer from a lack of gate capacity, with the consequence of flights waiting for a parking position, inducing delays to the airlines and the national network. Scenario 5b reveals that the investment in the medium term in more gate capacity would alleviate partially the limitation, but it would suggest that the double of gates would not be sufficient for solving the problem. The different scenarios reveal that by implementing the system NLU-MEX and with the proper

timely investments, the growth in the metropolitan region of Mexico City is unleashed and it has potential to grow up to a three digit level in terms of passengers.
The study presented, revealed the different capacities the system will have at different time horizons; the short term that consists of the current situation and some 5 years more, medium term for approximately 30 yrs and a long term scenario of 50+ years in which we can identify the amount of passengers, number of movements and potential problems that will arise during the operational life of the system. The analysis provides enough information for giving light about the potential areas of improvement and requirements of expansion in the coming years. This could not be achieved without the use of simulation technology; for this reason, the authors strongly encourage the use of this methods and technology during the planning phase of any critical infrastructure.

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An algorithm to reduce cascading failures in air transport networks

Joel Cumelles - joelcumelles@gmail.com
Universitat Politècnica de Catalunya
Jose M Sallan - jose.maria.sallan@upc.edu
Universitat Politècnica de Catalunya
Oriol Lordan - oriol.lordan@upc.edu
Universitat Politècnica de Catalunya

Abstract
Our aim is to define an algorithm to simulate the management of cascading failures in air transport networks. Cascading failures occur when an incident isolating a node or nodes triggers an avalanche caused by the overload of other nodes.
The input of the algorithm are the flights scheduled on a time window, and a specific incident. The algorithm tries to reduce the impact of the cascading failure assigning alternative departure or arrival airports to affected flights using several alternative rules. We have defined three rules for selecting alternative arriving airports, and one rule for rerouting flights to a new departure airport.
We have applied the algorithm to the Oceanic Airport Network. The closure of central airports has a much larger impact than random airports, selection rules are effective to reduce the impact of incidents affecting central airports, but less effective in the closure of a territory. The most effective rule of selection of destination airports is minimizing the product of load and distance to affected airport.
Existing models of cascading failures are not adequate for air transport networks, because in these networks the flow is not continuous, and load has to be redistributed among close airports, rather than previously existing connections. This model allows a more adequate modelling of cascading failures in air transport networks.

Keywords
Cascading failures; Air transport; Complex networks

An algorithm to reduce cascading failures in airport networks

Abstract

Cascading failure phenomena can appear in complex networks that distribute flows of information, people or goods, when flow going through nodes or edges exceeds the capacity of network elements (nodes or edges). Cascading failure models in previous research are not adequate for airport networks, as flow is not continuous, and load has to be redistributed among close airports, rather than previously existing connections. With these constraints in mind, we have defined an algorithm to simulate the management of cascading failures in airport networks. The algorithm tries to reduce the impact of an incident assigning alternative departure or arrival airports to affected flights with several alternative rules. We have applied the algorithm to the Oceanic Airport Network to assess the impact of several incidents. Results show that rules of selection of alternative airports have significant impact in reducing the effect of incidents affecting central airports.

Introduction

The air transport industry has been growing until becoming an essential part of the everyday life in today's economy. Air transport is generally considered safer and faster than other means of transport [6], particularly to connect isolated rural areas and islands with urbanized areas, or to connect mutually distant locations such as cities in different continents [18]. This system is shaped by historic, politic, geographic or economic factors [13], and is the result of the aggregation of routing decisions of airlines, that try to serve the air transport demand in the context of a competitive industry. Airline industry deregulation and liberalisation has lead to a continuous growth of air transport in the recent years [20, 5, 10].

The air transport network can be represented as an airport network, where nodes represent airports or cities and edges direct connections between nodes. This representation can be completed assigning weights to edges, usually representing intensity of connection (e.g. weekly frequency of flights). Following the pioneering study of Guimerà and Amaral [12] for the global airport network, the topology of several regional airport networks has been examined by [3] (India), [11] (Italy), China [22] [14] (Australia) and [19] (Greece), among others. All of these studies conclude, with minor differences between them, that air transport networks have the small-world property (a small average path length together with a high average clustering coefficient) and a truncated scale-free degree distribution [2]. In airport networks well-connected nodes have high values of node degree while central nodes have high values of betweenness, therefore degree and betweenness are measures of local and global centrality, respectively. [13] found that for the world airport network the better-connected nodes are not necessarily the most central, resulting in anomalous values of centrality.

Air transport can be particularly affected by airport closure. This event can be triggered for environmental causes, accidents, security alerts, strikes or terrorist attacks, producing high costs for the airline industry [16]. One example of closure of airports by environmental causes is the ash plume from Iceland's Eyjafallajökull volcano led to the progressive closure of much Europe's airspace over a period of seven days, causing over 100,000 flights to be cancelled [25, 4]. The magnitude of the effect of the closure of a particular airport depends of its role in the air transport network, i.e., the system shaped by airports and the flights that connect them.

The impact of airport closure can be analyzed through static robustness analysis, i.e., the study of the effect of the disconnection of subsets of nodes on network performance. Chi and Cai [7] performed a robustness analysis for the US airport network, and Lordan et al. [16] detected the critical nodes of the airport network using several node selection criteria. Both studies concluded that airport networks are robust to errors (isolation of nodes chosen at random), but not to attacks (isolation of important or central nodes). This behaviour is typical of scale free networks [1]. Static robustness analysis does not consider the dynamic effects that can occur after a network disruption. This failure can trigger secondary failures to other network components, leading to a cascading failure effect [17]. This phenomenon is a significant threat to some networked systems, like the power grid [15, 23] or the Internet [21]. Similar effects have been reported in some incidents in the air transport system, like the Eyjafallajökull volcano incident mentioned above. The aim of this study is to create a model of cascading failures in airport transport networks. This model has to consider the specificities of these networks, especially when defining capacity and load of network components, and rules of flow redistribution compatibles with air transport operations.

Models of cascading failures

Motter and Lai [17] defines a global load-based cascading model for analyzing cascading failures on complex networks. The basic assumption of this model is that flows of energy or information between nodes are transmitted along the shortest paths connecting them. Then L_i^0, the initial *load* of node *i*, is defined as the total number of shortest paths from all vertices to all other that pass through the node. In other versions of this problem [9], load is equal to node betweenness. The capacity, or maximum flow that a node is able to transmit, is defined as $C_i = (1 + a) L_i^0$, where $\alpha \geq 0$ is a tolerance parameter. If a disruption leading to the isolation of one or several nodes occurs, node loads may change. In a given iteration *t* of the cascading process, all nodes where $L_i^t > C_i$ are overloaded, then removed from the network. This causes a new load redistribution, which may lead to new overload of nodes, and so on. The cascading process finishes when no new nodes are overloaded. The damage caused by this process is measured with the parameter $G = N'/N$ where N and N' are the sizes of the largest connected component before and after the cascading process, respectively. Crucitti et al. [8] proposes an alternative model where the overload of a node degrades the communication through edges incident to that node, so shortest paths will go through other nodes. In this model, overloaded nodes are not removed from the network, and the damage caused by a cascade is quantified in terms of decrease of global efficiency.

The models described above are adequate to represent cascading phenomena where flows between nodes are transmitted through the shortest paths connecting them, and consequently flow redistribution takes place at the global level. This is an unrealistic assumption for air transport operations, where redistribution of flows takes place at the local level, as the congestion of an airport causes redistribution of traffic to neighbouring airports. Wu et al. [26] defines a local weighted flow redistribution model. In this model, the load or flow going through node *i* is equal to $L_i^0 = k_i^\theta$, where k_i is the degree of node *i* and θ is a tunable parameter. Node capacity is equal to $C_i = CL_i^0$, where $C > 1$ is a threshold parameter characterizing network tolerance. Once a node *i* is disconnected or overloaded, its load is redistributed among their neighbours according to the following expression:

$$\Delta L_j^{t+1} = L_i^t \frac{L_j^t}{\sum_{m \in \Omega_i} L_m^t}$$

where Ω_i is the set of neighbours of *i*. In this new iteration, the nodes to be overloaded will be those which hold:

$$L_j^{t+1} = L_j^t + \Delta L_j^{t+1} > C_i$$

Similarly, to the global load-based models, the redistribution of loads may lead to further overload of other nodes. Wang and Chen [24] defines a similar model of local weighted flow redistribution for edge overload.

Cascading failures model for air transport networks

Algorithm definition

The models defined in the previous section are not adequate to represent realistically cascading failures in air transport networks. A common assumption of the reviewed cascading failure models is continuous flow along the network, while the air transport network is a temporal network of scheduled flights. An implication of this modelling is that airport load is equal to the number of planes parked in the airport. Second, air traffic management establishes that load redistribution has to be made considering spatial considerations. Aircraft departures or arrivals will be rerouted to airports close to the original location, and with similar capacity. Third, although airports with high degree should have high capacity, in this model airport capacity (the maximum number of aircraft that can be parked to be operative) is an exogenous parameter, rather than proportional to initial load.

Considering these considerations, to analyse cascading failures in airport operations, we define a temporal network model, that considers the specificities of air traffic management. In this model, an airport a is modeled as a tuple with elements $\{L(t),C\}$. Load $L(t)$ is equal to the number of planes in the airport at time t, and C is airport capacity, defined as the maximum number of planes that can be parked at the airport to carry out normal operations. The value of C is specific for each airport, and is set to zero for attacked airports. If $L(t) > 1.3C$ the airport is closed. If $C \leq L(t) \leq 1.3C$, the airport is saturated. In a saturated airport only can land active flights with arriving airports closed, and no flights can depart from saturated or closed airports. For every airport is defined a Na of secondary airports where traffic can be redirected in case of saturation of closure. Airports belonging to this set must be closer than R from the airport, and have a similar or larger capacity. Conversely, a flight **f** is modeled as a tuple with elements $\{i, j, t_d, t_a, s\}$, where i and td are the departing airport and departing time, and j and ta are the arrival airport and arrival time. Variable s represents the state of the flight, which can be inactive (not yet departed), active (on flight), landed, cancelled or in emergency.

For each time interval, the algorithm begins setting the capacity of attacked airports equal to zero. Then, it checks the flights departing at that time. For these flights, if the departing airport is saturated, the algorithm assigns to the flight a new departing airport with nonzero load. Doing this we try to get enough load in arriving airports to start future flights. For the same flights, if the arriving airport is saturated, the algorithm assigns a new arriving airport. If it is not possible to assign a new departing or arriving airport, the flight is cancelled. After that, the algorithm registers the landing flights. We assume that the incident occurs at the end of the time interval, so all arriving flights can land. Finally, it checks the active flights that should land on closed airports, and tries to reassign them an alternative arrival airport. If it is not possible, the flight is in emergency. A pseudocode of the algorithm is presented in Algorithm 1.

The algorithm requires defining selection rules for alternative departing and arriving airports. We have defined two rules for departing airports, that prioritise airports with high load. The first rule (MD1) consist in select an airport from N_i randomly, with a probability proportional to its load. This rule is similar to the local redistribution rule defined in Wu et al. [26]. The second rule (MO2) consist in selecting the airport with minimal slack $C_{i*} - L_{i*}(t)$. In case of tie, the alternative departing airport is selected randomly among the ones of minimum slack. We have tested three rules for selecting alternative arrival airports. The first rule (MA1) selects the airport of N_j closest to j. The second rule (MA2) selects the airport of maximal $Cj* - Lj*(t)$. The third rule (MA3) selects the airport of minimal $L_{j*}(t)d_{jj*}$. Ties between candidate airports are broken randomly.


```
t ← 1
while t < T_max do
    Make C ← 0 for attacked airports
    for flights with t_d = t do
        if L_i(t) > C_i then
            select new departing airport i* ∈ N_i
            if i* = ∅ then
                flight is cancelled
            else
                recalculate arriving time
                L_i*(t) ← L_i*(t) − 1
                flight is active
            end
        else
            if L_i(t) > 0 then
                flight is active
            else
                cancel flight
            end
        end
        if L_j(t) > C_j then
            select new arriving airport j* ∈ N_j
            if j* = ∅ then
                flight is cancelled
            else
                recalculate arriving time
            end
        end
    end
    for flights with t_a = t do
        L_j(t) ← L_j(t) + 1
        flight is landed
    end
    for flights with t_d < t and t_a > t do
        if L_j(t) > 1.3C_j then
            select new arriving airport j* ∈ N_j
            if j* = ∅ then
                flight is in emergency
            else
                recalculate arriving time
            end
        end
    end
    t ← t + 1
end
```

Algorithm 1 - Cascading failures algorithm

Toy model application

To illustrate the algorithm, we present a toy model with four airports, labelled from A to D (Table 1) and eight scheduled flights, labelled from 1 to 8 (Table 2). In Table 3 is registered the load of each airport and the state of each flight in normal operations. To illustrate the evolution of a cascading failure, we will examine the effect of a closure of airport B at 10:00 during the rest of the day (see Table 4). Before the closure of B, flights 1 to 4 depart normally. The closure of B at 10:00 does not affect flight 1, but affects flights 2 and 3, which are rerouted to airport C. Arrival times of both flights need to be recalculated. This rerouting is affecting flight 4 critically, as it is expected to land in C, which is now closed. The alternative airport B is not available, so this flight is in emergency. At 10:10 has to depart flight 5 with destination to B. As B is closed, this flight is rerouted to A before departing. Flight 6 has to be cancelled, as it is departing from a closed airport C with no alternative. Flight 7 has to be also cancelled, as the alternatives for airport B are unavailable: airport C is closed and airport A has no load. Finally, flight 8 has to be also cancelled as its departing airport D has no load, and it has no alternative airport available.

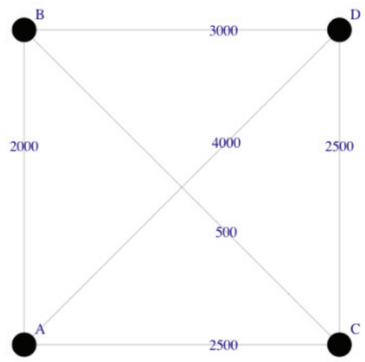


Figure 1 - Toy model: distances between airports (in kilometers)

Table 1 - Toy model: initial load, capacity and secondary airports

Airport i	$L_i(0)$	C_i	$\mathcal{N}_i$
A	3	3	B
B	0	2	A, C
C	0	2	B
D	2	2	—

Table 2 - Toy model: scheduled flights

Flight	Origin	Destination	ETD	ETA
1	A	C	08:10	10:40
2	A	B	08:20	10:30
3	A	B	08:40	10:50
4	D	C	09:30	12:45
5	D	B	10:10	13:15
6	C	D	12:00	14:50
7	B	D	13:00	17:50
8	D	C	15:25	16:05

Case Study: Oceanic Airport Network

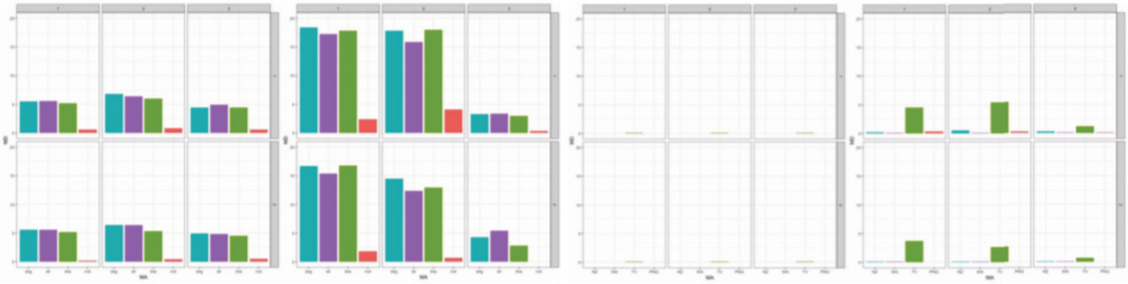
We simulate the cascading process in the Oceanic Airport Network (OAN). We have considered flights in the OAN between airports with at least 1 Km of asphalt runway between 4 and 17 August 2014. The resulting airport network, where two airports (nodes) are connected by a link when there is at least a direct flight between them, has *N = 169* nodes and *E = 726* edges.
We have checked the effectiveness of several selection rules of new arriving and departing airports, checking the six possible combinations of rules MD1 and MD2 for departing airports and MA1, MA2 and MA3 for arriving airports. We have checked the following incidents:

- Closure of ten airports selected by the following criteria: random, maximum degree, maximum strength (measured by number of arriving and departing flights) and maximum betweenness.
- Closure of all airports of the following territories: New Zealand, Western Australia, Tasmania and Victoria, Papua and New Guinea.

The number of airports closed by cascading failures (in addition to airports starting the incident) for *R = 100* and *R = 600*, and each combination of rules and for each incident are depicted in Figure 2. A similar graph for the number of affected flights (modified, cancelled and in emergency) is presented in Figure 3. Examining these two graphs, we can examine the impact of the incident initiating the cascading failure, the effect of parameter *R* defining the set of alternative airports, and what is the best selection rule for departing and arriving airports.

Table 3 - Normal operations of the toy model. Columns A to D show load of each airport at each time, and columns 1 to 8 show flight state (N: nonactive, A: active, L: landed).

Time	Event	A	B	C	D	1	2	3	4	5	6	7	8
08:00	Start	3	0	0	2	N	N	N	N	N	N	N	N
08:10	Depart 1	2	0	0	2	A	N	N	N	N	N	N	N
08:20	Depart 2	1	0	0	2	A	A	N	N	N	N	N	N
08:40	Depart 3	0	0	0	2	A	A	A	N	N	N	N	N
09:30	Depart 4	0	0	0	1	A	A	A	A	N	N	N	N
10:10	Depart 5	0	0	0	0	A	A	A	A	A	N	N	N
10:30	Arrive 2	0	1	0	0	A	A	A	A	A	N	N	N
10:40	Arrive 1	0	1	1	0	A	L	A	A	A	N	N	N
10:50	Arrive 3	0	2	1	0	L	L	A	A	A	N	N	N
12:00	Depart 6	0	2	0	0	L	L	L	A	A	A	N	N
12:45	Arrive 4	0	2	1	0	L	L	L	A	A	A	N	N
13:00	Depart 7	0	1	1	0	L	L	L	L	A	A	A	N
13:15	Arrive 5	0	2	1	0	L	L	L	L	A	A	A	N
14:50	Arrive 6	0	2	1	1	L	L	L	L	L	A	A	N
15:25	Depart 8	0	1	1	1	L	L	L	L	L	L	A	A
16:05	Arrive 8	0	1	2	1	L	L	L	L	L	L	A	A
17:50	Arrive 7	0	1	2	2	L	L	L	L	L	L	A	L



(a) Centrality (left $R = 100$, right $R = 600$) (b) Territories (left $R = 100$, right $R = 600$)

Figure 2 - Number of airports saturated and closed by cascading failures from several incidents with combinations of selection rules of departing and arriving airports.

The initiating incident that causes most damage is the closure of central nodes, selected by degree, strength or betweenness. These incidents are the ones affecting more flights and closing more airports. The three centrality measures have a similar impact, much larger than selection of random nodes or the closure of a whole territory. These results are similar to the ones obtained for the evaluation of static robustness in air transport networks [16], and are in line to theoretical predictions for scale free networks [1].

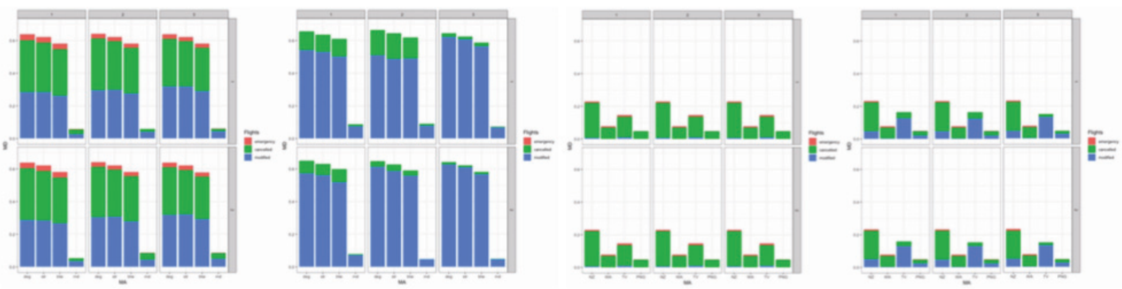
The effect of closure of territories shows evidence of the impact of spatial nature of air transport networks. Incidents in isolated regions, like New Zealand, lead to a relatively large number of cancellations, while incidents affecting less isolated regions like Tasmania have a smaller impact. Contrarily to closure of central airports, selection rules have little impact in reducing the magnitude of the cascading failure.

The *R* parameter defines the number of alternative airports for each affected flight: the larger the value of R, the larger the set of alternative departing or arriving airports will be. In Figure 3 we can observe that increasing *R* does not change the total number of affected flights, but reduces the number of cancelled flights and flights in emergency. The effect on closed airports is opposite: as we see in Figure 2, the number of closed airports *increases* when increasing the available alternative airports when increasing *R*. This can be explained for the heterogeneity of the airport network: the majority of airports of the OAN have small capacity, and the algorithm proceeds to divert flights to these small airports, therefore closing them, to protect the larger airports to collapse. A specific effect of closing a whole territory is that in these incidents the likelihood of finding emergency flights is higher, even for high values of *R* (see right panel of Figure 3). A flight in the middle of a closed territory when occurring the incident may be impossible of modification, as there may be no available airports around him.

The most effective rules for minimizing cascading failures involving closure of central airports involve selecting alternative arrival airports minimizing the product of load and distance to affected airport (MA3). This strategy is the most effective, irrespective of the selection rule for departing airports. Adopting MA3 mitigates significantly the impact of closure of central airports, reducing significantly the number of affected flights.

Table 4 - Operations of the toy model with closure of B at 10:00. Columns A to D show load of each airport at each time, and columns 1 to 8 show flight state (N: nonactive, A: active, L: landed, C: cancelled, E: emergency).

Time	Event	A	B	C	D	1	2	3	4	5	6	7	8
08:00	Start	3	0	0	2	N	N	N	N	N	N	N	N
08:10	Depart 1	2	0	0	2	A	A	N	N	N	N	N	N
08:20	Depart 2	1	0	0	2	A	A	N	N	N	N	N	N
08:40	Depart 3	0	0	0	2	A	A	A	N	N	N	N	N
09:30	Depart 4	0	0	0	1	A	A	A	A	N	N	N	N
10:00	Closure B					A	A	A	A	N	N	N	N
10:00	Reroute 2 new arrival C (arrival time 10:40)					A	A	A	A	N	N	N	N
10:00	Reroute 3 new arrival C (arrival time 10:50)					A	A	A	A	N	N	N	N
10:00	Flight 4 cannot land on C, and B is closed: emergency								E	N	N	N	N
10:10	Reroute 5 new arrival A (arrival time 13:15)					A	A	A	E	A	N	N	N
10:10	Depart 5	0	0	0	0	A	A	A	E	A	N	N	N
10:30	Arrival 2	0	0	1	0	A	A	A	E	A	N	N	N
10:40	Arrival 1	0	0	2	0	A	L	A	E	A	N	N	N
10:50	Arrival 3	0	0	3	0	L	L	A	E	A	N	N	N
12:00	Cancel 6: only alternative departing is B, which is closed					L	L	L	E	A	C	N	N
13:00	Cancel 7: only alternative departing is A, which has no load					L	L	L	E	A	C	C	N
13:15	Arrival 5	1	0	3	0	L	L	L	E	A	C	C	N
15:25	Cancel 8: departing airport is closed and alternative B is closed	1	0	3	0	L	L	L	E	A	C	C	C



(a) Centrality (left $R = 100$, right $R = 600$) (b) Territories (left $R = 100$, right $R = 600$)

Figure 3 - Number of flights affected by cascading failures (modified, cancelled and in emergency) from several incidents with combinations of selection rules of departing and arriving airports.

Conclusions

Cascading failure phenomena can appear in complex networks that distribute flows of information, people or goods, when flow going through nodes or edges exceeds the capacity of the element. Previous research has defined models where flow is redistributed globally or locally. In global redistribution rules flows are proportional to betweenness [17, 8], and in local redistribution to degree [26, 24]. These models are not adequate to model cascading failures in airport networks, because flow is not continuous, and criteria for redistributing load has to consider close airports, rather than previously existing connections.
We have defined an algorithm to simulate the management of cascading failures in airport networks. The algorithm tries to reduce the impact of an incident of the network assigning alternative departure or arrival airports to affected flights with several alternative rules. The impact of the incident can be measured by the number of affected flights (rerouted, cancelled or in emergency) and closed airports.
We have applied the algorithm to the Oceanic Airport Network, assessing the effectiveness of several rules of selection of alternative airports in three types of incidents: closure of central airports, of random airports or a whole territory. Results show that the closure of central airports has a much larger impact than random airports, and that selection rules are effective to reduce the impact of incidents affecting central airports, but less effective in the closure of a territory. The selection rule MA3, consisting of selecting the airport minimizing the product of load and distance to affected airport These results show the importance of considering spatial and temporal considerations when studying airport networks.
The methodology used to define this algorithm can be extended to other transportation networks, such as maritime or road networks, and to study other phenomena affecting the performance of transportation networks, like jamming transitions or delay propagation.

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Air Traffic Management Technological Strategies

Deviations from planned flights in the European navigation network

Jaume Carreras-Maide - jcarrerasmaide@gmail.com
Universitat Politècnica de Catalunya
Jose M Sallan - jose.maria.sallan@upc.edu
Universitat Politècnica de Catalunya
Oriol Lordan - oriol.lordan@upc.edu
Universitat Politècnica de Catalunya

Abstract
The policy of computation of en-route charges makes them dependent upon the planned route taken by aircrafts. The aim of this research is to analyse deviations between real and planned flights to detect possible opportunistic behaviour of airlines.
The Central Route Charges Office is the EUROCONTROL branch that establishes en-route nad terminal charges. En-route charges are fixed a priori, based on the planned flight route. The Demand Data Repository of EUROCONTROL allows comparing planned and real routes. Using statistical analysis of route deviations, we aim to detect possible systematic patterns of opportunistic behaviour of airlines in the European airspace.
We intend to detect patterns of deviations between planned and real flights routes that lead to real flight routes that would have resulted in higher en-route charges. These pattern can be interpreted as an intended action of airlines of providing a planned flight route leading to lower fees than the actual route airlines perform.
Data availability of spatial evolution of commercial aircrafts has lead to important advances in air traffic management and safety. This research takes advantage of the rich dataset curated by EUROCONTROL to detect systematic opportunistic behaviour taking advantage of the a priori computation of en-route charges. The results obtained are of interest for regulators and scholars and practitioners interested of airline strategy.

Keywords
En-route charges; Air plan deviations; Air navigation network

Deviations from planned flights in the European air traffic network

Introduction

Inasmuch as the air transport industry is one of the most economic constrained sectors in the world, it is essential for airlines to be able to reduce costs and increase revenues as much as possible. The aim of this study is to analyse trajectory deviations in the European airspace as to find out if airlines are changing flight plans in situ to minimise en-route charges and operational costs.

In the European airspace, en route charges are collected by EUROCONTROL on behalf of its member states through the Central Route Charges Office. The invoicing process for these charges is described in [1]. The amount of these charges is calculated with information stated in the flight plan reported by the airline before the flight takes place. For that reason, airlines may have incentives to behave opportunistically, delivering a flight plan which would report less en route charges at the expense of higher operational costs. Once the flight is started, pilots would request route modification that would diminish operational costs by crossing areas with higher en route charges. Acting this way, airlines could not only lower their operational cost, but also en route charges, reporting a route that passes through areas with cheaper en route charges, respect to the real route.

Secondly, the same analysis regarding the operational costs will be also examined by considering the treatment for the cheapest path explained in [2] taking into account two fundamental differences between the latter and the former. Firstly, they have much more weight in the global cost-revenue scheme of an airline. And secondly, they are directly dependent on the real operation of the airline instead of its planning.

As well as in the case of en-route charges, the deviations caused by an intentional pursuit of operational costs reduction would be effectuated in the same way, i. e., by asking for an in situ trajectory change to air traffic controllers.

To sum up, this study pretends to be an outstanding challenge to detect whether economical motivations, such as the reduction of operational costs and en-route navigation charges, are triggering air traffic deviations.

State of the Art

Increasingly, the importance of air traffic analysis is becoming more important nowadays. This is notably due to the fact that air transport is one of the sectors that are constantly growing. In fact according to [3], currently, ‘traffic grows twice as fast as GDP’. For that reason, inasmuch as this tendency goes on and on, it is necessary to study closely the air traffic networks to understand how they work, how they change by perturbations, how they interact with other factors so as to be able to improve its design and to find its optimal usage.

One of the aspects that are being studied is the air traffic deviations so as to understand more appropriately how air space network could become more efficient in the future. Articles such as [4] and [5] make an analysis of deviations in intent to characterise them within the European panorama. Since the latter is an evolution of the former, several issues about the last are commented in this section.

This study examines all commercial flights that endure more than 10 minutes, in their en-route phases, and that cross the German air space by excluding Sunday and Saturday traffic to avoid seasonality effects by means of the data provided by DDR.

In it, several metrics and concepts that are linked to deviations analysis are reviewed (efficiency[1], deviation[2], angle-to-destination[3], ratio of deviations[4] and the fork[5]) and a new one is introduced: the di-fork, which is defined for a specific direction of a pair of navigation points j and k (or k and j in the opposite direction) as the ratio between the amount of flights actually going from j to a navigation point that differs from k and the amount of flights planned to go from j to k.

To understand what is intended to be shown by the author in [5], it is proper to comprehend the way in which Air Traffic Controller (ATC) order the air traffic. Their principal mission can be divided in two aspects: firstly, they have to avoid safety problems and to make aircraft's trajectories conflict-free, but also, whenever possible, they can issue directs that shorten trajectories (so as to reduce fuel consumption) or that can improve the predictability of the system. According to [5], this gives a remarkable margin to study ATCs-pilot interactions as he tries to investigate 'how the planned flight trajectories are modified by controllers in relationship with unforeseen events or pilots' requests'.

Some of the main conclusions that are inferred from this article can help to shed light on the understanding of the nature of deviations. For that reason, they are enlisted in here:

- Deviations occur more frequently far from destination airports.
- Deviations happen more frequently during night and during other low-traffic phases of flight. This is interpreted as a clear proof of the fact that, since traffic is lower during night, deviations are not a need of dealing with safety problems, but rather the result of the possibility of issuing directs that will shorten the trajectory of flights.
- Deviations take place preferentially for angle-to-destination between 20 and 25 degrees.
- Performed routes tend to have a higher efficiency in contrast with planned routes.

By taking into account all this information, [5] deduced that deviations are pro-active rather than reactive ones triggered by high angles-to-destination and low traffic conditions, which are intrinsically related to the 'controllers-pilots interaction to optimise flight paths rather than interventions due to solve safety issues'.

Computation of en route charges and operational costs

In this section, a brief review of the definitions of en-route charges and the method of computation of operational costs is shown.

The CRCO 'runs an efficient system for the cost recovery of air traffic services made available to airspace users'. By this system, each Aircraft Operator (AO) receives a monthly bill in euro,

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[1] For a particular flight, efficiency is defined as the ratio between the minimum distance between the origin and the destination of that flight, i. e. the orthodromic distance, and the distance resulting from the summation of flight segments flown by the aircraft.

[2] The concept of deviation is defined in this article as the event in which an aircraft goes from a certain navigation point that is within the planned flight to another one that does not follow the path described in the latter.

[3] The angle-to-destination is defined as the angle between the airway that is being flown and the line that connects the aircraft and the destination airport.

[4] The ratio of deviations or fraction of deviations is defined as the division of the observed deviations by the possible deviations, where a possible deviation is interpreted as the amount of navigation points that appear in both planned and performed flights.

[5] This metric is a simplified and unidirectional version of the di-fork.

independently of the amount of the En-route Charging Zones (ECZ) that have been overflown by it. This bill contains intrinsically the summation of each charge of each flight performed by the AO in that month. The main responsibilities that are hold by the CRCO regarding the billing, the collecting and the distribution of airspace tariffs, are stated as follows:

- The CRCO is responsible for managing the route charges to fund air navigation facilities, services and Air Traffic Management (ATM) state's long-term developments.
- As well, it is accountable for the same task regarding the terminal charges (on behalf of member states), air navigation charges (on behalf of non-member states) and communication charges in the Shanwick area.

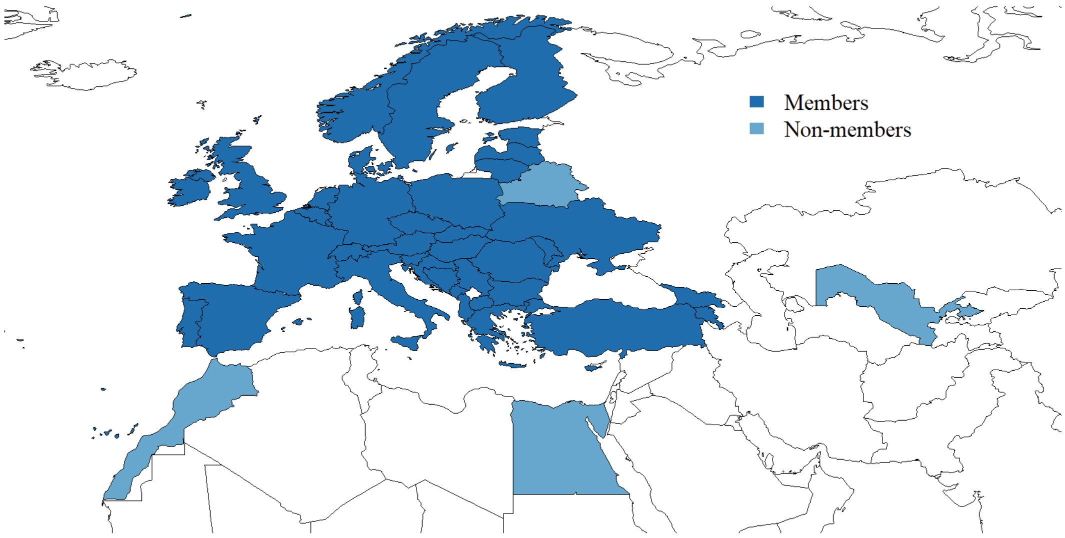

Figure 1 – Participants in the En-route Charges System (ECS) that are member or not of EUROCONTROL

The bills corresponding to a specific month are sent in the middle of the following month. As well, as it has been explained in the beginning of this document, the charging cost of a flight is calculated by what has been stated by the AO in the flight plan and posteriorly approved by the Network Manager (NM). After that, any changes notified by the Integrated Initial Flight Plan Processing System (IFPS) to the AO must be incorporated into the planned flight and communicated to the pilot.

The En-route Charge (EC) of a flight is calculated by the following formula, where: DF (Distance Factor for the i-th zone), AWF (Aircraft Factor constant along the whole flight) and URC (Unit Rate of Charge for the i-th charging zone).

$$EC = AWF \sum_{i=1}^{n} DF_i \, URC_i$$

In general terms and according to [1], these three factors are defined as follows. For more details, in [1] particular cases and further explanations are shown.

- AWF: the square root rounded to the second decimal of the Maximum Take-Off Weight (MTOW) (in metric tonnes, to one decimal) divided by 50.
- DF: the orthodromic distance between the entry and exit points of an ECZ expressed in km, divided by 100 and described in the last filed flight plan. For each take-off and each landing 20km are deducted, if there is a unique ECZ, the intersection points are substituted by the aerodromes of arrival and departure.

- URC: the charge in euro applied by a charging zone to a flight operated by an aircraft of 50 metric tonnes (weight factor of 1.00) and for a distance factor of 1.00' [1]. From 2019, this metric has changed slightly by adding an administrative unit rate (see further details in [1]) to URC, which has resulted in a Global Unit Rate (GUR).

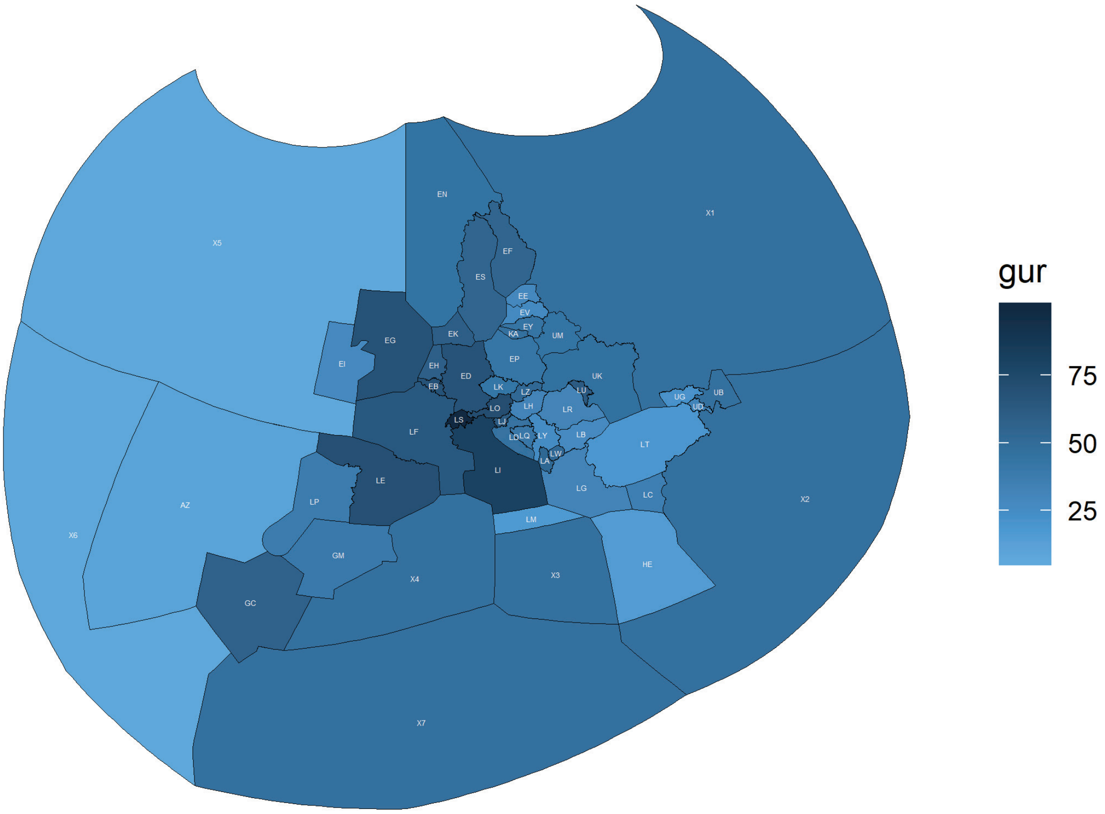

Figure 2 – En-route Charging Zones (ECZ) coloured by its URC (current GUR).

Apart from the latter, Value-Added Tax (VAT) could be also considered. However, according to [6], in an overwhelming majority of the cases studied, flights related to commercial transport are exempt from that taxation. Therefore, this aspect has been neglected.

According to the EC formula, and preliminary calculations, several facts can be asserted:
- Distance and MTOW are directly proportional to EC with an order of magnitude close to 10^0.
- URC depends on the will of the state associated with the ECZ and has an order of magnitude close to 10^1.

Therefore, URC is the most influential factor and is also arbitrary and totally independent of the operation of an aircraft. Ergo, it can be stated that, to optimise the EC, it is far more important to fly over cheaper ECZ than flying shorter distance or with lighter aircrafts. However, in reality, an AO will desire to optimise the total set of costs, which include the Operational Cost (OC)[6], which is inherently proportional to the distance flown. For that reason, it is immediate to perceive that there could be a conflict of interest between the minimisation of EC and the one of OC.

[6] In this study, Operational Cost has been defined as the cost linked to performance of flying without taking into account En-route Charges.

Although the historical tendency is the decrease of OCs [7], they possess a more considerable weight in comparison to the ECs, as it will be shown posteriorly and as it can be understood intuitively. Ergo, it can be advanced that if EC is not large enough in relation to OC, the strategy to minimise EC will not be probably the better choice, unless this minimisation also leaded to a simultaneous optimisation of the sum OC + EC.

Finally, OC have been assumed to be equal to 7.5 €/NM in accordance with the criterion used by EUROCONTROL's System for traffic Assignment and Analysis at a Macroscopic level (SAAM) when calculating the cheapest route [2]. To do so, SAAM uniquely takes into account OC and EC (calculated by the CRCO's formula) and sums both results to output a Global Flying Operation Cost (GFOC).

Methodology

In this section, the description of the *modus operandi* that has been used along this research is shown. First of all, the data sources from which all the results have been obtained are reduced to data provided by Demand Data Repository (DDR) [8] regarding historical information of planned flights (m1) and performed flights (m3) (*.so6* files). As well, aircraft weights (*.mwc* files), geometrical definitions of ECZs (*.are* files) and URCs (*.ur* files) have been also obtained from DDR. The latter have been subjected to a pre-processing in order to homogenise, compact and reduce the information and the former have been subjected to a *prefiltering* to reduce information and segregate traffic data in three different *data.tables*. Planned and historical traffic data from EUROCONTROL's DDR2 have been used to examine 579,243 flights of December 2018 by calculating their savings in terms of operational costs and en-route charges. R programming has been used to carry out this analysis.

R language has been used to deal with these files, to make the OC and EC calculations, to visualise route data and to analyse the results.

The Universe of Study (UoS) has been formed by the following these requirements:

- The temporal framework goes from the 1st to the 30th December of 2018.
- The main focus is put on commercial flights. No military or general aviation flights have been considered.
- All the flights that cross navigation points that are outside the whole set of charging zones are excluded.
- Flights containing navigation points ZZZZ and AFIL are excluded from the study.
- Circular flights are excluded.
- Flights with an ID higher than 1000000000 have been removed.

As well, several assumptions have been made along this research:

- Weights provided by *.mwc* files have been assumed to be MTOW values.
- Navigation points that begin with some of the following symbols have been removed: $, %, #, !. These are technical points that refine the route followed by flights but do not change the trajectory substantially.
- All flights that were planned to go to a specific airport and finally have gone to another one have been excluded of the resulting sample, since they in fact contaminate results, which try to examine if flights are deviating from planned routes for economic purposes.

Since polygons defined by *.are* files contained several imprecisions, it has been necessary to subject polygons related to December 2018 to a fixing process. This has enabled the optimisation of EC calculations.

To analyse results, several metrics have been created in order to understand what data is expressing intrinsically. They are explained as follows:

- DOC is the difference between planned OC (OC_1) and performed OC (OC_3). DOC being positive means that the flight has achieved savings in terms of pure operational costs.
- DEC is the difference between performed EC (EC_3) and planned EC (EC_1). DEC being positive means that the flight has achieved savings in terms of en-route charges.
- TS (Total Savings) is the summation of DOC and DEC and represents the savings achieved for a flight. A positive value of TS means positive savings during the flight.
- sDOC is the specific DOC. It is defined as the average DOC within a certain group of flights that share a particular characteristic.
- sDEC is the specific DEC. It is defined as the average DEC within a certain group of flights that share a particular characteristic.
- sTS is the specific TS. It is defined as the average TS within a certain group of flights that share a particular characteristic.
- dsTS is the specific TS per nautical mile. It is defined as the average TS per nautical mile within a certain group of flights that share a particular characteristic. It has been studied uniquely by airlines.

In total, 579.243 flights have been analysed (in its planned and performed versions).

Results and discussion

In this section, results are shown and discussed. First of all, it is convenient to consider general results. As it is possible to observe in Table 1, DEC are supposing insignificant losses for airlines (0,3% of EC1) and that DOC are supposing slight savings per flight (1,4% of OC1), which cumulated represent important figures for airlines.

Table 1-General results
Source: Jaume Carreras

Concept	Value	Concept	Value
Average OC1	5.549,43 €	Flights DOC>0	65,32%
Average OC3	5.474,31 €	Flights DEC>0	11,71%
Average DOC	75,12 €	Flights TS>0	64,77%
Average EC1	873,53 €	Total DOC	43.513.798 €
Average EC3	870,91 €	Total DEC	-1.514.702 €
Average DEC	-2,62 €	Total TS	41.999.096 €

In Figure 3, the distribution of DOC savings can be seen. It is possible to appreciate that a remarkable 4% of flights have DOC=0, which seems to be quite high in spite of the fact that data source has been reviewed and it has been observed that the distance flown is exactly the same for several flights of that group. In the histogram, extreme cases have been neglected in order to visualise more appropriately the information. In the case of DEC, the 56.1% of flights have a 0 value due to the fact that domestic flights have a DEC=0 by definition as well as all international flights that have the same intersection points with the ECZ. The 98% of DEC values are between -500 € and 500 €.

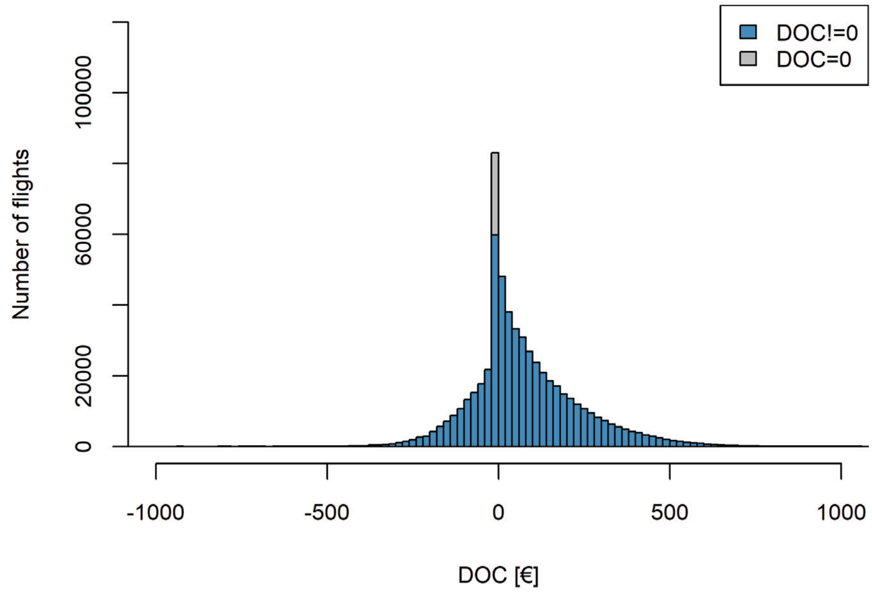

Figure 3 – DOC histogram

After having viewed that, two principal perceptions can begin to be outlined. Firstly, it seems that airlines are systematically and considerably economising from OC. Secondly, it can be noticed that EC savings are not supposing gains for airlines, from a global perspective and if the majority of AOs had a strategy to reduce ECs premeditatedly, they would not be doing this task in that catastrophic way since the airline sector is characterised by its competitiveness. Therefore, it is possible to assert that it seems that there is no generalised strategy among airlines to reduce ECs systematically. As well, it can be perceived that DOC is much higher than DEC.

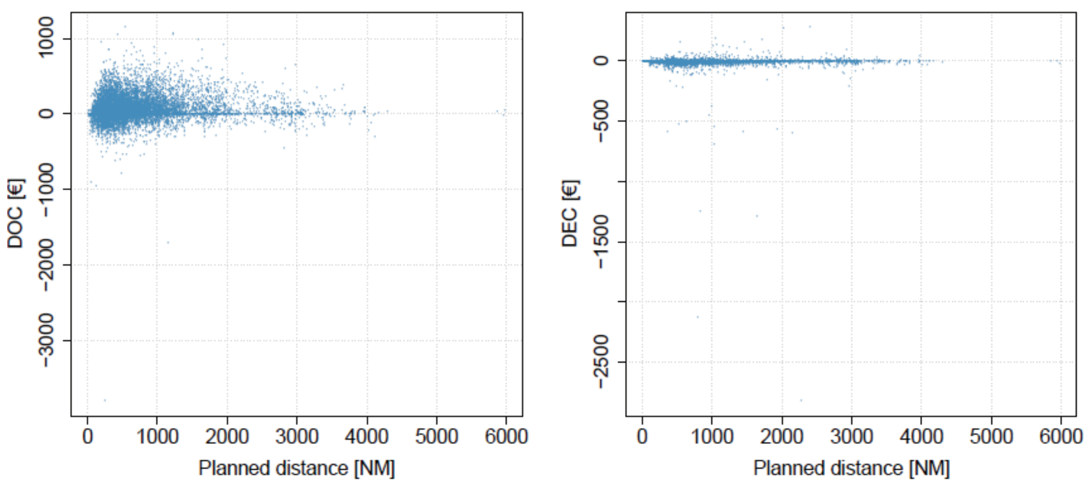

Figure 4 – DOC (left) and DEC (right) vs distance planned to fly

By the analysis of distance and since it is the unique variable to compute OC, it is possible to observe that DEC is totally independent from the distance planned to fly and that DOC savings are relatively proportional to distance for distances up to the higher ones, from which an attenuation factor is appreciated. This can be interpreted as the flexibility of a longer flight of reducing the planned distance, which seems not to affect considerably longer flights. It can be asserted that, on average, airlines are saving 0,10 € per nautical mile.

This fact is inherently related to the analysis that has been carried out between domestic and international flights. Domestic flights (flights that overfly a unique ECZ) have an sTS value of 52,25 €, and international flights, 80,77 €.

As well, a territorial analysis has been carried out regarding the En-route Charging Zones (ECZ) and airports in order to observe if there were sTS patterns at arrival and departure. Therefore, the most plausible contention would be to assert that differences of sTS per region or airport at arrival or departure are more linked to the intrinsic nature of the routes performed in those flights than to a deliberateness of airlines.

Concerning the airline analysis, the Table 2 is presented. In it, the top 25 airlines, according to the computed Global Share (GS) of the Universe of Study, can be appreciated. The field OVR represents the relative overrepresentation of airlines in terms of Total Savings (TS) in comparison to the GS.

Probably, the most important variable to analyse could be the dsTS and OVR. This factor represents the savings achieved by each airline per each nautical mile planned to fly. As it is possible to see there is an important disparity among airlines and no relation has been detected between those values and the business model. However, it seems that there is a tendency for LCC to have notable values.

Table 2-Airline results

AO	DOC [€]	DEC [€]	TS[€]	GS [%]	OVR [%]	sTS [€/fl]	d[7] [NM]	dsTS
RYR	6.690.796	-204.450	6.486.346	9,40	64,30	119,12	750	0,16
EZY	2.715.484	-51.351	2.664.133	6,68	-5,04	68,85	612	0,11
DLH	2.252.980	-156.562	2.096.418	6,28	-20,52	57,65	522,43	0,11
THY	1.024.654	-28.913	995.741	5,90	-59,82	29,16	790,69	0,04
AFR	1.436.130	-23.056	1.413.074	3,81	-11,69	64,11	580,75	0,11
SAS	1.139.351	-55.490	1.083.861	3,38	-23,65	55,33	448,93	0,12
EWG	1.683.011	-117.708	1.565.303	2,83	31,70	95,33	511,96	0,19
KLM	502.422	-65.430	436.992	2,81	-62,97	26,83	537,17	0,05
VLG	1.079.669	-25.051	1.054.618	2,55	-1,53	71,49	565,03	0,13
BAW	45.060	-26.386	18.674	2,51	-98,23	1,28	846,4	0,00
AZA	1.864.375	-14.858	1.849.517	2,43	81,22	131,55	478,13	0,28
WZZ	1.915.445	-79.545	1.835.900	2,40	82,14	132,31	829,79	0,16
PGT	353.070	-9.882	343.188	2,26	-63,84	26,19	642,67	0,04
BEE	16.306	-8.302	8.004	1,84	-98,96	0,75	281,27	0,00
SWR	1.030.639	-40.606	990.033	1,78	32,43	95,9	545,42	0,18
LOT	2.312.933	-56.330	2.256.603	1,66	223,67	235,31	484,6	0,49
TAP	1.456.528	-17.564	1.438.964	1,64	108,91	151,02	813,16	0,19
AFL	658.581	-22.397	636.184	1,63	-7,07	67,38	1.179,00	0,06
AUA	83.131	-28.310	54.821	1,59	-91,79	5,95	457,25	0,01
FIN	558.986	2.533	561.519	1,53	-12,62	63,33	616,12	0,10
NAX	680.342	-79.597	600.745	1,50	-4,64	68,99	628,3	0,11
WIF	732.052	-1.885	730.167	1,48	17,47	85,43	157,96	0,54
IBK	934.235	-96.665	837.570	1,29	54,59	111,81	1.043,04	0,11
AEA	444.835	-1.405	443.430	1,22	-13,46	62,68	459,64	0,14
QTR	369.326	-10.467	358.859	1,11	-23,02	55,65	2.408,57	0,02

The time slot has been also analysed. Figures showing sTS values in some of the most important ECZ for flights arriving and departing to/ from that region are exposed below. Time slot of these countries is expressed in UTC. In spite of the fact that these countries have different time zones, they are close to UTC +0.

[7] Mean distance.

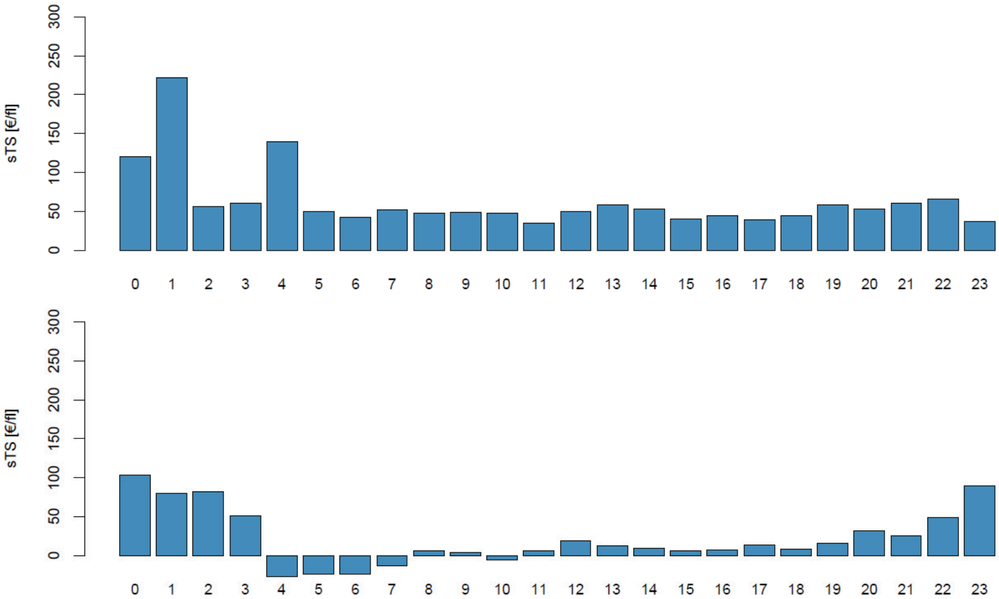

Figure 5 – sTS in EG per time slot for departing (top) and arriving (bottom) flights

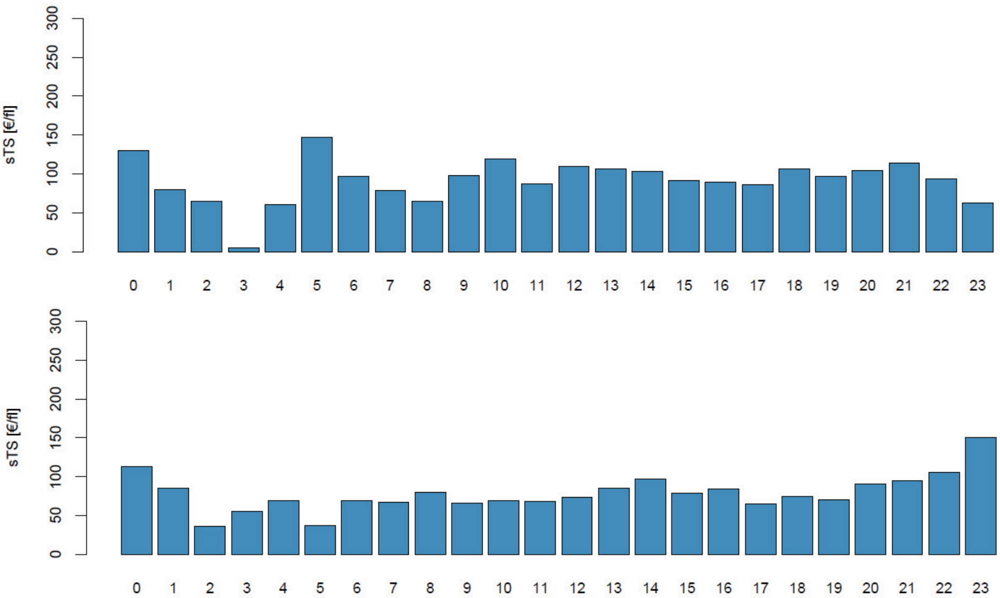

Figure 6 – sTS in LE per time slot for departing (top) and arriving (bottom) flights

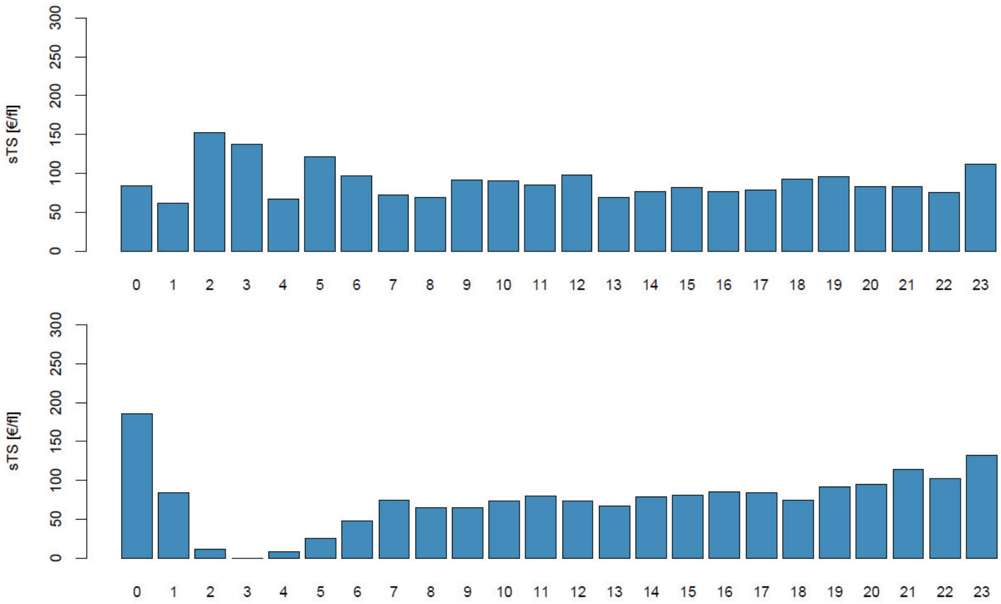

Figure 7 – sTS in ED per time slot for departing (top) and arriving (bottom) flights

As it is possible to observe, in both extremes sTS values tend to be higher. This could be linked to the fact remarked by [5], in which reductions of the distance planned to fly in relation to distance flown are higher during night time than day time. This is also related to low traffic conditions according to [5].

Conclusions

This study has been focused on the analysis of deviations from planned flights in the European space network hypothetically triggered by economical motivations of airlines. For that reason, planned and performed historical traffic data from EUROCONTROL's DDR2 [8] have been used to examine the month of December of year 2018 by considering the operational costs (OC) and en-route charging costs (EC) as they are treated in [1] and [2]. Both costs must be treated differently, since, in the case of OC, the AOs pays for what they actually fly and, in the case of EC, AOs pay for what they plan instead of for what they perform in reality.

After obtaining results of 579.243 flights, it is important to emphasise several facts. The first fundamental point to bear in mind is that pure operational costs (OC) have outstandingly more weight than en-route charges (EC) not only regarding the global cost of an average flight, but also in terms of average savings.

For that reason, on the one hand, from a global perspective if the majority of AOs had a strategy to reduce ECs premeditatedly, they would not be doing this task in that catastrophic way since the airline sector is characterised by its competitiveness. Therefore, it is possible to assert that there is no generalised strategy among airlines to reduce en-route charges systematically. In fact, the current system seems to be slightly disadvantageous for airlines. On the other hand, airlines are achieving savings in terms of pure operational costs regularly.

Having discarded that airlines are not achieving planned savings by means of paying lower navigation charges than those that were expected according to their performance, it has been proceed to analyse which is the origin of the OC savings. Several scenarios can be found: Are airlines achieving savings due to premeditated or spontaneous human factors or is it due to the

inherent nature of flights performed in the middle of a specific juncture independent of the airline? Or is it triggered by a mix of both?

It has been found that on average 0.10 € are being saved per each nautical mile planned to fly, which leads to the fact that higher savings are achieved in higher trips with an attenuation of this effect for much longer flights. This can be seen as triggered by the more flexibility of operation that have longer trip due to their longer distances. As well, as it was proved by [5], flights are commonly shorter on average in their real performance than in their planning. This causes higher savings in OC since they are intrinsically related to distance flown.

During the analysis of the results, a new term has been found as useful to evaluate the capability of saving money in relation to the planned performance: the specific Total Savings (sTS). This factor represents the summation of OC and EC savings divided by the amount of flights that are being evaluated in a particular value of a particular field. As well, the dsST factor has been created to have a perception of the AO's saving capacity per nautical mile. For instance, AOs such as BAW, QTR or THY have low dsTS values between 0,00 and 0,04 €/NM in comparison to airlines such as WIF, LOT, RYR, EZY or EWG with values between 0,10 and 0,60 €/NM.

As it is shown in [5], night-time flights tend to be shorter than planned ones in a major way than during day-time flights. This effect has been observed by appreciating higher sTS in different regions in night hours. According to [5], this coincides with low-traffic conditions, which would provide more flexibility to the system.

By considering all these results and sources, and as [5] explains, it is possible to give a response to the question presented few paragraphs above. The most plausible contention would be to assert that OC savings are being achieved by a combination of the inherent nature of flights and human factors related to interactions between pilots, air traffic controllers and airline policies. It has been seen that low-traffic conditions and longer flights seem to be triggering higher sTS, which must be accompanied by a human will. In reality, this human will must be an interaction between an air traffic controller and a pilot, who both look for operating more efficiently without compromising safety and capacity [5].

In tandem with that, the fact that airlines with similar business models (e. g. FSC, LCC, RC) have different dsTS values might suggest that airlines could have distinct legitimate internal policies that would lead pilots of different companies to behave distinguishably when facing possibilities of reducing planned distance when performing the flight.

Further research must be carried out regarding the tracking of flights (ECZ overflown, traffic analysis). The temporal scope should be enlarged in order to identify more stable trends. As well, a multivariable linear regression analysis should be carried out in order to propose a model that could explain adequately the aforementioned deviations.

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ATC-workload model to assess the impact of Continuous Climb Operations

Javier A. Pérez-Castán - javier.perez.castan@upm.es
Universidad Politécnica de Madrid
Beatriz Asensio - beatriz.asensio.jimenez@alumnos.upm.es
Universidad Politécnica de Madrid
Alvaro Rodriguez-Sanz - alvaro.rodriguez.sanz@upm.es
Universidad Politécnica de Madrid
Fernando Gómez Comendador - fernando.gcomendador@upm.es
Universidad Politécnica de Madrid
Luis Pérez Sanz - l.perez@upm.es
Universidad Politécnica de Madrid
Rosa M. Arnaldo Valdés - rosamaria.arnaldo@upm.es
Universidad Politécnica de Madrid

Abstract

This research assesses the impact on Air Traffic Control (ATC) workload by the integration of Continuous Climb operations (CCOs) in a high-density Terminal Manoeuvre Area (TMA).

The methodology encompasses different modules: CCO, standard departing and arriving trajectories are extracted from an external database, an ad-hoc algorithm detects conflicts and the number of ATC interventions, and an ATC-workload model is developed including CCO-task modifications. Lastly, numerical simulations based on Monte Carlo (MC) method analyse different scheduling combinations.

The methodology is applied to Palma TMA (Spain). Numerical simulations will vary the scenario from 0% to 100% CCO, and scheduling combinations are expected to provide significant statistical results. These results will confirm how the integration of CCOs affects on ATC workload, and whether or not the CCO integration is feasible regarding ATC workload.

This paper is the first approach to quantify the impact on ATC workload by the integration of CCOs. These results will provide remarkable information to the aviation community that will underlie the CCO integration in high-density TMAs.

Keywords

Continuous Climb Operations; Air Transport; Air Traffic Management; ATC workload

ATC-workload model to assess the impact of Continuous Climb Operations

1. Introduction

The current Air Transportation System is expected to increase seamless the number of movements throughout the following years. This increase cannot be assumed without research, development and implementation of new technologies and procedures for the future Air Transportation System [1]. Continuous Climb Operations (CCOs), Continuous Cruise Climb and Continuous Descent Approaches (CDAs) provide fuel, environmental and economic benefits in specific stages of the flight [2] although they usually cut off the capacity due to the path uncertainty and increase on Air Traffic Control (ATC) workload [3]–[5].
The International Civil Aviation Organization (ICAO) [6] defines CCO as “an aircraft operating technique enabled by airspace design, procedure design and facilitation by Air Traffic Control (ATC), allowing for the execution of a flight profile optimised to the performance of the aircraft”. The integration of CCO should avoid the coexistence with any non-optimal climbing trajectory due to aircraft segregation requirements. Thus, the CCO concept is a step forward in trajectory management since CCO seeks to operate a continuous climbing path without altitude and airspace constraints [7], [8]. IFATCA [9] presented the main summary of the potential benefits that will bring the systematic introduction of CCO in terms of delay, fuel consumption and pollutants: the average potential fuel savings from CCO range between 6-19 kg per departure, with annual CO_2 savings around 5.000 kg per high-density airport [10].
Different studies [11]–[13] assessed the impact of optimised departures regarding fuel consumption, noise and emissions, and all the studies share the benefits of implementing CCOs due to economic and environmental benefits. However, the crucial issue collides on the CCO impact in high-density airports. The primary problems for the integration of new procedures are capacity and safety [14], [15]. Mainly, CDAs underly the development and integration of CCOs. Previous studies showed that the integration of CDAs in high-density airports was feasible, but it led to a significant reduction in capacity [16], [17]. The reason was that the uncertainties of CDAs were so high that the separation minima must be enlarged to encompass every feasible path [18]. Similar results were obtained for CCOs [19]. Ren and Clarke [20] developed a theoretical framework to introduce RNAV procedures in Terminal Manoeuvre Areas (TMAs) based on a separation methodology. They concluded that distance-based separation was not efficient, and one of the major limitations would be the impact on ATC workload.
The impact on ATC workload by the introduction of continuous procedures is far from being covered. ATC primary role is to ensure aircraft safety at the same time of an efficient air traffic flow. ATC workload is directly related to sector capacity; therefore, the primary limitation to introduce more aircraft considering new operational concepts is the ATC workload. There have been a considerable number of investigations into modelling ATC workload [21]–[24]. Most of them modelled ATC workload as the sum of different tasks during a period of time. However, few of them provide the quantification of the ATC tasks, which is crucial to develop a common framework on ATC’s workload models.
In this article, the authors develop a model to assess the CCO impact on the ATC workload. The ATC workload model follows the main features of existing models, but new tasks are included to encompass CCO needs. CCO trajectories consist of fuel-optimised paths free of ATC segregation requirements with landing flows. The aim is to analyse how the integration of CCO de-conflicted on the ground affect the ATC workload on the Control Tower (TWR) and the Approach Control Center (APP). To ensure statistical values, Monte Carlo simulations analyse random departure and landing schedules according to a complex set of operational features. To the best of our knowledge, no research due to the impact of CCOs on ATC workload can be found in the literature.

The paper is organised as follows. Section II sets forth the problem, the operational concept and the methodology. Section III details the ATC workload model to assess the impact of CCO integration. Section IV introduces the scenario - Palma airport (Spain) - and the main operational features. Section V presents the results and discussion of the ATC workload variation due to CCO integration. Finally, Section VI presents the concluding remarks.

2. Problem description

2.1. Standard versus Continuous Climb Operations

Typically, ATC manages standard operations and achieve a safe operation through tactical interventions. ATC provides speed, heading and ad-hoc altitude commands to ensure a safe and seamless air traffic flow while Standard Instrumental Departures (SIDs) and STandard ARivals (STARs) dictate segregation requirements to ease ATC work. When ATC acts to solve the conflict between aircraft, it increases the planned fuel burn, flight time, emissions and noise values [11], [25], [26]. If aircraft could operate optimised trajectories, then fuel burn and other factors – such as emissions or noise - could be significantly improved. However, the main issue is that, to achieve this situation, ATC workload increases and can block the integration of optimised trajectories by reducing the number of operations.
A CCO is an operational procedure characterised by the execution of an optimised departure prevented from ATC segregation requirements, which reduce fuel burn, noise and pollutant emissions. The operation of CCOs requires that ATC seeks not to intervene on them to avoid minimising benefits. Ideally, ATC adapts the airspace for an efficient CCO integration. Figure 1 depicts different departing trajectories: standard departure and CCO.

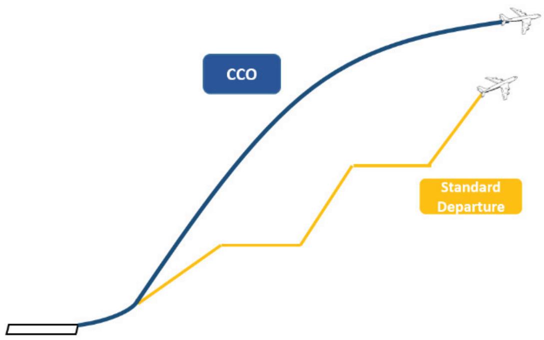

Figure 1 - CCO versus standard departure trajectory. Source: Authors

2.3. Proposed Operational Concept

The primary problem is that the integration of CCO in high-density scenarios cannot be tackled without new ATC tools neither without balancing safety and capacity. In previous studies, the authors developed different techniques to analyse the integration of CCOs in high-density scenarios [19], [27], [28]. Capacity is diminished because of the large path uncertainties of CCOs that demanded an increase on the separation minima. Moreover, the integration of CCOs provided an increase in conflict detection and ATC intervention. The reasons were that consecutive aircraft needed larger separations and conflict must be solved on the ground.
This paper assesses the CCO impact on ATC workload. Hence, the primary issue encompasses ATC and the way to deal with CCOs. Although ATC has the responsibility of managing air traffic in each airspace sector, the main goal is to provide a schedule of conflict-free CCOs. Hence, the first hypothesis assumes the use of new separation minima between CCOs: the runway separation of consecutive CCOs is large enough to ensure departures without ATC interactions with other CCOs until the en-route phase [19]. Moreover, airspace design cannot avoid conflicts between departing and landing flows because the airspace is reduced and should be harnessed.

Nowadays, ATC uses different strategies to safely manage the air traffic: a level off, a vectoring, a speed- change or to regulate the entry to the airspace of flights involved. Every strategy affects ATC workload and aircraft performance. Herein, the solution selected is to delay the CCO take-off until it is calculated that no separation minima infringement will occur aloft with arrivals. In other words, CCO solely takes off if the ATC does not have to intervene while it is climbing. This situation is assumed by the development of an on-ground Conflict-Detection and Resolution (CD&R) tool that provides in real time the CCO delay required. A strength of the proposed operational concept is that CCOs climb without interruption until the en-route phase, which is essential to accomplish many of the environmental and operational benefits.

2.3. Methodology

This section describes the methodology to assess the CCO impact on ATC workload. The methodology is based on Monte Carlo simulations that vary the conditions of an experiment. The methodology calculates for each simulation the ATC workload. The authors recommend the previous work [3] for a thorough explanation of the methodology. The mainstream of the simulation is depicted in Figure 2 and is constituted by the following steps:

1. The Trajectory Generator simulates CCO, standard departure and standard landing trajectories.
2. The Scheduling process provides a departure and landing schedule considering different operational features of the airport (aircraft type distribution, route density and CCO percentage).
3. The CD&R algorithm analyses the departure and landing trajectories to detect conflicts between both standard trajectories and solve conflicts between CCOs and standard landings.

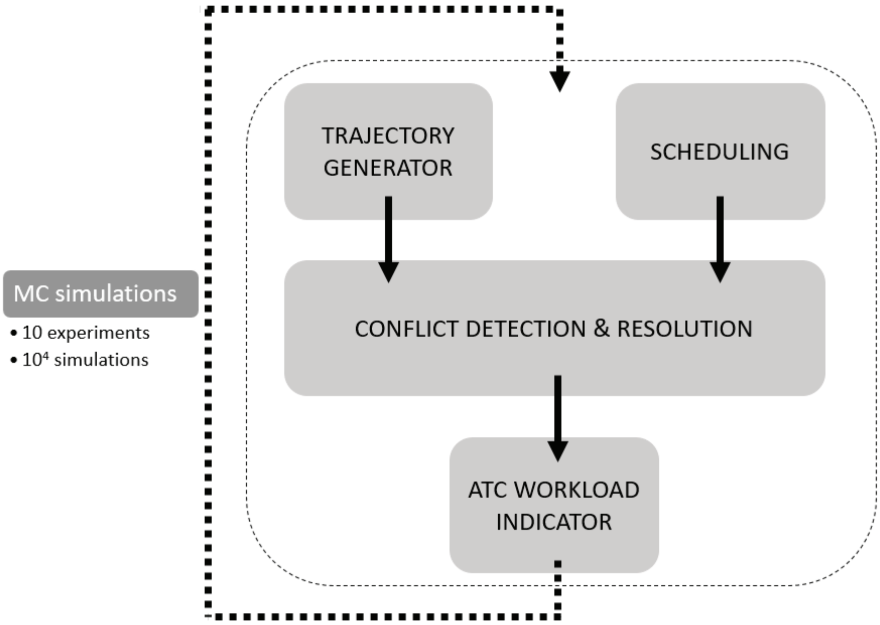

Figure 2 - Schema of the methodology to assess the CCO impact on ATC workload. Source: Authors.

The MC simulations assess the introduction of CCO based on the percentage of CCOs selected. Herein, ten experiments from 0% to 100% were performed; each experiment varies on 10% of CCOs. Each experiment permutes the variables, applies the methodology and obtain the indicators of ATC workload. Thus, each simulation provides a different scenario because of the entire set of variables changes: the landing and departing trajectories and schedules. Finally, ATC workload is statistically calculated for the statistics values: minimum, average and maximum values.

3. ATC Workload Model

The goal of this study is to calculate the workload required for different ATC controllers to handle CCOs. The ATC workload is modelled based on the Reorganised ATC Mathematical Simulator (RAMS) developed by ISA Software model [29]. RAMS Plus is an Air Traffic Management (ATM) fast-time simulation model that calculates the ATC workload based on a set of independent tasks.

Each ATC controller is responsible for the aircraft inside one specific air traffic volume. ATC services in a high-density scenario are split into two primary units: TWR located at the airport and APP responsible for the TMA. TWR is constituted by three positions (local, ground and clearance) and APP provides two positions for each air traffic sector (tactical and planner). However, this work models the work of the TWR by local controller only and the APP by a single controller (tactical + planner). This methodology does not perform human-in-the-loop simulations and, therefore, it does not distinguish the tasks for tactical or planning controllers. Moreover, the number of sub-tasks that constitute each type of tasks is not entirely developed due to the inaccessibility to the RAMS model. Then, most of the ATC tasks are big groups that encompass different sub-tasks that are not modelled. The tasks are the set of events ATC must perform to ensure safe management of the air traffic. These limitations are assumed due to the inaccessibility to the RAMS model.

The ATC model splits control tasks into five different types:

- Conflict search: it evaluates the situation and analyses potential conflict situations between aircraft before piercing into the sector.
- Coordination: communications between centres (external) and between sectors of the same centre (internal).
- Flight Data Management: includes tasks of loading, preparing and discarding flight progress.
- Communications: includes all the radio communication tasks (first call, last call, position report, the transmission of a new clearance, and so on)
- Radar activity: tasks of maintaining aircraft separation by radar actions (speed, altitude or vectoring).

Therefore, ATC workload (WL) is the addition of the duration of all tasks during one-hour period:

$$WL = \sum_{\forall i} (a^i + b^i + c^i + d^i + e^i) \tag{1}$$

Where a^i are the sum of conflict-search sub-tasks, b^i are the sum of coordination sub-tasks, c^i are the sum of flight-data management sub-tasks, d^i are the sum of communication sub-tasks and e^i are the sum of radar-activity sub-tasks. All of the previous tasks are defined for each aircraft i. Moreover, each task is characterised depending on the operation: standard departures (D_e), standard arrivals (A_e) and CCOs (CCO) does not require the same tasks. Besides, they constitute different groups: N_{De} are the total number of standard departures, N_{Ae} are the total number of standard arrivals and N_{CCO} are the total number of CCOs. Finally, each type of tasks is characterised depending on the ATC unit: WL^{TWR} and WL^{APP} represents the ATC workload for TWR and APP dependency.

The introduction of CCOs implies the modification of several tasks due to the new operational concept described in section 2:

- Conflict search is different at TWR unit because they have to manage the on-ground CD&R algorithm to avoid conflicts aloft (tasks a_2 and a_3).

- Coordination, Flight-data management and communications do not require new tasks, although hese type of tasks are numbered differently for CCOs because they will require an increase of theirvalues compared with standard operations.
- Radar tasks are not considered for CCOs because they are de-conflicted by the intro duction of new CCO separation minima and the CD&R algorithm at TWR. Then,in the case something happens in the air, the ATC will act on the standard departure or arrival to avoid a conflict with CCOs.

Table 1 presents a brief description, the nomenclature and the ATC unit affected for each type of task.

4. Case-study: Palma airport

This section details the main features of Palma. Palma TMA (Spain) is located in Barcelona Flight Information Region (FIR), adjacent to Marseilles FIR and comprises three airports (Palma de Mallorca, Menorca e Ibiza), where Palma is the primary airport and the scenario of this work. Palma airport is a high-density scenario with two parallel runways. Herein, East configuration of Palma airport is selected, and 11 SIDs and STARs intersections are detected.
The fleet distribution that operated at Palma airport in the year 2017 was: 2,5% Light, 33% B737 family (Medium), 40% A320 family (Medium), and 2,5% Heavy. The 95% of the Palma fleet was Medium and specifically B738, and A320 families tackled together over 73% of the fleet distribution. Thus, there was an extreme influence of the Medium aircraft.
CCO paths are extracted from previous works [19] and are performed based on the most extended aircraft at Palma– PRM1 (Light), B738 (Medium) and A332 (Heavy). Data of landing flows are assessed from a landing sample of Palma in 2017.
Moreover, Palma TMA sets 14 elementary sectors that constitute 64 possible configurations. The most typical configuration at rush hours demands 8 ATC sectors, see Figure 3.

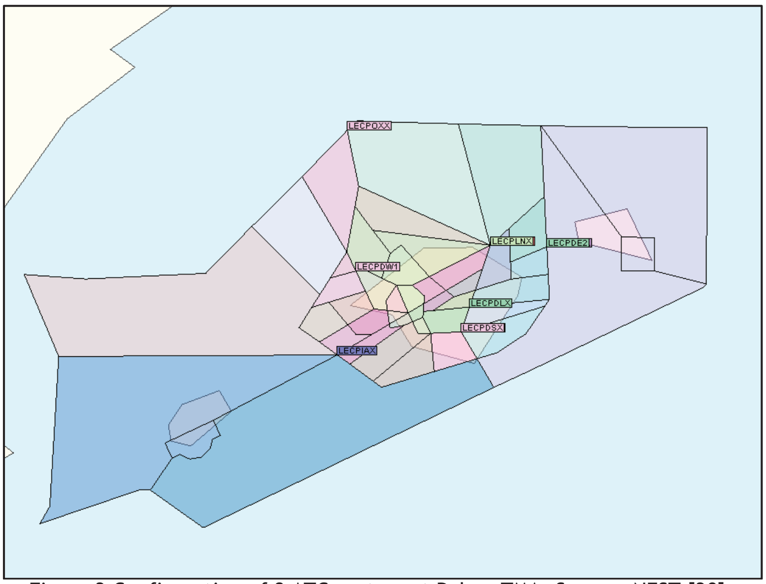

Figure 3 Configuration of 8 ATC sectors at Palma TMA. Source: NEST [30].

Therefore, this scenario requires the modelling of 2 ATC controllers at the TWR (one for landings and one for departures) and 8 ATC controllers at the APP.

Table 1 – ATC task glossary. Source: Authors.

Type	Operation	ATC Unit	Variable	Task
Conflict search (a)	De	APP	a1	Conflict search
	Ae	APP	a1	Conflict search
	CCO	APP	a1	Conflict search
		TWR	a2	No conflict detected (algorithm search)
			a3	Conflict detected (algorithm search)
Coordination (b)	De	APP	b1	Transfer of departure traffic
		TWR	b2	Departure sequence
			b3	Coordination with APP
	Ae	APP	b1	Transfer of arriving traffic
			b4	Landing sequence (Final sector)
		TWR	b3	Coordination with APP
	CCO	APP	b1	Transfer of CCO traffic
		TWR	b2	Departure sequence
			b5	Coordination with APP
Flight-data Management (c)	De	APP	c1	Flight data management
		TWR	c1	
	Ae	APP	c1	
		TWR	c1	
	CCO	APP	c2	CCO Flight data management
		TWR	c2	
Communications (d)	De	APP	d1	Communications pilot - controller
			d2	Waypoint notification
		TWR	d3	Take-off clearance
			d4	Traffic and meteorological information
	Ae	APP	d1	Communications pilot - controller
			d2	Waypoint notification
		TWR	d4	Traffic and meteorological information
			d5	Landing clearance
	CCO	APP	d1	Traffic and meteorological information
			d2	Waypoint notification
		TWR	d4	Traffic and meteorological information
			d6	CCO clearance
Radar (e)	De	APP	e1	Climbing clearance
			e2	Separation minima management
	Ae	APP	e4	Descending clearance
			e2	Separation minima management
	CCO	TWR	e5	On-ground separation minima management

5. Results & Discussion

This section presents the results for the different MC simulations. In every MC simulation, the trajectories are selected from a database, the landing and departing schedule is defined randomly, and the route distribution of the trajectories are different. As the ATC model is developed by the authors, the values of the variables for the different types of tasks are unknown. Hence, the first step is to calibrate the ATC model by considering only standard operations. Then, assuming modifications in ATC tasks by the integration of CCOs, different experiments varying the CCO percentage are performed to assess how the integration of CCOs affects ATC workload. Each experiment is characterised by 10^4 MC simulations with 30 departures and 40 arrivals.

5.1. Calibration

The calibration process was to perform 10^4 MC simulations only with standard operations to ensure that the ATC workload does not exceed workload limits. Typically, the ATC workload limits are 70% of one-hour period (42 minutes). Then, the sum of every ATC task should not exceed this limit. Palma TWR has two ATC controllers (one for departures and one for arrivals) and APP has at rush hours 8 ATC controllers. The calibration requires the estimation of the different variables to ensure that the ATC limit is not exceeded. In this case, the maximum ATC workload for the different ATC units were:

$$\begin{aligned} WL^{APP} &= 200a_1 + 200b_1 + 30b_4 + 200c_1 + 60d_1 + 60d_2 + 18e_2 \\ WL^{TWR} &= 30b_2 + 60b_3 + 60c_1 + 30d_3 + 60d_4 + 30d_5 \end{aligned} \tag{2}$$

According to experience and different studies, the distribution for each set of tasks should be around 10%. With this assumption, the values for the different tasks calculated with this model were where these of Table 2
:

Table 2 Values of the ATC model tasks for calibration. Source: Authors.

Task	a_1	b_1	b_2	b_3	b_4	c_1	c_1	d_1	d_3	d_4	d_5	d_2	e_2
Duration (s)	19,2	18	18	19	24	19,2	28	35	14	14	14	37	214

There was one divergence with the task c_1. It acquired different values depending on the APP (19,2) and TWR (28). The reason was they were different ATC units that should perform different sub-tasks that were not modelled. This was a significant difference but necessary to correctly calibrate the model.

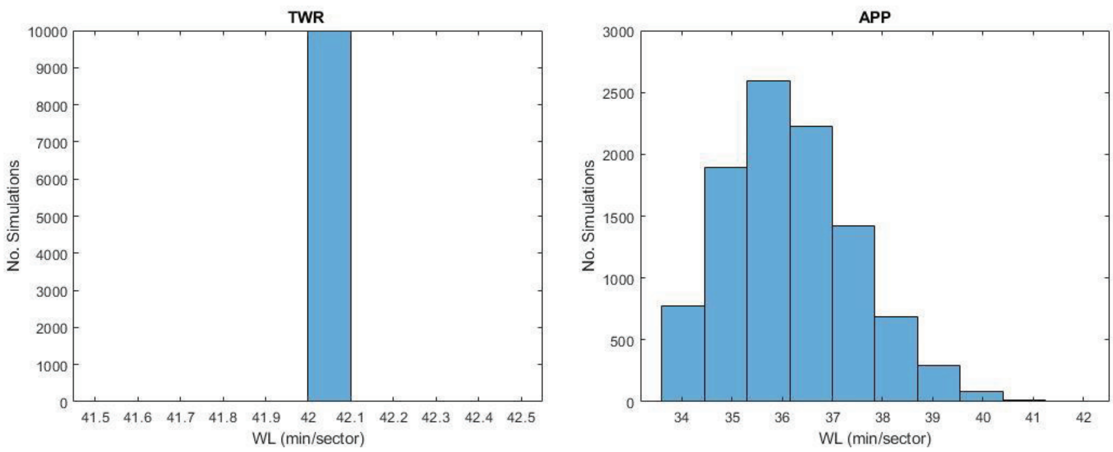

Figure 4 Histograms of the ATC workload for TWR (left) and APP (right). Source: Authors.

Figure 4 provides the ATC workload histograms for the different ATC units. The histograms represent one of two TWR controllers and one of the eight APP controllers. The main results were:

- TWR unit was calibrated for 42 minutes (70% of one-hour period). The histogram was fixed because all the operations were standard departures or arrivals. Therefore, the ATC workload only depended on the number of departures and arrivals according to the defined tasks, and this value did not vary in these simulations.
- APP unit was also calibrated for 42 minutes. In this case, the histogram was not fixed and varied between a minimum value of 32 minutes and a maximum value of 42 minutes. This variation is the result of the different conflicts detected aloft and solved by ATC controllers.

Therefore, TWR and APP units provided the calibration for one scenario of 70 operations that demanded the maximum ATC workload.

5.2. Integration of CCOs

Once the ATC model was calibrated, different experiments varying the CCO percentage were performed (from 10% to 100%). The experiments executed 10^4 MC simulations without varying the number of departures or arrivals. Particularly, this research assumed that the same tasks performed by ATC for CCOs demanded a 10% increase for the calibration values. This is a conservative value that was selected by several interviews with different APP controllers in Spain that worked in airports with CDAs. Particularly, the tasks a_2, a_3 and e_2 were new tasks due to the integration of CCOs. As there was no previous knowledge of these tasks, it was assumed values of $a_2 = 10, a_3 = 15$ and $e_3 = 15$.
Figure 5 shows the evolution of the ATC workload for TWR and APP.

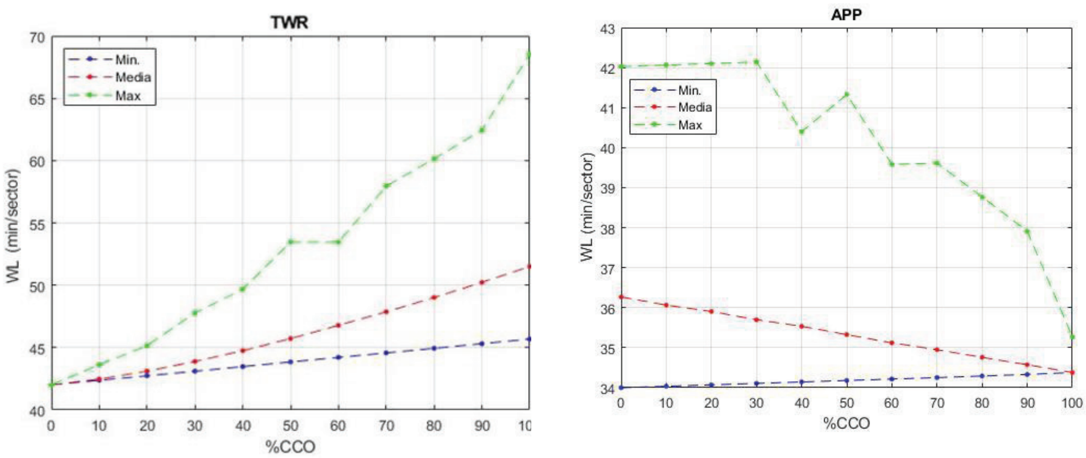

Figure 5 ATC workload for TWR (left) and APP (right) depending on %CCO. Source: Authors.

The following conclusions can be extracted from the results:

- The integration of CCOs implied an increase of the ATC workload for the TWR. The reason was simple because, with the operational concept considered herein, CCOs were conflict-free from the runway by the action of the TWR.
- TWR's workload increased its value for 100% CCOs almost 70 minutes (64%) in the worst scenario. However, minimum and mean workload values constantly increased up to 110% (minimum) and 123% (average) of the initial workload (42 minutes).
- Conversely, APP's workload decreased by the integration of CCOs. The reason was the same for the TWR's workload increase: APP controllers did not perform the conflict resolution. Indeed, 100% CCOs provided the best scenario for APP unit because they do not have to act to solve any conflict, and they just had to perform routine tasks.

- Minimum and mean workload values barely varied for APP unit. However, the maximum value sharply decreased until the minimum value. The decrease in the maximum workload was about 25% (8 minutes).

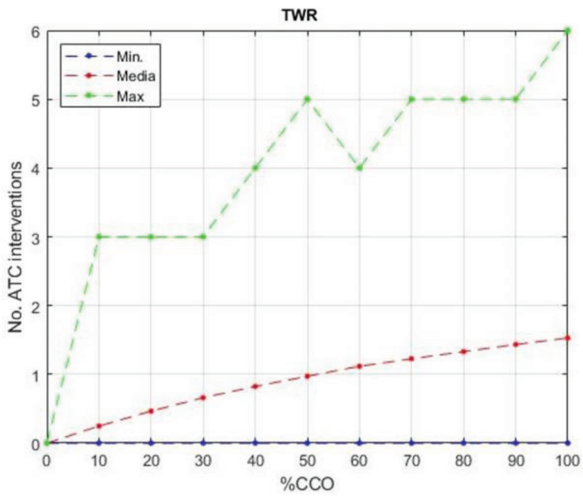

Figure 6 Evolution of the ATC interventions by TWR unit. Source: Authors.

- Figure 6 shows the evolution of the ATC interventions by TWR unit depending on the CCO percentage. The maximum values were obtained for 100% COO although there are schedules or simulations that reached 0 ATC interventions. Then, the increase of TWR workload for the integration of CCOs was because of the increase on the task workload for CCO tasks.

Therefore, the integration of CCOs provided precise results about their impact on the ATC units. With these assumptions, TWR unit could not introduce CCOs because the CCO on-ground de-confliction implied an increase of the ATC workload limit. Then, a thorough analysis of the current situation is required to assess the integration of CCOs correctly. In the case TWR units were not at their workload limit, they could introduce a CCO percentage depending on their workload gap. Moreover, there are other possible solutions such as to increase the number of controllers in TWR units (one extra controller would solve the workload problem) or to cut off the number of departures (which actually would imply an airport capacity reduction). However, new studies must focus on a thorough analysis of the correct calibration of the tasks as well as to reduce the 10% workload increase for CCO tasks.

6. Conclusions

In this paper, the authors presented an analysis of the impact on ATC workload due to the integration of CCOs. The proposed methodology consisted of the evaluation of MC simulations varying the CCO percentage and the operational factors of an scenario. Each simulation provided a different scenario because of the variation of the entire set of operational variables: the landing and departing trajectories and schedules. Then, an ATC workload model was developed based on basics controller tasks that encompassed different sub-tasks. They were divided into five groups: conflict-search, coordination, flight-data management, communication and radar. The ATC workload assessment was applied to a real scenario at Palma airport in Spain. In this case study, 30 departures and 40 arrivals were considered, and the introduction of CCOs varied from 0% to 100%. First, the scenario without CCOs was selected to calibrate the ATC workload model. The calibration required the estimation of the different variables to ensure that the ATC limit. TWR and APP units were calibrated for 42 minutes (70% of one-hour period), which is the ATC workload limit. TWR unit provided a fixed one-bar

histogram because all the operations were standard departures or arrivals. APP unit varied between 32 and 42 minutes due to the conflicts detected aloft. Second, the integration of CCOs implied an increase in the TWR workload and a decrease in the APP workload. TWR workload increased on average 150% and APP workload decreased on average 25%. The reason is due to the fact that the operational concept considered that TWR solved conflicts on-ground. The calibration of the TWR unit with the workload limit entailed that TWR units could not introduce CCOs. The CCO on-ground de-confliction implied an overload of the ATC limits. Then, it is necessary to correctly calibrate the current TWR workload unit to know which CCO percentage can be introduced. Further work will focus on accurate calibration of the workload increase that it is required for the new CCO tasks.

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The Evolution of Regulation of the Air Navigation Activity in Brazil

Marcus V. do Amaral Gurgel - marcus_gurgel@infraero.gov.br
Empresa Brasileira de Infraestrutura Aeroportuaria - Infraero
Jefferson Luis Ferreira Martins - jmartins@infraero.gov.br
Empresa Brasileira de Infraestrutura Aeroportuaria - Infraero

Abstract
The objective of this work is to analyze the evolution of the regulation of air navigation activity in Brazil, identifying the main stages of regulation in the last years.
Greater emphasis will be given to showing the need to make normative adjustments, to fill gaps and occasional conflicts with the improvement of the sector's governance structure, regarding the assignment of roles and responsibilities.
The governance structure of the sector presents areas that can be improved. With regard to the regulation, execution and inspection of Brazilian airspace, it is identified here an opportunity for improvement in the attribution of responsibilities for aviation regulation in the Country, mainly to airspace control, since, currently, these three functions are carried out by the same governmental and military body, the Department of Airspace Control - DECEA.
The identification of the benefit of the level of coordination between civil aviation regulators, focusing on airspace control, is a key issue in this work. With the elimination of the concentration of functions by the country's air navigation regulatory agency, the State can improve governance, assign roles and responsibilities to the sector, manage incentives, coordinate operations and regulate the structure, resulting in improved performance economic-operational.

Keywords
regulation; governance structure; airspace control; coordination

A Evolução da Regulação da Atividade de Navegação Aérea no Brasil

1. INTRODUÇÃO

Poucos anos depois do primeiro e histórico voo de Alberto Santos Dumont em Paris no ano de 1906, a aviação passa a conhecer um desenvolvimento gigantesco, quando os aviões passaram a cobrir distâncias cada vez maiores e, muito antes da 2ª Guerra Mundial, conhecidos pioneiros voaram de continente a continente, cruzando oceanos em viagens heroicas e aventureiras.

No início os aviões decolavam de “aeroportos” que nada mais eram do que áreas similares a pastos e campos de futebol ou, com sorte, de trechos de estradas [1].

A década de 20, já liberta dos conflitos da 1ª Guerra Mundial, beneficiou-se do recente desenvolvimento da fabricação aeronáutica para fins militares. O potencial aeronáutico passou a ser subsidiariamente empregado no transporte de correio, cujas malhas foram se consolidando e regularizando progressivamente. As linhas de correio aéreo passaram a levar, eventualmente, passageiros. A incorporação progressiva do passageiro ao transporte aéreo deu-lhe novo impulso nos Estados Unidos e Europa. Além dos serviços domésticos, os voos internacionais começaram a multiplicar-se. As travessias oceânicas romperam os últimos obstáculos à grande rede de ligações em todo o mundo. Muitas empresas de transporte aéreo foram criadas com sucesso, baseadas no apoio aos governos. A credibilidade e confiabilidade despertaram a demanda. A organização dos serviços amadureceu companhias e desenvolveu a infraestrutura. No Brasil, em 1920, foi criada a Inspetoria Federal de Viação Marítima e Fluvial, acumulando atribuições referentes à navegação e à indústria aeronáuticas, à época, emergentes.

Em 1927, foram formadas as primeiras empresas de transporte aéreo regular: VARIG e o Sindicato Condor – posteriormente, Cruzeiro do Sul. Nesse ano, as diversas ligações domésticas e internacionais, atendiam ao mercado. A companhia francesa Latecoère passou a ligar o Brasil à França a partir de 1927. Em 1929 a Nyrba, mais tarde Panair do Brasil, iniciou suas operações [2].

A década de 40 assistiu a consolidação da aviação civil brasileira. Em 22 de abril de 1932, era criado, pelo Presidente Getulio Vargas, o Departamento de Aviação Civil, subordinado ao então Ministério de Viação e Obras Públicas.

Posteriormente, foi criado o Ministério da Aeronáutica em 20 de janeiro de 1941, que congregou a aviação naval, a aviação militar e a aviação civil. Esta última, deslocada do Ministério da Viação e Obras Públicas. Outros fatos marcantes dessa década, foram a criação de duas dezenas de empresas de transporte aéreo, a constituição de uma grande frota, a criação de centenas de aeroclubes dedicados à formação de pilotos e a construção durante a guerra, de uma rede de aeroportos pavimentados e dotados de auxílios para aproximação por instrumentos. Este impulso só veio na década de 1940, em função das aeronaves americanas excedentes de guerra, adquiridas a baixo custo e em boas condições de financiamento, o que permitiu o surgimento de inúmeras empresas aéreas, quase todas funcionando, no entanto, com estrutura econômica precária. Neste contexto, o transporte aéreo ganhou importância, em um efeito de integração e de desenvolvimento, em função do amplo território do país (o que promoveu uma continuidade e similitude com o processo americano), da precariedade do transporte rodoviário e da dificuldade de acesso a pontos longínquos do território, em especial a região norte do país.

Essa consolidação, ocorrida também em nível mundial, representou um grande patamar alcançado, embora tivessem suas repercussões, sido em muito sobrepujadas pela década seguinte, com a introdução nos principais países do mundo, de aeronaves a jato no transporte aéreo. Realmente, a década de 50, foi revolucionária e projetou solidamente a aviação civil em termos de produção, tecnologia, segurança e conforto. Este marco decisivo inicia-se no Brasil, em 1959, quando a Varig colocou em serviço duas aeronaves Caravele.

Ao findar-se a década de 80, a aviação brasileira manteve-se entre as 10 (dez) maiores do mundo em termos de produção de serviços, números de aeroportos, quantidades de pilotos e rede de controle de tráfego aéreo. Essa posição de destaque no conceito internacional teve seu início ainda na década de 40 sendo mantida ao longo do tempo, tendo cristalizado seus ganhos na expansão da economia nos anos 70 [3]. Tanto, que o Brasil é o único país em desenvolvimento, considerado potência aeronáutica no seio da Organização Internacional de Aviação Civil – OACI, tendo ocupado desde sua criação lugar privilegiado no seu Conselho de Direção.

2. ELEMENTOS DA ECONOMIA NA REGULAÇÃO

2.1 Introdução

A implementação de uma regulação, ou a reforma de uma existente, requer um procedimento particular e cauteloso. Deve-se implementá-la à semelhança de um processo de planejamento, contemplando as fases de estudo, estabelecimento de objetivos, geração de opções de intervenção, avaliação e seleção, assim como a organização desta implementação. O “Decálogo do Regulador” desenvolvido pela OECD [4] sistematiza as etapas de uma concepção regulatória, etapas essas que serão descritas e analisadas em seguida.
Devido à sua importância, no que tange ao desenvolvimento dos países, um dos setores de maior relevância no quesito “regulação” é o de infraestrutura. Este possui como características: tecnologias específicas; com economias de escala e de escopo na prestação de serviços básicos - monopólio natural. Possui também, como característica, produtos consumidos em grande escala, normalmente por consumidores cativos e com bastante demanda.
Muitas das atividades de infraestrutura econômica são monopólios naturais. Em razão disso, a maioria dos governos regula os preços cobrados pelos monopólios para proteger os consumidores. Pressionados pelos usuários, os governos tendem a regular os preços, para fixá-los aos custos de suprimento. Os investidores privados, por sua vez, tornam-se vulneráveis à ação arbitrária dos governos, uma vez que os investimentos em infraestrutura, via de regra, são difíceis de se recuperar. Desse modo, a regulação também é um meio de proteger os investidores, ao induzi-los a fazer investimentos a um custo razoável.
Assim, pode-se dizer que a regulação é necessária para proteger tanto os usuários quanto os investidores [5]. Isto, contudo, implica em custos diretos e indiretos.
A implantação da regulação deve ser repensada: a necessidade de regular, sempre que for possível, deverá ser substituída por soluções competitivas? Para isso, entretanto, é fundamental que se leve em conta a estrutura do mercado que está sendo regulado; as barreiras ao ingresso; o número de concorrentes reais e potenciais (estrutura horizontal); e vinculações verticais que afetam o poder de mercado (estrutura vertical), conforme a Sistematização do Traçado Regulatório, Figura 1. Frequentemente, as características institucionais de um país não se ajustam bem a seu marco regulatório, o que produz efeitos imprevistos.

Sistematização do Traçado Regulatório - Figura 1

2.2. Elementos Para o Traçado Regulatório

No que concerne à implementação de uma regulação, ou a reforma de uma existente, deve-se requerer um procedimento particular e cauteloso. De forma semelhante a um processo de planejamento, distinguem-se, concepção regulatória, fases de estudo, estabelecimento de objetivos, geração de opções de intervenção, a respectiva avaliação e seleção, assim como a organização de sua implementação. Segundo [6] inspirada no "Decálogo do Regulador" desenvolvido pela Organization for Economic Co-operation and Development - OECD, Quadro 1 abaixo, sistematiza as etapas de uma concepção regulatória, etapas essas que serão descritas e analisadas em seguida. Ressalte-se aqui que, em 2012, o Conselho da OCDE recomendou 12 (doze) Princípios sobre Política e Governança Regulatória, como um sumário ou guia aos Governos que necessitam melhorar o desenho, aplicação e a revisão de seus marcos regulatórios [7].

Na verdade, as falhas de mercado são múltiplas, e sua identificação em cada caso concreto exige que se analise de uma forma cuidadosa as condições básicas de consumo e de produção dos bens e serviços em causa. A razão principal para a existência da intervenção estatal em uma atividade econômica é saber se a atividade é necessariamente essencial para o processo econômico e a qualidade de vida e ambiental.

Dessa forma, temos de verificar não só se estamos diante de um serviço realmente essencial, qual a sua relação com outros produtos e setores, a existência ou não de produtos substitutos, mas também as condições que o consumidor goza para tomar decisões racionais.

Ainda sob o efeito da análise das estruturas do mercado do setor e de setores correlatos, deve-se atentar para as externalidades geradas pelo setor para outros setores e, em sentido contrário, aquelas geradas por outros setores em relação à atividade sob análise.

Finalizando, torna-se muito importante observar a situação econômica e política, já que as condições de mercado e a disposição dos investidores dependerão diretamente disto.

Disposições contrárias nestas áreas tendem a acarretar em dificuldades de investimentos e conflitos entre as empresas, consumidores e o órgão regulador.

O DECÁLOGO DO REGULADOR

Conforme a OECD *Reference Checklist for Regulatory Decision-making* (OECD 1997), toda iniciativa ou reforma regulatória haveria de ser definida com base na resposta às seguintes questões:

Questão1: O problema está corretamente definido?
O problema a ser resolvido deveria estar precisamente definido, fornecendo uma evidência clara de sua natureza e magnitude, explicando como ele surgiu (e identificando os incentivos das entidades afetadas).

Questão 2: A ação governamental justifica-se?
A intervenção governamental deveria ter por base uma comprovação clara que a ação governamental é justificada, dados a natureza do problema, assim como os prováveis benefícios e custos (com lastro em uma avaliação realista da efetividade da ação governamental), e analisados mecanismos alternativos para tratar o problema.

Questão 3: Será a regulação a melhor forma de ação governamental?
Os responsáveis pela regulação deveriam realizar, ainda em uma fase incipiente do processo regulatório, uma comparação fundamentada de uma gama variada de instrumentos governamentais regulatórios e não-regulatórios, levando em consideração questões relevantes tais como custos, benefícios, efeitos distributivos e requisitos administrativos.

Questão 4: Existe um lastro legal para a regulação?
Os processos regulatórios deveriam ser estruturados de tal forma que todas as decisões regulatórias respeitam rigorosamente as "normas do Direito"; isso é, deverá ser explicitamente atribuída uma responsabilidade de se garantir que todos os regulamentos estejam autorizados por normas superiores, assim como consistentes com as obrigações derivadas de Tratados, e obedeçam aos princípios legais relevantes tais como certeza, proporcionalidade e normas procedimentais aplicáveis.

Questão 5: Quais níveis de governo se apropriam para essa ação?
Os responsáveis pela regulação deverão escolher o nível de governo mais apropriado para assumir a ação, ou, se forem envolvidos diversos níveis, deverão ser estruturados sistemas efetivos de coordenação entre os níveis governamentais.

Questão 6: Será que os benefícios justificam os custos?
Os responsáveis pela regulação deverão escolher o nível de governo mais apropriado para assumir a ação, ou, se forem envolvidos diversos níveis, deverão ser estruturados sistemas efetivos de coordenação entre os níveis governamentais.

Questão 7: Os efeitos distributivos através da sociedade estão transparentes?
Na medida em que valores referentes à distribuição e à equitatividade sejam afetados pela intervenção governamental, os responsáveis pela regulação deveriam tornar transparente a distribuição dos custos e benefícios regulatórios pelos grupos sociais.

Questão 8: A regulação está clara, consistente, compreensível e acessível aos usuários?

Os responsáveis pela regulação deveriam avaliar se as regras vão ser compreendidas pelos prováveis usuários e, para tal fim, deverão assegurar que o texto e a estrutura das regras estejam tão claros como possível.
Questão 9: Todas as partes interessadas tiveram a oportunidade de apresentar suas visões?
As regulações deveriam ser desenvolvidas de uma forma aberta e transparente, com lastro em procedimentos apropriados para a contribuição efetiva e tempestiva de partes interessadas tais como os setores econômicos e os sindicatos, outros grupos de interesse ou outros níveis governamentais afetados.
Questão 10: Como a obediência será garantida?
Os responsáveis pela regulação deverão avaliar os incentivos e as instituições que levarão efeito à regulação e deverão desenvolver estratégias sensíveis de implementação que assegurem o melhor uso deles.

Quadro 1 – Decálogo do Regulador [8]

2.2.1. Objetivos e Diretrizes da Regulamentação

Ao descrevermos as bases teóricas da regulação econômica, não podemos deixar de citar objetivos básicos a serem perseguidos pelo desenho regulatório. Obviamente que, tais objetivos deverão ser concretizados para cada caso de intervenção regulatória, em função direta das falhas que estiverem sido detectadas após cuidadoso estudo das características das condições de produção no mercado sob análise. Deve-se buscar a compensação ou o impedimento dos efeitos de uma imperfeição competitiva; incentivar a eficiência produtiva; da inovação e os correspondentes investimentos; maximizar o bem-estar, sobretudo dos consumidores; instaurar um comportamento competitivo e incentivar a inovação, assim como de atender objetivos sociais e econômicos gerais estabelecidos [9].
O atendimento aos objetivos sociais e econômicos gerais estabelecidos é considerado o elemento fundamental da estruturação institucional dos setores de utilidade pública, principalmente nos países onde tais objetivos submetem-se à pessoa jurídica do serviço público, partindo-se do princípio de que estes serviços seriam essenciais como garantia de direito de cidadania. Assim, cabe ao Estado não só garantir a "melhor configuração possível de mercado", mas também prestá-los diretamente, por intermédio de entidades estatais ou mediante contratação de empresas privadas, em alguns casos, utilizando-se de concessão, instrumento bastante utilizado atualmente para o caso dos aeroportos no Brasil. Verifica-se que a regulamentação não deve apenas estar orientada para cumprir tais objetivos, mas também apresentar custos mínimos de desenvolvimento e aplicação. Deve também reduzir ao máximo os custos de transação entre os agentes presentes no mercado, entre o interesse final da sociedade e o interesse e ações específicos dos agentes públicos e privados - conflitos entre agentes e principais, assim como o risco de capturação da regulamentação pelos interesses de grupos, o que exigirá que o aparato regulatório adquira um satisfatório nível de transparência [9].

2.2.2 Estratégias e Dimensões da Intervenção Regulatória

Desta forma, temos as diversas categorias de "remédios", como os contornos da atividade que deve ser regulada; definição das condições de entrada; competências do Poder Administrativo para determinar os tipos e quantidades de serviços a serem oferecidos (regulação de quantidade); condições de saída; política de preços; indicadores de desempenho e de qualidade; além de outros aspectos referentes à regulação.
Uma vez determinados os objetivos, deve-se avaliar as opções de ações regulatórias nos diversos segmentos e dos recursos a serem utilizados, indo da restrição à entrada e saída à especificação dos produtos e preços, equipamentos e diversos outros parâmetros. Esses "remédios regulatórios" fazem parte de uma tática regulatória, a qual pode ser classificada em termos de como o Poder Público poderá assumir a garantia da provisão do bem ou serviço objeto da regulação, bem como a escolha das intervenções.

2.2.3 Avaliação das Proposições Regulatórias

Coadunando com os objetivos determinados para a regulamentação, as medidas e as estratégias definidas deverão ser submetidas a um teste de sua eficácia. Geralmente, a regulação deve ser testada em sua capacidade de: melhoria da eficiência produtiva e alocativa; inovação; controle de poder monopolista; desenvolvimento de um ambiente competitivo, além de atender os objetivos de política social, industrial e regional.

A regulamentação também deve ser medida quanto aos seus custos administrativos de aplicação e seus efeitos, pois é sabido que o regulador e sua política regulatória estão sujeitos a diversos riscos, os quais na literatura encontram-se sistematizados sob a dominação de falhas regulatórias ou governamentais [10]; [11].
Existe uma limitação do Poder Público na sua capacidade de controlar os setores regulados, estando geralmente, em desvantagem no que tange a informação acerca da realidade econômica do setor, com relação às empresas. Assim, os reguladores sempre correm o risco de realizar uma avaliação equivocada dos prós e contras que suas medidas poderão acarretar às empresas, aos consumidores e à sociedade em geral. Não podemos deixar de mencionar que, a estes entes, devem os reguladores prestar contas, não apenas à sociedade em geral, mas também aos principais agentes políticos - distribuídos por diversas agências e níveis administrativos.
Ressalte-se que, a ação regulatória se faz em um complicado campo de interesses conflituosos, onde os representantes dos interesses gerais da sociedade encontram-se pressionados por diversos interesses particulares, podendo resultar na apresentação de várias falhas e resultados ruins.
O tratamento dessas falhas não só requer a escolha de medidas relativas à reestruturação administrativa, mas também a implantação de métodos mais rigorosos de checagem dos custos e benefícios das ações regulatórias.

2.2.4 Processo de Implantação

Assim sendo, deve-se esperar ações de influência e de resistência, originadas nos segmentos envolvidos, objetivando a captura da regulamentação de acordo com os respectivos interesses.
Deve-se considerar também que as empresas sujeitas à regulamentação, normalmente reagem às limitações impostas, adotando procedimentos contrários aos objetivos da regulamentação como a cooptação de setores do Poder Público.
Pode-se afirmar que as medidas regulatórias têm uma vida útil de eficácia, a partir de cujo esgotamento faz-se necessário reformar a regulamentação.
As novas técnicas regulatórias pressupõem que antes da assinatura de novos contratos de concessão, o Poder Público esteja solidamente estruturado, possuindo agências equipadas com as competências necessárias e que disponham dos recursos humanos e materiais necessários para cumprir sua função [12]. As agências têm de ser instituídas visando sua capacitação para cumprir três principais objetivos: proteger os consumidores dos abusos de empresas com grande poder de mercado; apoiar o processo de investimento protegendo os investidores de ações arbitrárias por parte do Governo; e promover a eficiência [13].
No intuito de atender a esses objetivos, a agência deverá realizar várias funções, tais como [14]:

- Definição de base e critério para permissão de entrada no mercado;
- Garantir o cumprimento das especificações regulamentares;
- Estabelecer a regulamentação técnica em matéria de segurança e procedimentos técnicos, assim como monitorar seu cumprimento;
- Monitorar o processo de coleta de receita, assim como a continuidade e a acessibilidade dos serviços e respectiva qualidade;
- Definição das bases para o cálculo tarifário;
- Tornar públicos os direitos dos usuários;
- Organizar audiências públicas;
- Regulamentar e aplicar os procedimentos de disciplinamento;
- Levar questões relevantes à Justiça;
- Editar relatório anual e recomendar medidas políticas para o Executivo, na medida das necessidades.

Obviamente que, a realização desses objetivos acarreta na existência de desafios. Eis que geralmente a definição de tarifas é um processo repleto de combustível político; em contrapartida, os investidores exigem perspectivas confiáveis de lucratividade para decidirem investir; todavia, os efeitos dos investimentos e a evolução do ambiente político e econômico ao longo prazo é imprevisível [14].

Um ponto muito importante a ser discutido refere-se à estrutura de como se regular, ou seja: se cada setor deve possuir uma agência própria, ou a regulação de diversos setores deve ser confiada a uma agência única.
Essa discussão tem merecido destaque especial na literatura [5]. Segundo [6], de um lado, a agência especializada teria melhor condição de adquirir conhecimentos específicos sobre o respectivo setor; de outro, ela ficaria muito próxima do ente regulado, podendo desencadear em um processo de captura por parte deste. A agência unificada, por sua vez, costuma ficar politicamente mais fortalecida, tanto frente ao regulado quando aos administradores setoriais, desde que, exista interface entre seus limites setoriais.

3.O CENÁRIO BRASILEIRO

No Brasil, a aviação civil passou por inúmeras transformações desde 1927, ano do voo inaugural da primeira empresa de aviação civil do Brasil. De um mercado incipiente, na década de 20, o País passou a possuir um Sistema de Transporte Aéreo Regular Brasileiro, constituído de linhas aéreas regulares, regulado e fiscalizado, inicialmente pelo Departamento de Aviação Civil - DAC, órgão militar e, posteriormente, pela Agência Nacional de Aviação Civil – ANAC, criada em 2005. No controle do espaço aéreo, a regulação inicia-se um pouco mais tarde, a partir da criação da Diretoria de Rotas – DR, em 1942. Retornando um pouco no tempo, observa-se que a aviação no Brasil estava dividida entre a militar do Exército e a Naval. Em paralelo, as comunicações entre as autoridades brasileiras e europeias já nos davam uma ideia da importância de uma Força Aérea independente, e foi, justamente a partir desse antigo desejo de união desses grupos de aviação, somado a episódios desencadeados por conta da 2ª Guerra Mundial, que permitiram um passo de proporções incomensuráveis na história das Forças Armadas: a criação do Ministério da Aeronáutica em 20 de janeiro de 1941, através do Decreto-Lei nº 2.961/41, com a missão de garantir a segurança nacional e promover o desenvolvimento tecnológico, econômico e social do Brasil. Proveniente de três origens distintas, Exército, Marinha e Ministério da Viação e Obras Públicas, caberia ao novo Ministério, harmonizar os interesses simultâneos de segurança Nacional, desenvolvimento econômico, tecnológico e social que substanciavam o poder aéreo: Força Aérea, Aviação Civil, Infraestrutura e Indústria Aeronáutica e formação de profissionais de Aeronáutica. Com a 2ª Guerra na Europa, a posição geográfica do País e a imponência do tamanho do seu território logo, passaram a ser foco das atenções dos Estados Unidos da América, pressionando o Brasil para que se ocupasse principalmente a região do Nordeste Brasileiro e a instalação, ali, de bases aéreas que permitissem a escala de voos rumo à África e ao Oriente. Ao mesmo tempo, pretendiam impedir que os países do Eixo não ocupassem essa rotas. Em meados de 1941, essas bases e rotas aéreas já eram uma realidade [2]. A partir de ações conjuntas entre os dois países, houve um incremento da aviação no Brasil, com o recebimento de aeronaves, formação e capacitação de profissionais. Ainda em outubro de 1941, foram criadas oito Diretorias, entre elas a Diretoria de Rotas, vindo a ser implementada já em 1942. Com o término da Guerra, uma das maiores tarefas foi receber as bases aéreas dos norte-americanos, pois os efetivos brasileiros ainda eram muito pequenos, tendo em vista que, naquela ocasião, um grande número de oficiais saíram da Força Aérea Brasileira – FAB para outras atividades, principalmente, a aviação comercial. Tendo por meta suprir essas deficiências, relativas à proteção ao voo, o Ministério da Aeronáutica expandiu os Serviços de Proteção ao Voo. Cada sede de Zona Aérea, passou a ter, então, um Serviço Regional de Proteção ao Voo (SRPV), formando um enorme sistema, tendo como órgão central a Diretoria de Rotas Aéreas. No campo internacional, ao final da 2ª Guerra Mundial, a comunidade internacional identificou a necessidade do desenvolvimento de normas, princípios e padrões comuns para regular o rápido crescimento de um modal de transporte que revolucionaria, nos anos subsequentes, o modo como o ser humano lidaria com as distâncias geográficas e com a velocidade dos fluxos comerciais: a aviação civil. Neste sentido, normas precisariam ser estabelecidas para garantir a segurança e a compatibilidade das operações entre os Estados [15].
Por conta deste crescente na aviação civil nacional e internacional, foi criada em 20 de outubro de 1949 a Comissão de Estudos à Navegação Aérea – CERNAI, por meio do Decreto nº 27.353, tendo por finalidade tratar dos assuntos referentes à fixação e condução da política aérea brasileira no campo internacional.

Ainda no que se refere à proteção ao voo no início da década de 1950, a Diretoria de Rotas Aéreas, desempenhou papel de fundamental relevância na organização inicial do controle do espaço aéreo brasileiro. Houve um grande investimento na região amazônica e em ciência e tecnologia aeroespacial. Já no início da década de 1960, após detectar problemas operacionais nos equipamentos de proteção ao voo, a Diretoria de Rotas Aéreas, com o objetivo de eliminá-las, mandou instalar os primeiros radares de controle de tráfego aéreo nos aeroportos, radiofaróis VOR (VHF *Omnidirectional Range*) e ILS (*Instrument Landing System*) [16].
Já pensando em uma maior integração, foi criada a Diretoria de Eletrônica e Proteção ao Voo – DEPV [16], em substituição à Diretoria de Rotas Aéreas, com a finalidade de dirigir, orientar, coordenar e controlar as atividades especializadas em eletrônica, comunicações, tráfego aéreo, navegação, meteorologia, fototécnica e cartografia. Também neste ano o Ministério da Aeronáutica aprovou o início de estudos para a implantação do Sistema de Defesa Aérea e Controle de Tráfego Aéreo (SISDACTA). Estava então selada a integração dos serviços de controle de tráfego aéreo e de defesa aérea brasileiros. Em 05 de outubro de 2001, foi criado o Departamento de Controle do Espaço Aéreo – DECEA, em substituição à DEPV. A partir daí, consolida-se todo um planejamento iniciado com a criação da Diretoria de Rotas Aéreas, onde se fazia o controle do tráfego aéreo "dentro do possível", passando pela criação da DEPV, onde se passou a controlar praticamente todo o espaço aéreo brasileiro por meio de fonia, com a proteção do Serviço de Busca e Salvamento – Salvaero e de todo um Sistema de Proteção ao Voo, chegando finalmente, por meio da criação do DECEA, ao "terceiro grau", que não é somente informação nem proteção ao voo, mas o controle efetivo, com todo o Sistema de Vigilância montado – inclusive na Amazônia, onde se detém a visualização de todo o território brasileiro e de áreas adjacentes, seja no mar, seja na zona de fronteira e de forma integrada com a defesa do espaço aéreo brasileiro. O paradigma mudou: a partir daí, não seria mais o piloto que informaria sua posição. O controlador de tráfego aéreo passou a identificar onde a aeronave se encontra e o que deve ser feito para um efetivo controle do tráfego aéreo, em mais de 22 milhões de km^2. Desta forma e, ao longo do tempo, o Comando da Aeronáutica se consolidou, por meio do DECEA, como regulador/normatizador, fiscalizador e provedor dos serviços de navegação aérea no país.

3.1 Governança

Ao longo do tempo, a Força Aérea Brasileira assumiu o protagonismo os assuntos relativos à regulação do espaço aéreo brasileiro não só nacional como internacionalmente. Ao longo da História "marcos" foram instituídos de forma a se regulamentar a atividade no País. Iniciou-se com a celebração do Código Brasileiro do Ar, em 1938, considerando que se tornava necessário dotar o país de uma legislação capaz de regular eficientemente a aviação civil e comercial e que a legislação brasileira estivesse de acordo com as convenções e com as tendências, à época, do direito aéreo [17] e com a criação da Diretoria de Rotas Aéreas, em 1942, em que pese a ênfase na dedicação primária nos serviços inerentes às rotas aéreas e o Correio Aéreo Nacional - CAN, foi criada internamente a Divisão de Proteção ao Voo que estabelecia dentre suas atribuições organizar e padronizar os serviços de interesse da segurança do tráfego aéreo. Em 18.11.1966 o Código Brasileiro do Ar foi alterado pelo Decreto-Lei nº 32, o qual já fazia referência ao Direito Aéreo, Convenções e Tratados. Observa-se também, referência às Zonas de Proteção de Aeródromos. No item relativo ao Tráfego Aéreo há citação quanto às observações ao Código, Convenções e Atos Internacionais, bem como aos regulamentos e instruções expedidas. Em 1972 é criada a Diretoria de Eletrônica e Proteção ao Voo – DEPV, [18], e seu Regulamento estabelecido por meio do Decreto nº 81.998, de 19.07.1978, onde, dentre suas competências, estão a elaboração de normas, procedimentos, princípios, critérios e programas pertinentes à Proteção ao Voo, bem como a coordenação e o controle nas áreas de Eletrônica, Telecomunicações Aeronáuticas, Pesquisa e Desenvolvimento, além da investigação às infrações às regras de tráfego aéreo, o que demonstra a ampliação do espectro da regulação dos serviços de Navegação Aérea.
Em dezembro de 1986, foi criado o Código Brasileiro de Aeronáutica [19], em substituição ao Código Brasileiro do Ar, com o objetivo de simplificar a legislação existente, assim como, compatibilizá-la com a Constituição Federal do Brasil, de forma a adequá-la às necessidades resultantes das profundas transformações porque passou o transporte aéreo, a aviação civil e comercial e todos os serviços, direta ou indiretamente vinculados à navegação aérea, como um dos segmentos mais dinâmicos do mundo em que vivemos, atualizando-a e aperfeiçoando-a sistematicamente.

A partir do ano de 2006, houve uma ruptura quanto à condição econômica do País, com o crescimento exponencial da aviação como modal de transporte. Passou-se a se substituir o transporte rodoviário pelo aéreo. Grande parte da população que não possuía acesso ao modal aéreo, passou a tê-lo. Com isto, houve um contraponto entre a infraestrutura aeroportuária e de navegação aérea instalada e a demanda reprimida, acarretando no chamado "apagão aéreo"[1]. Assim, em que pese o Brasil possuir disponibilidade de aeroportos e a cobertura da malha aérea doméstica mostrando-se de maneira geral, adequadas e do País ser um dos poucos com indústria aeronáutica relevante, o crescimento recente trouxe uma série de desafios. A infraestrutura aeroportuária, em sua grande parte a cargo da Infraero, empresa que administrava os aeroportos responsáveis, à época, por mais de 95% do tráfego aéreo civil, não cresceu no mesmo ritmo da demanda. O sistema de pistas e pátios também encontrava limitações, acarretando também na gestão do controle do espaço aéreo, porém em menor monta, conforme demonstrado na figura 3.1 [20].

O crescimento acelerado trouxe para a infraestrutura aeroportuária desafios de capacidade já em 2009

Utilização na hora-pico para pista/pátio e no ano para TPS

- Com restrições hoje
- Necessidade de investimento até 2030
- Capacidade atual suficiente até 2030
- ( ) Ano limite para saturação

		Lado ar[1]			Lado terra
	Aeroporto	Pista DECEA	Pista ITA	Pátio[2]	TPS
SP	Guarulhos	(2030)	(2030)	Saturado	Saturado
	Congonhas	Limitado	(2014)	Saturado	Saturado
	Viracopos	(2020)	(2020)	(2014)	(2014)
RJ	Galeão				(2030)
	Santos Dumont	(2030)	(2030)	Saturado	(2030)
BH	Confins			(2020)	Saturado
	Pampulha	(2030)		(2014)	(2014)
Demais	Brasília	(2030)	(2030)	Saturado	Saturado
	Porto Alegre	(2030)	(2030)	(2030)	Saturado
	Curitiba			(2030)	(2020)
	Recife	(2030)		(2030)	(2020)
	Salvador	(2020)	(2030)	Saturado	(2014)
	Fortaleza			(2030)	Saturado
	Manaus			(2020)	(2030)
	Cuiabá	(2030)		Saturado	Saturado
	Natal			Saturado	(2014)
	Florianópolis			Saturado	Saturado
	Vitória	(2030)		Saturado	Saturado
	Belém			(2014)	(2030)
	Goiânia	(2030)		Saturado	Saturado

1 Considera mesmo nível de crescimento tanto para aviação geral quanto para aviação regular
2 Não considera equipamento para movimentação de passageiros (p.ex., ônibus, escada) que pode afetar o nível de serviço percebido pelo passageiro
FONTE: ITA; DECEA; análise da equipe

Figura 3.1 – Limitações de Infraestrutura [20]

No médio e longo prazo (até 2030), dado o crescimento projetado, serão necessários investimentos para aumentar a capacidade atual em 2,4 vezes (de 130 milhões para 310 milhões de passageiros ao ano, ou o equivalente a nove aeroportos de Guarulhos). Limitar a capacidade significa não somente deixar passageiros desatendidos, com reflexos adversos na economia, mas regredir em muitas das conquistas recentes do setor, como a maior competição, que permitiu a redução dos preços aos passageiros e incremento do uso do modal aéreo (figura 3.2) [20].
À época, observou-se que, ao mesmo tempo em que a expansão da infraestrutura aeroportuária despontava como a necessidade de ação mais importante e imediata existia em paralelo, outras oportunidades de atuação no setor, para que o País pudesse atingir seu "pleno potencial".
Por exemplo, a combinação de investimentos em pátio com aperfeiçoamentos no controle de tráfego aéreo, em certa medida, poderia diminuir o tempo necessário de viagem, permitindo rotas

Nota[1]: Crise no setor aéreo brasileiro, ocorrida em 2006, acarretando no colapso do Sistema de Aviação Civil, que envolveu inúmeros atrasos e cancelamentos de voos, até o início de 2007.

com traçado mais direto, progressão de subida e descida mais eficiente e menores circuitos de espera para aproximação e pouso.

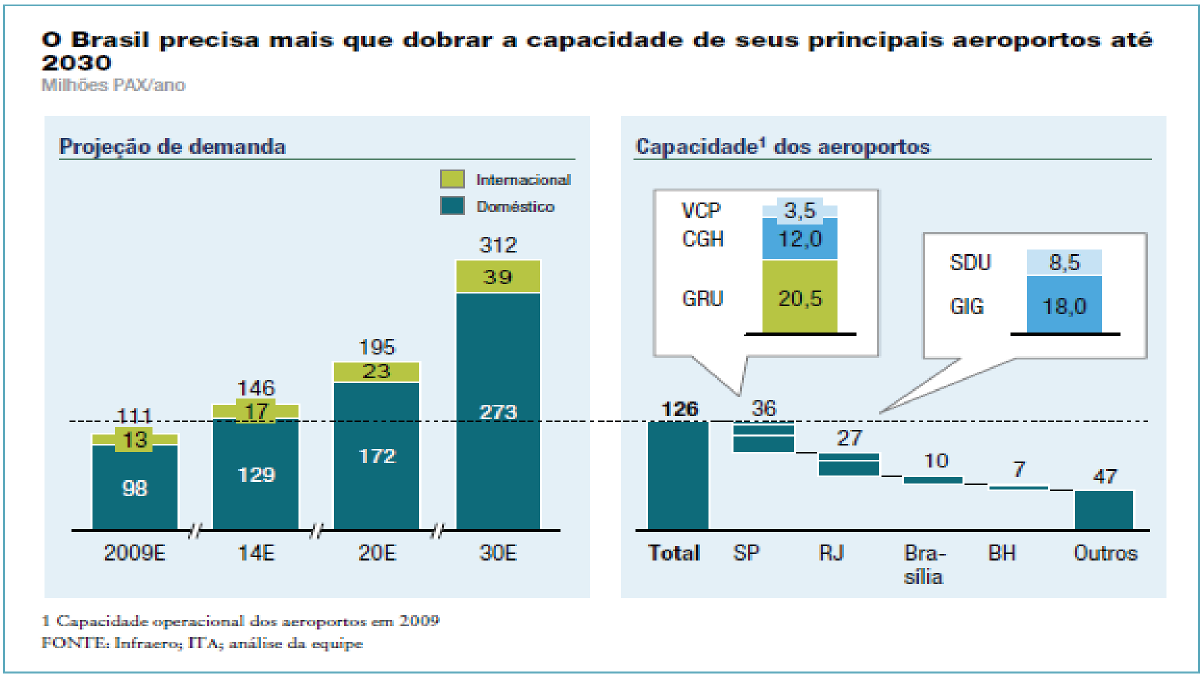

Figura 3.2 – Projeção de Demanda e Capacidade [20]

Menor tempo de voo implica menor consumo de combustível, menores custos operacionais e impacto ambiental positivo. Ressalte-se aqui a evolução tecnológica de aviônica e sistemas por satélites, dos quais o Brasil pode fazer uso de tal forma a viabilizar as ações acima descritas. No que se relacionava à atribuição de papéis e responsabilidades e arquitetura (incluindo hierarquia e sistema de freios e contrapesos), observou-se que a estrutura de governança do setor apresentava pontos passíveis de aprimoramento. Por exemplo, não estava claro, qual entidade era responsável pelo planejamento de longo prazo e coordenação do setor como um todo, incluindo serviços de transporte aéreo, infraestrutura aeroportuária e controle de tráfego aéreo, algo primordial tendo em vista a intensa interação entre esses três componentes.
Atrelada à necessidade aqui apontada, foi criada a Secretaria de Aviação Civil – SAC, por meio da Medida-Provisória n.º 527 de 18.03.2011 e alterada pela Lei nº 12.462 de 04.08.2011, a qual tratou de suas competências, com o propósito de coordenar e supervisionar ações voltadas para o desenvolvimento estratégico do setor da aviação civil e da infraestrutura aeroportuária e aeronáutica no Brasil.
De fato, esta necessidade de coordenação vai além das atividades internas do setor aéreo: ao contrário do Brasil, onde o órgão regulador da navegação aérea está vinculado ao Ministério da Defesa, a quase totalidade dos países analisados em [20] tem órgão regulador ligado ao Ministério dos Transportes ou da Indústria/Desenvolvimento, para facilitar o planejamento integrado da matriz de transportes.
No que concerne à boa prática de alocação das funções de regulação, execução e fiscalização para órgãos distintos, foi identificada uma oportunidade de aperfeiçoamento na atribuição de responsabilidades quanto ao serviço de navegação aérea, uma vez que atualmente essas três funções estão sob a responsabilidade de um mesmo órgão, o DECEA (Departamento de Controle do Espaço Aéreo). Em que pese o acima mencionado é preciso reconhecer que, no intenso desenvolvimento do transporte aéreo no País, muito se deveu à competente gestão da Força Aérea Brasileira, por meio do Ministério da Aeronáutica (1941) e, depois, Comando da Aeronáutica (1999), através de uma política de fomento à atividade que incluiu desde a formação de pilotos e de outros profissionais especializados, com o estímulo a escolas e aeroclubes, pelo Departamento de Aviação Civil; a construção de pistas de pouso, em especial na região Amazônica pela Comissão de Aeroportos da

Amazônia (COMARA); o apoio imediato à sociedade, através do Correio Aéreo Nacional (1941); a formação de uma firme e pujante base de conhecimento, através da criação do Instituto de Tecnológico da Aeronáutica (ITA: 1950) e de outros importantes institutos do Departamento de Ciência e Tecnologia Aeroespaciais (DCTA), em São José dos Campos; que resultaram no surgimento de diversas iniciativas empresariais, com realce para a indústria aeronáutica brasileira, tendo como principal representante, a EMBRAER.
No que tange à atribuição de papéis e responsabilidades, desde o "apagão aéreo" de 2006, houve avanços consideráveis e aprimoramento quanto à governança do setor, com maior aproximação entre os órgãos de coordenação e reguladores da aviação (SAC/ANAC/DECEA), com maior interação entre esses componentes, com ênfase para a regulação técnico-operacional por parte do DECEA e órgãos subordinados.
Como exemplos dos avanços, temos a implementação de rotas com traçado mais direto, minimizando o impacto ambiental; novas circulações aéreas nas Áreas Terminais de São Paulo e Macaé, início da operação segregada de pistas no aeroporto de Guarulhos e, posteriormente, simultâneas; participação no projeto do "SWIM Brasileiro"; coordenação do "Projeto A-CDM GRU"; revisão dos procedimentos de saídas e chegadas em todo o país; revisão dos Programas de Qualidade nos Serviços de Tráfego Aéreo; fortalecimento do Centro de Gerenciamento da Navegação Aérea – CGNA, com foco na gestão colaborativa (coordenação e decisão das medidas de gerenciamento de fluxo do tráfego aéreo); revisão dos Planos de Zona de Proteção de Aeródromos; dentre outros.
Quanto à regulação econômica, revisão das Tarifas de Navegação Aérea; regulamentação dos serviços nacionais de tráfego aéreo e aconselhamento econômico de políticas para o governo, incluindo estatísticas e realização de pesquisas; participação no Comitê Técnico de Navegação Aérea Civil (CTNAV), recém implantado e inserido na COMISSÃO NACIONAL DE AUTORIDADES AEROPORTUÁRIAS (CONAERO) - com a participação da SAC, ANAC, DECEA e Infraero.

4. CONCLUSÃO

Diante deste cenário, observa-se hoje, que a estrutura de governança do setor ainda apresenta pontos passíveis de aprimoramento, tendo em vista que a mesma se faz, quase que em sua totalidade, por meio de Diretrizes (DCA), Instruções (ICA), Portarias Governamentais, Resoluções, dentre outras similares. Em um mercado potencialmente competitivo, como o da aviação, é preciso que se estabeleçam condições de monitoramento do mercado com a constante revisão das políticas públicas, como parte integrante de um projeto de governo e, ao mesmo tempo, atender aos anseios da sociedade, por meio de audiências públicas, esclarecimentos e análises de impacto regulatório (AIR), à população de uma maneira geral. Como exemplo, temos o Reino Unido, onde o processo de avaliações de impacto divide-se em seis estágios: desenvolvimento, opções, consulta pública, proposta final, implementação e revisão.
Assim, considerando-se que a sociedade é afetada pelas intervenções governamentais, é desejável que a mesma tenha amplo acesso ao processo regulatório, participando ativamente da formulação de políticas. Importa também que sejam claros os critérios que fundamentaram determinada regulação, e explicitados quais os seus efeitos esperados e quais os grupos serão mais impactados.
Com isto, a aplicação de uma política de aperfeiçoamento do sistema regulatório é acompanhada, na maioria dos casos, pela adoção da AIR, percebida como o principal instrumento no bojo deste processo [21].
Pode-se, dessa maneira, caracterizar o momento atual como o de busca por instrumentos que auxiliem no aperfeiçoamento do sistema regulatório brasileiro. Estes instrumentos devem permitir o aprimoramento das escolhas regulatórias, com o desenvolvimento de um sistema adequado para a implantação e a aplicação da AIR e de uma metodologia de consulta pública que assegure a efetiva participação social no processo regulatório.
No que tange à regulação, execução e fiscalização do espaço aéreo brasileiro, identifica-se aqui uma oportunidade de aperfeiçoamento na atribuição de responsabilidades quanto à regulação da navegação aérea no País, uma vez que, atualmente, essas três funções estão a cargo de um mesmo órgão governamental e militar, o Departamento de Controle do Espaço Aéreo - DECEA. A concentração dessas três atividades em um mesmo órgão não é a melhor prática de governança, pois em se tratando de órgãos componentes da mesma estrutura, e com mesma subordinação, há risco de interferência e conflito na execução das atividades de regulação, fiscalização e execução. Faz-se necessária,

discussão mais ampla do modelo regulatório da navegação aérea existente no País, principalmente no que se refere à essa concentração. Atualmente, está no Congresso Nacional Brasileiro, Medida-Provisória (MP), com a proposta de constituição de uma futura empresa de navegação aérea civil, vinculada ao Ministério da Defesa, denominada NAV Brasil Serviços de Navegação Aérea S.A., de maneira a descentralizar a execução do serviço de navegação aérea, com dedicação exclusiva à atividade. Espera-se, que as ações aqui citadas colaborem na transformação para um modelo a ser considerado como ideal. No caso de uma empresa dedicada exclusivamente à prestação do serviço de navegação aérea, tal solução, atenderia também, ao que recomenda a ICAO, através de seu "Doc 9161" (*Manual on Air Navigation Services Economics*), item 2.14, que apresenta a instituição de entidade governamental autônoma com a finalidade de explorar serviços de navegação aérea, como alternativa que tem proporcionado, mundo afora, as seguintes vantagens: assegura que as receitas geradas pela utilização dos serviços e instalações destinadas a apoiar à navegação aérea sejam transparentemente reinvestidas na manutenção e no desenvolvimento das respectivas facilidades; assegura que os usuários contribuam diretamente para a manutenção e o desenvolvimento dos serviços e instalações por si utilizados (princípio do utilizador-pagador); reduz os encargos financeiros sobre os governos; incentiva o crescimento de uma cultura empresarial e a melhoria da qualidade dos serviços; permite o acesso da entidade aos mercados de capitais privados; e estabelece uma clara separação entre a organização de Estado responsável pela regulação da atividade em relação à organização responsável pela prestação dos serviços. No caso da impossibilidade de criação da empresa NAV Brasil, a Empresa Brasileira de Infraestrutura Aeroportuária – Infraero poderia ser utilizada em substituição daquela, desde que adequado seu modelo de governança, pois, esta já presta o serviço de navegação aérea com 61 (sessenta e uma) unidades no país, porém, em seu portfolio, há também a administração de aeroportos.
Desta forma, os seguintes benefícios poderão ser alcançados:

a) Maior nível de transparência, através da publicação de balanços com indicadores operacionais e financeiros, atuação de Conselho de Administração e adoção de regras de governança;

b) Melhor capacidade de gestão de incentivos, através do estabelecimento de um sistema de cargos e salários mais próximo da governança existente na atividade, programas de capacitação, maior facilidade para aplicação dos recursos destinados ao sistema e da definição clara de metas individuais e coletivas;

c) Estrutura própria, conferindo maior importância à atividade, através da adoção de presidência e diretoria dedicadas especificamente a essa função, com receitas próprias e responsabilidade pela geração de resultados.

Assim, considerando-se que a sociedade é afetada pelas intervenções governamentais, é desejável que ela tenha amplo acesso ao processo regulatório, participando ativamente da formulação de políticas. É importante que sejam claros os critérios que fundamentaram determinada regulação, e explicitados quais os seus efeitos esperados e quais os grupos serão mais impactados e que com isso, seja possível aperfeiçoar as decisões regulatórias, determinando como componentes principais do processo de formulação de políticas a participação social, a transparência, a prestação de contas, o respeito ao devido processo legal, e o modo de pensar econômico, ponderando custos e benefícios.

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Characterizing air traffic performance in the Brazilian airspace via trajectory data analytics

Mayara Condé Rocha Murça - mayara@ita.br
Aeronautics Institute of Technology
Marcelo Xavier Guterres - m.guterres@gmail.com
Aeronautics Institute of Technology
Joao Basilio Tarelho Szenczuk - jb_pva@hotmail.com
Aeronautics Institute of Technology
McWillian de Oliveira - mcwillianoliveira@gmail.com
Aeronautics Institute of Technology
Wallace Silva Santanna Souza - wallace2silva2souza@gmail.com
Aeronautics Institute of Technology

Abstract
This paper presents a data-driven approach for multi-scale characterization of air traffic performance from aircraft tracking data recorded by surveillance systems.
A trajectory clustering analysis is first performed to automatically identify spatial traffic patterns at both the terminal and the en route airspace for major origin-destination pairs in the Brazilian air transportation system. Based on the learned airspace structure, actual flight trajectories are projected onto reference nominal trajectories in space and time in order to quantify the efficiency of the traffic flows at different flight phases.
An interactive data analytics tool is created to output performance statistics and air traffic visualizations. The results allow for cross-route comparisons of air traffic flow efficiency as well as for the identification of potential causal factors of trajectory deviations from nominal routes.
As a systematic approach for high-fidelity characterization of the air traffic behavior and airspace monitoring, the trajectory data analytics framework is envisioned to assist airspace design decisions and to provide the basis for developing predictive tools in support of traffic flow management.

Keywords
air traffic management; air traffic performance; trajectory clustering; data analytics

Characterizing air traffic performance in the Brazilian airspace via trajectory data analytics

1 Introduction

As a key element of air transportation, Air Traffic Management (ATM) is the system of systems in charge of promoting a safe and orderly air traffic flow. Global air traffic has doubled in size once every 15 years since 1977 and is expected to continue to do so. The International Air Transport Association (IATA) forecasts that the air traffic demand will double by 2035, reaching 7.2 billion passengers globally (IATA, 2017). As aviation has evolved, technological and operational improvements for modernization of the ATM system have become necessary to enable the continued growth in air traffic while meeting increasingly stringent targets on efficiency, safety and environmental impact.

Besides the deployment of new technologies and operational procedures, efficient use of operational data is also key to improve ATM and increase the performance of air traffic operations. Every minute, a high volume of data is generated from the flight planning phase to the execution of the flight operation and will become increasingly available and accessible as the digital transformation of the ATM system takes place. Exploiting this big aviation data with advanced analytics techniques is a promising way for better assessing and predicting air traffic operational performance and developing new decision support tools for ATM.

Aircraft trajectory data is an example of operational data that has become increasingly accessible with new surveillance technologies. With Automatic Dependent Surveillance-Broadcast (ADS-B), high-fidelity aircraft trajectory data is recorded and made available to the general public through online flight tracking services such as FlightRadar24 and FlightAware. Detailed analysis of flight trajectory data using advanced analytics techniques provides an opportunity for quantitatively assessing the air traffic performance at different dimensions and better understanding how this performance is affected by the various operational factors driving ATM decisions. From this knowledge, sources of inefficiencies can be addressed and new models and tools can be developed to better predict and control the performance of the system.

This paper presents a data-driven approach for multi-scale characterization of air traffic performance based on aircraft tracking data recorded by surveillance systems. We use unsupervised learning and apply a flight trajectory clustering framework to identify traffic patterns at both the terminal and the en route airspace for major origin-destination (OD) pairs in the Brazilian air transportation system. Based on the airspace structure learned, we develop metrics to describe the spatial and temporal efficiency of the traffic flows at different flight phases. The output allows for cross-route comparisons of air traffic flow performance in the Brazilian network and for the development of a statistical model to investigate causal factors for inefficiencies observed in the system. Finally, the paper also presents an interactive prototype tool for air traffic performance analysis created upon the trajectory data analytics framework.

2 Literature review

Trajectory data mining is a topic of growing interest across a variety of domains. A number of recent studies have taken advantage of the increasing availability of tracking datasets provided by various position sensing technologies to gain insights about the behavior of moving targets such as vehicles, people, animals etc (Lee *et al.*, 2007; Kim and Mahmassani, 2015; Antonini and Thiran, 2016). In the aviation domain, several studies have applied advanced analytics methods to exploit flight tracking data in order to characterize the air traffic behavior towards supporting performance assessment, airspace monitoring, airspace design and traffic flow management.

Eckstein (2009) developed algorithms for flight track filtering, segment identification and decomposition to evaluate the conformance of flight trajectories against standard procedures in the terminal airspace. Gariel *et al.* (2011) also developed a framework for monitoring aircraft behavior in the terminal airspace. For this, they used a density-based clustering algorithm to learn typical trajectory patterns in the terminal area and assess the conformance of flight trajectories against the as-flown route structure learned. Similarly, Rehm (2010) and Enriquez (2013) performed flight trajectory clustering to identify spatial traffic patterns and abnormal trajectories to/from a specific airport. Murça *et al.* (2018) applied clustering methods at spatial and temporal dimensions to learn both trajectory patterns and traffic flow patterns in super dense and complex metroplex airspace towards characterizing the dynamics of air traffic operations and quantitatively assessing metroplex efficiency, capacity and predictability.

Another set of studies has focused on characterizing en route operations through flight trajectory data analytics. Sabhnani *et al.* (2010) developed a greedy grid-based trajectory clustering to learn standard flows and critical points at en route sectors. Their goal was to identify sectors with highly structured traffic patterns that could potentially be redesigned. Arneson *et al.* (2017) identified dominant routing structures between the Forth Worth Center and New York Center through trajectory clustering in order to assess the impacts of convective weather on flow rates. Marzuoli *et al.* (2014) and Bombelli *et al.* (2017) also clustered en route trajectories in order to identify common routing structures in the U.S. airspace. Their goal was to learn the actual air traffic route network and develop higher-fidelity models for traffic flow management optimization. Air traffic route networks learned from flight trajectory data for the U.S. and China were compared in the work of Ren and Li (2018), revealing very distinctive network structures and airspace utilization patterns. Liu *et al.* (2017) evaluated the horizontal efficiency of en route flows learned with flight trajectory clustering for the U.S. airspace and developed a statistical model to estimate the influence of different factors on trajectory inefficiency. They found that convective weather was the most important causal factor for en route inefficiencies. A similar analysis was performed by Marcos *et al.* (2018) for the Bordeaux Control Center.

In all the studies described above, the scope of the analysis is limited to a single flight phase (terminal or en route airspace) and air traffic behavior and performance dependencies between these different scales are not explored. By contrast, in this paper, we look at the entire flight trajectory to characterize and compare air traffic flow performance at different scales.

3 Methodology

3.1 Data description

This work leveraged flight trajectory data to characterize air traffic performance in the Brazilian airspace. The raw dataset contains flight tracks from 44 days of the last trimester of 2017 obtained through the FlightRadar24 flight tracking service (FlightRadar24, 2019). FlightRadar24 is one of the various online flight tracking services made available after the introduction of new surveillance technologies in ATM, such as Automatic Dependent Surveillance - Broadcast (ADS-B). FlightRadar24 relies on a huge network of crowdsourced ADS-B receivers around the world that pick up flight information (flight ID, aircraft position etc) broadcasted by the aircraft's ADS-B transponder and send this information to their servers to provide open-source live flight tracking. The raw dataset fields include flight ID, timestamp, latitude, longitude, altitude, speed, origin airport, destination airport and aircraft type.

In order to develop the causal analysis of traffic flow efficiency, two complementary datasets were used. Historical Meteorological Terminal Aviation Routine Weather Report (METAR) data was used to characterize the weather conditions for the time period analyzed. Besides, a dataset of historical traffic management initiatives taken by the Brazilian Air Navigation Management Center (CGNA) for the same period was also used.

3.2 Data-driven approach for air traffic performance characterization

The data-driven approach for air traffic performance characterization is based on three steps, as summarized in Fig. 1. First, data pre-processing is performed to clean, filter and structure the flight tracking dataset. A trajectory clustering framework is then applied to identify air traffic patterns at the terminal airspace and the en route airspace for the OD pairs of interest. Once clusters of flight trajectories are identified, a nominal route is calculated for each cluster. Finally, actual flight trajectories are compared with the nominal routes in order to quantify the efficiency of the traffic flows at both spatial and temporal dimensions. A detailed description of each step is provided next.

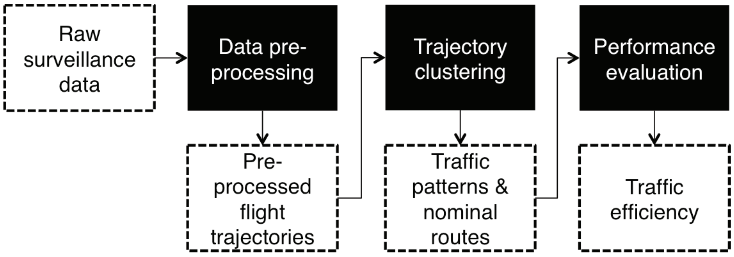

Fig. 1. Schematic overview of the data-driven approach for air traffic performance characterization. Source: Authors.

3.2.1 Data pre-processing

The data-preprocessing step consisted of cleaning, filtering and structuring the raw flight tracking dataset. Flights associated with the OD pairs of interest and with complete trajectory information from origin to destination were filtered. For the purpose of our analysis, we considered that a trajectory was complete if the first and the last tracking observations were at most 3 nm from the origin and destination airports. Flight trajectories were then segmented according to the different flight phases. To extract the terminal area departure phase, we considered the trajectory information between the origin airport and the terminal area boundary, which was modeled as a circle of 40 nm radius with its center at the origin airport. Similarly, a circle of 40 nm radius with its center at the destination airport was used to extract the portion of the trajectory associated with the terminal area arrival phase. The remaining portion of the trajectory, outside the terminal area circles, composed the en route phase.

3.2.2 Trajectory clustering

A trajectory clustering framework is developed to identify air traffic patterns at the terminal airspace and the en route airspace for the OD pairs of interest. Clustering refers to the unsupervised machine learning process of identifying groups of observations that have similar characteristics in a dataset without prior knowledge about the existence of these groups or about the distribution of observations among them. Clustering flight trajectories then refers to the process of identifying groups of trajectories that are quite similar to one another at the spatial dimension and that define a traffic pattern, without any prior knowledge about the structure of the airspace under analysis.

The trajectory clustering process is performed with the Density-Based Spatial Clustering of Applications with Noise (DBSCAN) algorithm (Ester *et al.*, 1996). This density-based clustering algorithm is chosen for some reasons. First, DBSCAN can automatically handle noise observations, i.e., it enables the identification of the core trajectory patterns in the presence of abnormal trajectories that can occur for a variety of reasons. Moreover, DBSCAN can handle non-convex clusters and does not require the user to predetermine the number of clusters. Finally, DBSCAN has been the primary choice of algorithm for clustering flight trajectory datasets in previous works (Gariel *et al.*, 2011; Liu *et al.*, 2017; Murça *et al.*, 2018). Fig. 2 illustrates how the DBSCAN algorithm works with a toy 2D dataset. A cluster is formed when an observation has at least *m* observations in its neighborhood defined by ε, with *m* and ε set by the user.

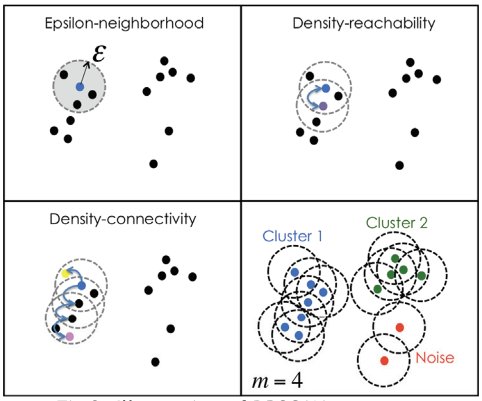

Fig 2. Illustration of DBSCAN concepts.
Source: Murça (2018).

Prior to applying the clustering algorithm, a data resampling and scaling process is performed to represent the data appropriately. The data resampling ensures that each trajectory is represented with a high-dimensional vector of a fixed dimension, which indicates the 2D spatial position of the aircraft throughout the flight duration:

$$F_i = (x_{i1}, y_{i1}, x_{i2}, y_{i2}, \ldots, x_{in}, y_{in})$$

The data scaling process ensures that the trajectory vectors F_i are standardized so that each individual dimension is centered to have mean 0 and scaled to have standard deviation 1, allowing each feature of the trajectory vector to contribute equally to the distance measure.

After the clusters of trajectories are identified, a nominal route is determined for each cluster by solving a 1-median problem, in other words, a representative trajectory for each cluster is obtained by calculating the "center" of the cluster. For each nominal route associated with a cluster, an unimpeded flight time is calculated as the 10th percentile of the distribution of flight times observed for the members of the cluster. The nominal routes are defined as the reference ideal trajectories with which actual trajectories are compared in order to characterize performance.

3.2.3 Performance evaluation

In the final step, the nominal routes identified are used to calculate performance metrics describing the efficiency of the traffic flows at both spatial and temporal dimensions. Two metrics are defined: the Horizontal Traffic Efficiency (HTE) and the Temporal Traffic Efficiency (TTE).

The HTE for the traffic flows observed during a given time period *T* is defined as follows:

$$HTE_T = \frac{\sum_{i;t(i)\in T} s_i}{\sum_{i;t(i)\in T} S_i}$$

where S_i is the actual horizontal flight distance associated with trajectory i and s_i is the minimum between the actual horizontal flight distance associated with trajectory i and the horizontal flight distance associated with the reference nominal route.

Similarly, the TTE for the traffic flows observed during a given time period T is defined as follows:

$$TTE_T = \frac{\sum_{i;t(i)\in T} l_i}{\sum_{i;t(i)\in T} L_i}$$

where L_i is the actual flight time associated with trajectory i and l_i is the minimum between the actual flight time associated with trajectory i and the unimpeded flight time associated with the reference nominal route.

It can be easily shown that $HTE_T \in [0,1]$ and $TTE_T \in [0,1]$. The higher is the metric, the higher is the efficiency of the traffic flows.

3.3 Case study

The focus of this study is the Brazilian airspace. The data-driven approach for air traffic performance characterization is applied to the top-20 OD pairs (in terms of number of movements) in the Brazilian domestic network. These OD pairs are depicted in Fig 3. They are mainly short-haul routes serving the largest metropolitan regions in the country. Table 1 shows their number of movements in 2018, according to the Active Regular Flight Report (VRA) of the National Civil Aviation Agency (ANAC, 2018). Sao Paulo/Congonhas (CGH) – Rio de Janeiro/Santos Dumont (SDU) stands out with the highest (and well above average) number of movements. It is often in the top-5 busiest domestic routes in the world.

Table 1. Number of movements for the top-20 OD pairs in Brazil in 2018.
Source: Authors.

Rank	OD pair		Number of movements
1	Sao Paulo/Congonhas - Rio de Janeiro/Santos Dumont	CGH-SDU	19278
2	Rio de Janeiro/Santos Dumont - Sao Paulo/Congonhas	SDU-CGH	19167
3	Sao Paulo/Guarulhos - Porto Alegre/Salgado Filho	GRU-POA	8407
4	Porto Alegre/Salgado Filho - Sao Paulo/Guarulhos	POA-GRU	8377
5	Sao Paulo/Congonhas - Brasilia//President Juscelino Kubitschek	CGH-BSB	8268
6	Brasilia/President Juscelino Kubitschek - Sao Paulo/Congonhas	BSB-CGH	8229
7	Belo Horizonte/Confins - Sao Paulo/Congonhas	CNF-CGH	7531
8	Sao Paulo/Congonhas - Belo Horizonte/Confins	CGH-CNF	7490
9	Sao Paulo/Congonhas – Porto Alegre/Salgado Filho	CGH-POA	6957
10	Porto Alegre/Salgado Filho - Sao Paulo/Congonhas	POA-CGH	6944
11	Sao Paulo/Guarulhos - Belo Horizonte/Confins	GRU-CNF	6587
12	Belo Horizonte/Confins - Sao Paulo/Guarulhos	CNF-GRU	6584
13	Curitiba/Afonso Pena - Sao Paulo/Guarulhos	CWB-GRU	6540
14	Sao Paulo/Guarulhos - Curitiba/Afonso Pena	GRU-CWB	6500
15	Sao Paulo/Guarulhos - Salvador/Deputado Luis Eduardo Magalhaes	GRU-SSA	6343
16	Salvador/Deputado Luis Eduardo Magalhaes - Sao Paulo/Guarulhos	SSA-GRU	6343
17	Sao Paulo/Congonhas - Curitiba/Afonso Pena	CGH-CWB	6308
18	Curitiba/Afonso Pena - Sao Paulo/Congonhas	CWB-CGH	6292
19	Recife/Guararapes - Sao Paulo/Guarulhos	REC-GRU	6182
20	Sao Paulo/Guarulhos - Recife/Guararapes	GRU-REC	6178

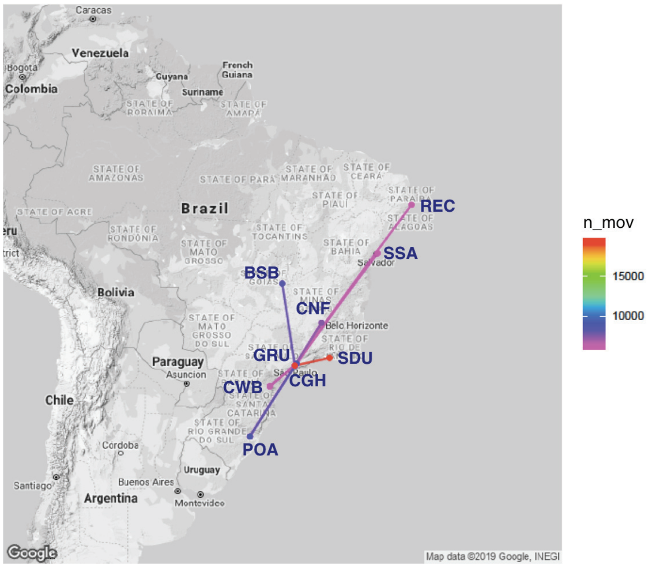

Fig 3. Top-20 OD pairs in Brazil in 2018.
Source: Authors.

4 Results and discussion

4.1 Identification of air traffic patterns

The trajectory clustering framework was applied to the top-20 OD pairs listed in Table 1. The clustering process was performed separately for each OD pair and for each flight phase. To exemplify, this section shows the clustering results for the SSA-GRU pair. In Fig. 4, clusters of trajectories identified are represented with different colors and trajectories classified as noise are represented in grey. The nominal routes associated with the clusters identified for the SSA-GRU pair are shown in Fig. 5.

For the terminal area departure, two clusters were identified for flights departing from SSA to GRU. One cluster dominates, concentrating 88% of the trajectories. This cluster represents the traffic pattern for flights departing from runway 10 to the south. Fig. 6 shows the boxplot of flight times for trajectories within the different clusters as well as for noise trajectories. The median flight time for the most frequently traffic pattern is approximately 8.5 minutes.

For the en route phase, three different clusters were identified. The median flight time for the most frequently used route is approximately 100 minutes. Fig. 6 shows that noise trajectories generally exhibit increased flight times. It is also noticeable the higher dispersion in the distribution of flight times for noise trajectories.

Finally, for the terminal area arrival phase, six clusters were identified for flights arriving at GRU from SSA. While the departure traffic is concentrated in one major flow, the arrival traffic is distributed within different arrival gates. The dominant cluster captures 45% of the trajectories. This cluster represents the traffic pattern for flights arriving from the northeast gate and landing at runway 09R. The median flight time for this traffic pattern is approximately 15 minutes. Fig. 6 shows that the difference between the median flight times of different arrival traffic patterns can be as large as 10 minutes.

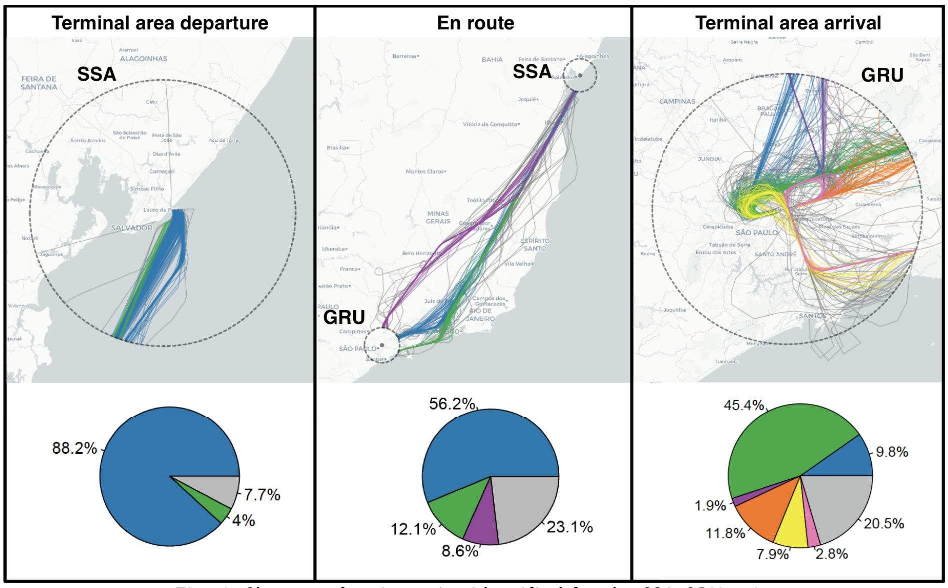

Fig. 4. Clusters of trajectories identified for the SSA-GRU pair.
Source: Authors.

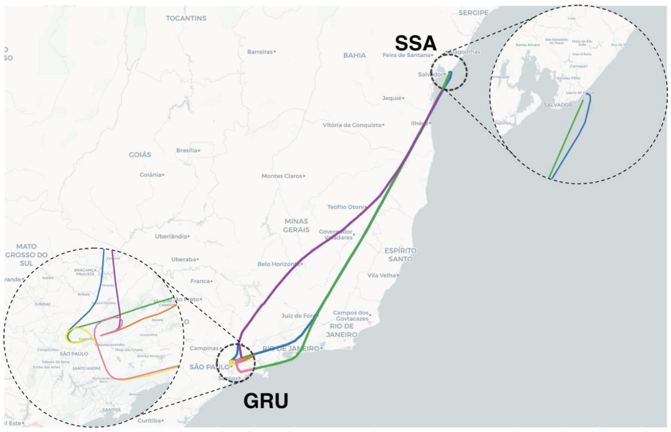

Fig. 5. Nominal routes associated with the clusters of trajectories identified for the SSA-GRU pair.
Source: Authors.

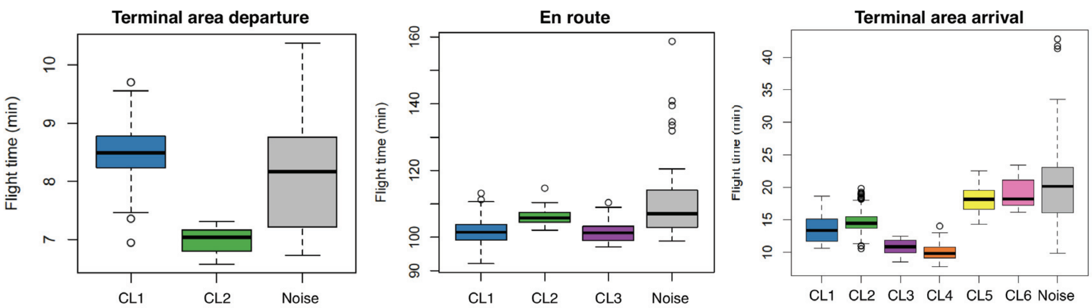

Fig. 6. Distribution of flight times for each terminal area and en route cluster identified for the SSA-GRU pair.
Source: Authors.

4.2 Assessment of traffic flow efficiency

The horizontal and temporal traffic flow efficiencies were calculated on an hourly basis for the terminal and en route traffic patterns associated with each OD pair. Fig. 7 and Fig. 8 show the boxplot of the HTE and TTE metrics by flight phase for the top-20 OD pairs analyzed in this work.

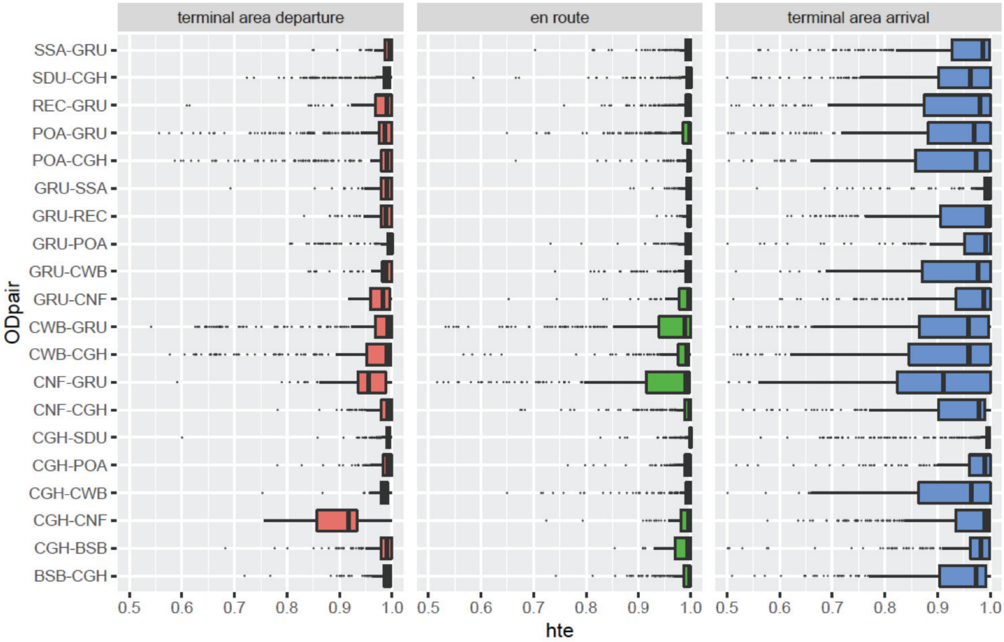

Fig. 7. Horizontal traffic efficiency (HTE) by flight phase for the top-20 OD pairs in Brazil.
Source: Authors.

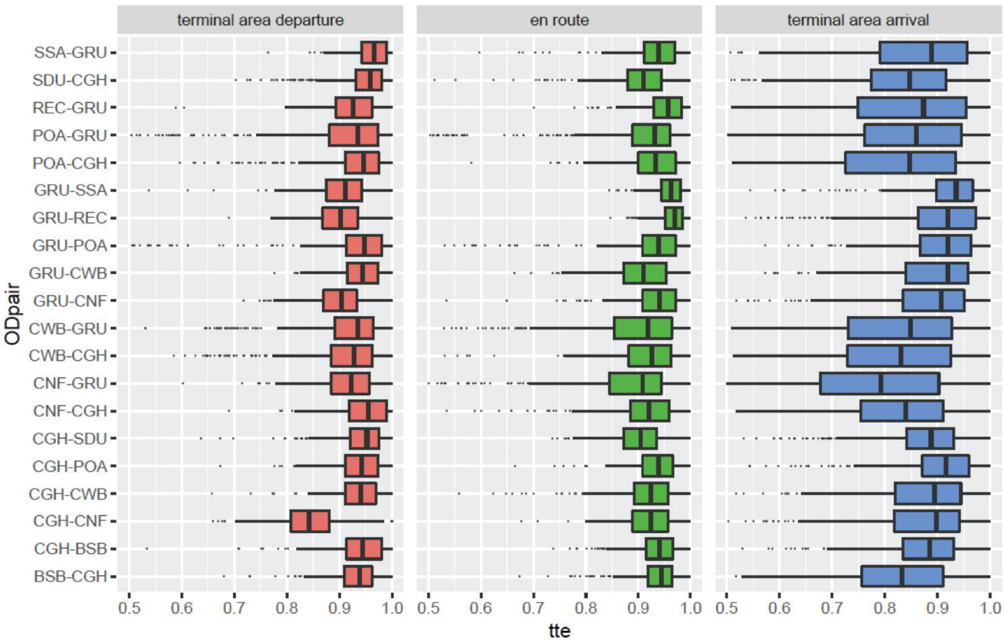

Fig. 8. Temporal traffic efficiency (TTE) by flight phase for the top-20 OD pairs in Brazil.
Source: Authors.

Overall, it is observed that the terminal area arrival phase presents the lowest horizontal and temporal efficiencies on average. It also shows the highest variability in traffic flow efficiency, suggesting that terminal area arrival trajectories are less predictable. The results can be attributed to the complexity of terminal area arrival operations, especially in busy metroplex airspace. Indeed, arrival flows into the Sao Paulo metroplex via GRU and CGH (the two busiest airports in the country) consistently show lower efficiency values. Particularly, the CNF-GRU traffic exhibits the lowest horizontal and temporal traffic efficiencies among all arrival flows.

For departure and en route flows, the median HTE and TTE are generally higher. Departure and en route operations also show lower variability in traffic efficiency. Yet, a couple of traffic flows stand out. A significant part of the CWB-GRU and CNF-GRU traffic appears to have degraded horizontal efficiency at the en route phase, indicating that flights for these OD pairs are more likely to be deviated from the nominal routes. For the terminal area departure phase, traffic from CGH to CNF also stands out with lower horizontal and temporal efficiencies.

The results also show that there can be high variability in efficiency across terminal area traffic patterns for one same airport. For instance, flights departing from GRU to CNF, SSA or REC consistently exhibit lower temporal efficiency than flights departing from GRU to POA or CWB.

Finally, although the horizontal and temporal efficiencies tend to be correlated, this is not always true. For example, while the SDU-CGH en route traffic is among the most efficient at the horizontal efficiency perspective, its median TTE is one of the lowest. This might suggest that delays on this route are more likely to be absorbed with speed control than route changes.

4.3 Causal analysis of traffic flow efficiency

The results presented in Section 4.2 emphasize the variability in traffic flow efficiency. In order to investigate the mechanisms behind the performance observed, we developed a linear regression model for the traffic efficiency. We focus on the en route traffic inbound Sao Paulo airports (CGH and GRU). The same analysis can be done for the other flight phases and it is left for future work. In the linear regression model, the dependent variable is the en route horizontal traffic efficiency for hour *t* and route *k*:

$$HTE_{kt} = \beta_1\, DEMAND_{kt} + \beta_2\, LIFR_{kt} + \beta_3\, WX_{kt} + \beta_4\, GUSTS_{kt} + \beta_5\, MIT_{kt} + \beta_6\, NC_{kt} + \beta_7\, k_t + u_{kt}$$

The independent variables account for factors that are expected to affect the performance of the traffic flows, such as demand, meteorology, traffic flow management restrictions and route fixed effects. Regressors are discussed below.

- $DEMAND_{kt}$ is the number of flights delivered to the terminal area of the destination airport of route *k* in hour *t*. Since demand increases traffic complexity, we expect this variable to have a negative impact on efficiency.
- $LIFR_{kt}$ is a dummy variable that indicates Low Instrument Flight Rules (LIFR) meteorological conditions. It is 1 if the visibility is less than 1 nm or if the ceiling is lower than 500 ft at the destination airport of route *k* and hour *t*. In LIFR meteorological conditions, ATC may adopt higher separation minimums, decreasing capacity. Thus, this variable is expected to have negative sign.
- WX_{kt} is a dummy variable that indicates the presence of convective weather. It is 1 if rain (RA), thunderstorm (TS), or cumulonimbus clouds (CB) were present at the surrounding airspace of the destination airport of route *k* and hour *t*. This variable is expected to have negative sign, as tactical rerouting to avoid convective weather can induce to longer flight paths.
- $GUSTS_{kt}$ is a dummy variable that indicates the presence of wind gusts at the destination airport of route *k* and hour *t*. Strong winds may severely degrade airport capacity and make the sequencing of aircraft more complex. Therefore, this variable is expected to negatively impact the efficiency of the traffic flows.
- MIT_{kt} is a dummy variable that indicates the occurrence of miles-in-trail (MIT) restrictions along route *k* and hour *t*. MIT restrictions are the most common traffic flow management strategy used in the Brazilian airspace to regulate the traffic and handle demand-capacity imbalances. It involves increasing the separation between successive aircraft at a

specified waypoint. Since vectoring or en route speed reductions may be used by ATC to comply with MIT restrictions, this variable is also expected to have a negative sign.

- NC_{kt} is a dummy variable that indicates that the majority of the flights in hour t and route k were not conforming to any nominal route.
- k_t are dummy variables for each OD pair. The baseline case is the SDU-CGH pair.

Table 2 presents the estimation results for the linear regression model.

Table 2. Estimation results for the linear regression model of en route horizontal traffic efficiency. Source: Authors.

Variable	β
DEMAND	-0.0006***
LIFR	-0.0051**
WX	-0.0153***
GUSTS	-0.0004
MIT	-0.0118***
NC	-0.0667***
SSA_GRU	0.0042
REC_GRU	0.0129***
CWB_GRU	-0.0345***
POA_GRU	0.0025
CNF_GRU	-0.0434***
BSB_CGH	0.0124***
CWB_CGH	-0.0131***
POA_CGH	0.0115***
CNF_CGH	0.0057**
Adjusted R^2	0.3765
RMSE	0.0461
Number of observations	4549
* p<0.10, ** p<0.05, *** p<0.01	

As reported in Table 2, most of the coefficients in the linear regression model are significant and their signs generally match the theoretical expectations. DEMAND is statistically significant at 1% and negatively impacts efficiency. Among the weather variables, LIFR and WX are statistically significant with negative sign, indicating that convective weather, low ceiling and low visibility reduce efficiency. Although showing a negative sign, GUSTS was not found to be statistically significant. The variable MIT is statistically significant and negatively impacts efficiency, indicating that trajectories are deviated from nominal routes due to traffic flow management restrictions. The variable NC is statistically significant at 1% and shows a negative sign, indicating that non-conforming trajectories tend to be longer and less efficient than trajectories that conform to nominal routes. The coefficients of each OD pair fixed effect indicate the difference in performance with respect to the SDU-CGH pair (baseline). The negative and statistically significant coefficients of CWB_GRU, CNF_GRU and CWB_CGH reveal degraded horizontal efficiency for these OD pairs, as also pointed out in Section 4.2.

4.4 Network Efficiency Analysis Tool (NEAT)

The methodology presented in this paper was leveraged to create an interactive prototype tool for air traffic performance analysis. The Network Efficiency Analysis Tool (NEAT) enables the user to select an OD pair and a time period of interest to evaluate the horizontal and temporal traffic flow efficiency. The NEAT outputs histograms of traffic efficiency as well as trajectory visualizations to facilitate the understanding about the behavior of the traffic. As an example, Fig. 9 and Fig. 10 show the NEAT display for two different queries. Fig. 9 shows the efficiency of the en route traffic from CWB to GRU on a clear weather day. Fig. 10 shows the efficiency of the en route traffic from CWB to GRU on a day with inclement weather conditions. The visualization makes the impacts of the weather conditions on the traffic flow efficiency clearly noticeable.

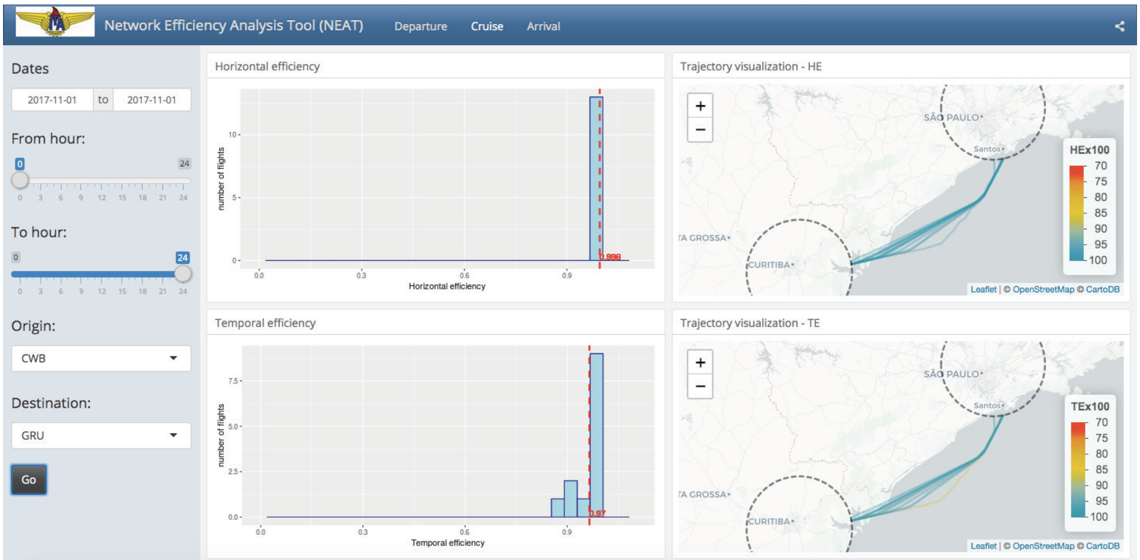

Fig. 9. NEAT display showing the horizontal and temporal traffic flow efficiencies for the CWB-GRU en route traffic on a clear weather day (November 1, 2017).
Source: Authors.

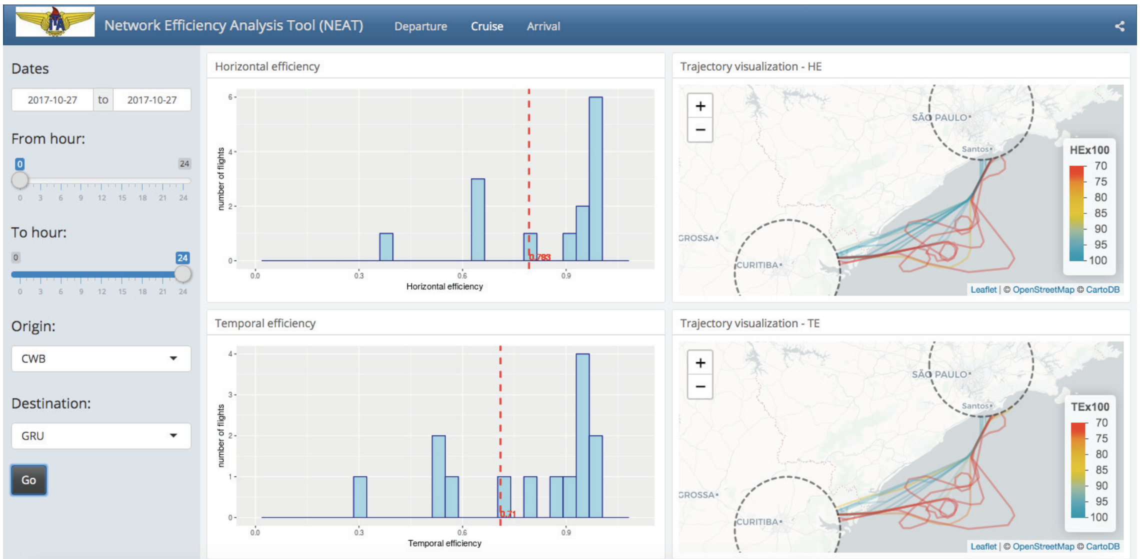

Fig. 10. NEAT display showing the horizontal and temporal traffic flow efficiencies for the CWB-GRU en route traffic on a day with convective weather impacts (October 27, 2017).
Source: Authors.

5 Conclusions

This paper presented a data-driven approach for multi-scale characterization of air traffic performance based on flight tracking data. Trajectory clustering analysis is performed to automatically identify traffic patterns at the terminal and en route airspace for the top-20 OD pairs in the Brazilian air transportation system. Based on the airspace structured learned, nominal routes are computed and used to assess and compare the efficiency of the traffic flows in spatial and temporal dimensions. The results showed significant differences in traffic flow efficiency for the OD pairs and flight phases analyzed. We observed that the terminal area arrival phase is characterized by the lowest horizontal and temporal efficiencies on average and by the highest variability in performance, suggesting that terminal area arrival trajectories are less predictable. Arrival flows into the Sao Paulo metroplex were generally

less efficient. At the en route phase, CWB-GRU and CNF-GRU stood out with a significant portion of the traffic showing degraded horizontal efficiency. Based on the performance results, a statistical model was developed to investigate causal factors for en route inefficiencies. We found that inclement weather conditions such as convective weather, low ceiling and visibility at the destination as well as demand volume and traffic flow management restrictions do have a negative impact on the en route traffic flow efficiency. Finally, we presented a prototype interactive tool for air traffic performance analysis created upon the methodology developed. The Network Efficiency Analysis Tool (NEAT) outputs traffic flow efficiency statistics and trajectory visualizations given an OD pair and time period of interest selected by the user. By providing a systematic approach for high-fidelity characterization of the air traffic behavior and for post-event performance assessment, the methods and tools presented in this paper are envisioned to assist airspace management decisions and to provide the basis for developing predictive tools in support of traffic flow management.

Acknowledgements

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Analysis of weather conditions impact on Airlines on-time performance using a LOGIT probabilistic model

McWillian de Oliveira - mcwillianoliveira@gmail.com
Aeronautics Institute of Technology
Ana Beatriz Rebouças Eufrásio - anabeatrizre@gmail.com
Aeronautics Institute of Technology
Marcelo Xavier Guterres - m.guterras@gmail.com
Aeronautics Institute of Technology
Rogéria de Arantes Gomes - rogeria@ita.br
Aeronautics Institute of Technology
Mayara Condé Rocha Murça - may.crm@gmail.com
Aeronautics Institute of Technology

Abstract
Air transport operations are frequently disturbed by adverse weather conditions. These external factors may affect airlines' on-time performance and flight safety, eventually imposing several operational restrictions.
Moreover, delays and cancellations not only lead to an inefficient utilization of airport systems, but also generate additional costs to airlines and inconveniences to passengers. In this study, we develop a Logit model to estimate delays probabilities, considering airports weather conditions.
We use data of flights on-time performance from Brazilian airlines and hourly meteorological information of Brazilian airports in 2017. We analyze the impact of weather conditions at each flight' destination airport and estimate the arrival delay probability based on this information.
Our investigation of the weather effect on delays could assist flight time scheduling decisions, by improving delay predictions analysis.

Keywords
weather; meteorological; airport; probabilistic

Analysis of weather conditions impact on Airlines' on-time performance using a LOGIT probabilistic model

Introduction

Adverse weather conditions may impact airline and airport operations. The reduced visibility during rainfalls, for instance, can pose a risk to landing and takeoff operations. In general, adverse weather conditions may result in delays and even flight cancellations, leading to higher costs for operators and inconvenience to passengers.

In this context, the objective of this study is to investigate the effect of weather conditions on flight delays, using as a case study the Brazilian domestic market. Thus, we want to correlate the information on flight delays obtained from the Active Regular Flight (VRA) database provided by the National Civil Aviation Agency (ANAC) with the weather reports of the Brazilian airports (METAR). So, this study develops a Logit model to estimate the impact of weather conditions on the likelihood of a delayed arrival.

Literature Review

Aircraft landings can be performed under two flight rules, Visual Flight Rules (VFR) and Instrument Flight Rules (IFR). In both cases, minimum horizontal and vertical (ceiling) visibility parameters are defined. Thus, weather conditions are identified as determining factors in air operations.

Many different approaches focusing on the influence of weather conditions on flight operations can be identified in literature. Pitfield and Halpern [1] evaluate the weather impact on runway capacity of aerodromes through Monte Carlo simulation.

Markovic et al. [2] evaluate the impact of different meteorological variables (wind, temperature, visibility, ceiling and snow) on the on time performance of takeoffs and landings at Frankfurt International Airport (FRA) through a hybrid regression model (linear and logarithmic). Although the study does not present absolute values in the relationship between weather conditions and on time performance, the results show a strong relationship between these variables. Wesonga et al. [3] analyze ground and airborne delays. The model estimates the conditional probability of delays in takeoffs and landings.

Pérez-Rodríguez et al. [4] estimate the daily odds of arrival delays at various US airports, that are categorized by demand. The study presents an analysis from three LOGIT models (asymmetric bayesian, frequency logit and symmetric bayesian).

Santos et al. [5] correlate accumulated rainfall rates with flight delay and cancellation data from 2011 to 2015 of Guarulhos Airport (GRU). With this model, the possibility of delays and cancellations caused by precipitation from 2016 to 2020 is projected. Using the Spearman correlation and correcting the trend through the bias correction by the power transformation method, the authors create a variable relating precipitation with delays and cancellations.

Borsky and Unterberger [6] assess the impact of weather on delayed takeoffs at the 10 busiest airports in the US with a sample of over 2 million operations. The study uses an econometric model applied in two distinct scenarios: (i) recent weather events and (ii) continuous weather events. The results indicate a significant weather impact on takeoff delays. On average, adverse weather increases delay by 23 minutes, but the effect depends on the weather pattern and intensity of meteorological events.

Methodology

Data

In this study, flight scheduling data were combined with airport weather data. Flight schedule data were obtained from the Active Regular Flight (VRA) database, made publicly available by ANAC. The VRA provides schedule and delay information for domestic and international scheduled flights. In addition, information about the origin and destination aerodrome, the flight number and the airline operating it is provided. In case of delays and cancellations, the justifications informed by the companies are presented. Data are published monthly by ANAC since January 2000. We exclude from analysis international and cancelled flights.

The Meteorological information was obtained through the climatological data repository, available in the database of the Aeronautic Command Meteorology Network (REDEMET). In this repository, Meteorological Aerodrome Reports (METARs) were obtained. METAR is a coded report, with data on wind direction and intensity, visibility, atmospheric pressure, cloud base height, temperature, and significant weather (e.g. rain and hail). Such reports are published hourly for each aerodrome, and special reports (SPECI) are also available in the event of sudden changes in weather conditions at times not coinciding with those of METAR. For this study, METAR reports and eventual SPECI reports from 79 Brazilian aerodromes in 2017 (detailed in the Appendix) were collected. Each domestic flight recorded in 2017 was associated with the last METAR (or SPECI) of the destination airport, published until the scheduled arrival date and time. Flights with delays longer than 5 hours were excluded from the sample in order to avoid possible outliers. This procedure yields a database of 693,126 observations, including flight information (flight number, airline, origin/destination airports and estimated/real arrival/departure times) and weather conditions at the destination airport, obtained from the corresponding METAR (visibility, ceiling, gust and present weather).

Statistical Model

Equation (1) presents the logit model adopted to estimate the probability of delayed arrivals:

$$p(delayed\_arrival = 1) = G(X\beta) = \frac{exp(X\beta)}{1 + exp(X\beta)} \quad (1)$$

$$X\beta = \beta_0 + \beta_1 delayed\_departure + \beta_2 visibility + \beta_3 ceiling + \beta_4 wind\_gust + \beta_5 rain \quad (2)$$

Where *delayed_arrival* is a binary variable (delayed = 1). A flight is considered delayed when the actual arrival time exceeds the planned arrival time by more than 15 minutes. The probability of a delayed arrival *p(arrival delay = 1)* is estimated through an accumulated logistic distribution G (Xβ), where X are the independent variables, detailed in equation (2), and β represents the coefficients to be estimated.

Among the independent variables, delayed_departure is a binary variable that equals to 1 when the flight departs late and 0 when there is no departure delay[1]. As with delayed arrivals, a flight is delayed when the actual departure time exceeds the planned departure time by more than 15 minutes. Since flights departing late tend to consequently arrive late, this variable is used to control this effect.

The other variables are intended to capture the effects of weather conditions at the destination airport, extracted from the last METAR published until the arrival time of the flight at the destination airport. The *visibility* variable represents the predominant horizontal visibility at the destination, with values ranging from 0 to 9999 meters and reported as 9999 m when it is greater than or equal to 10 km. The *ceiling* variable represents the vertical visibility (when available) or the cloud base height for cloudy sky (BKN) and overcast sky (OVC), up to the limit of 10,000 feet. For few clouds (FEW), scattered clouds (SCT), CAVOK and NCD, the maximum vertical visibility value was adopted. Higher horizontal and ceiling visibility values indicate better visual conditions for operation, possibly with less delays.

The variable *wind_gust* is binary (1 when there is gust). Wind gusts are considered to occur when the maximum wind speed exceeds the average speed by at least 10 kt. Since gusts can affect landings, this variable is expected to be positively related with delays. The binary variable *rain* is 1 when the METAR reports thunderstorm, rain shower or rain (codes TS, SH and RA, respectively). The occurrence of these phenomena is also expected to impair operation, increasing the likelihood of delays. Table 1 presents the descriptive statistics of the variables used in the model. To control possible seasonality effects, we also employ dummy variables for each month and day of the week.

Table 1- Descriptive statistics of variables.
Source: Authors

Variable	Unit	N obs.	Mean	Standard Dev.	Max.	Min.
delayed_arrival (dummy)	-	693.126	0.15	0.357	1	0
Visibility	Metros	693.126	9568	1404	9999	0
Ceiling	100 ft	693.126	87.88	29.34	10000	0
Gust (dummy)	-	693.126	0.0098	0.0986	1	0
Rain (dummy)	-	693.126	0.0653	0.2471	1	0
delayed_departure (dummy)	-	693.126	0.1368	0.3437	1	0

A second version of the model was analyzed considering the visibility and ceiling information as dummy variables, grouped into 5 categories, as presented in Table 2.

Table 2 - Categorization of visibility and ceiling variables
Source: Authors

	Group 1	Group 2	Group 3	Group 4	Group 5
visibility (m)	9999	[5000-9999[	[3000-5000[	[1000-3000[	[0-1000[
ceiling (ft)	≥ 5000	[3750-5000[	[2500-3750[	[1250-2500[	[0-1250[

For data analysis and model estimation, the software R (version 3.4.4) was used, with the aid of stringr, lubidate and sqldf packages. The following section describes the results.

Results

Table 3 presents the estimation results. In column (2) *delayed_departure* is added to the model and in column (3) the days of the week.

The estimated coefficients of *delayed_arrival* suggest the existence of a positive and statistically significant effect, consistent with the expected, since more arrival delay is likely to occur if the flight is already delayed.

The *visibility* and *ceiling* variables presented negative coefficients in the 3 models, as expected, since operations are not affected with higher visibility and ceiling conditions. Both variables were statistically significant in all specifications, except for the *ceiling* variable in model 1 (subspecified model, without the *delayed_departure* variable). The estimated positive and significant coefficients for the binary variables rain and wind gust support the assumption that there is a greater likelihood of a delayed arrival when there is wind gust or convective weather at the destination airport.

Table 3 – Estimation Results
Source: Authors

	delayed_arrival		
	(1)	(2)	(3)
Constant	-1.323***	-2.187***	-2.280***
delayed_departure		4.492***	4.484***
visibility	-0.00004***	-0.0001***	-0.0001***
ceiling	-0.0002	-0.0004**	-0.0004**
rain	0.450***	0.515***	0.506***
wind_gust	0.255***	0.483***	0.493***
Monday			0.127***
Tuesday			0.001
Wednesday			0.061***
Thursday			0.252***
Friday			0.282***
Saturday			-0.175***
Observations	693126	693126	693126
Log Likelihood	-289144	-155432	-155029
Pseudo R^2 (McFadden)	0.01297	0.4694	0.4708

Note 1. * p<0.1; ** p<0.05; *** p<0.01.
Note 2. dummies for each month were used in all models.

In column (3) Sunday is the baseline. The estimated coefficients indicate that delayed arrivals are greater during the week. Alderighi and Gaggero [7] observed similar behavior for flight cancellations.

A second version of the model was analyzed, replacing the continuous values of the visibility and ceiling variables with dummies, as defined in Table 2. The results are presented in Table 4.

Table 4 – Estimation results (categorization of visibility and ceiling variables)
Source: Authors

	delayed_arrival		
	(4)	(5)	(6)
Constant	-0.556***	-1.311***	-1.397***
delayed_departure		4.493***	4.485***
visib 9999	-1.179***	-1.736***	-1.744***
visib 5000_9999	-1.175***	-1.647***	-1.656***
visib 3000_5000	-1.069***	-1.408***	-1.423***
visib 1000_3000	-0.598***	-0.739***	-0.741***
ceiling ≥ 5000	-0.049***	-0.061***	-0.058***
ceiling 3750_5000	-0.097***	-0.118**	-0.115**
ceiling 2500_3750	-0.104***	-0.083**	-0.074**
ceiling 1250_2500	-0.048**	-0.043	-0.032
rain	0.510***	0.600***	0.592***
gust	0.244***	0.463***	0.471***
Monday			0.125***
Tuesday			-0.001
Wednesday			0.063***
Thursday			0.255***

Friday			0.281***
Saturday			-0.177***
Observations	693126	693126	693126
Log Likelihood	-288934	-155255	-154849
Pseudo R^2 (McFadden)	0.01368	0.4700	0.4714

Note 1. * p<0.1; ** p<0.05; *** p<0.01.
Note 2. baseline: Visibility below 1000 m and ceiling below 1250 ft.
Note 3. dummies for each month were used in all models.

In general, a behavior like that observed in the previous model can be observed. The higher the visibility the lower the likelihood of arrival delays, as higher visibility categories have larger negative coefficients in modulus (compared to the baseline category of visibility below 1000 m). Delay is therefore more likely to occur when the visibility of the airport is below 1000 m. For the ceiling, in models (5) and (6) the ceiling category between 1250 and 2500 feet (ceiling 1250_2500) was not statistically significant compared to the baseline (below 1250 ft). Therefore, delays are more likely to occur when the airport's vertical visibility is less than 2500 feet.

Final considerations

This study developed a Logit model to estimate the impact of different weather conditions on flight delays at arrivals. The models presented indicate that the visibility and ceiling variables have a significant influence on landing operations. The model also took into account the occurrence of departure delay, an important condition to provide greater consistency of analysis.

Further research may cover canceled flights and differences among airlines. Other weather phenomena may be included according to the climate of the case study airports, such as haze and hail. Ceiling and visibility operational minimums of each airport can also be incorporated to the model to capture the effects of different available navigation infrastructure and traffic volume in each airport. Finally, in order to build a more accurate model for forecasting delays, it is important to include variables of airport operating conditions related to capacity and demand management.

Appendix

Table 5 presents the 79 airports considered in the study.

Table 5 - Airports considered in the study
Source: Author

ICAO	Airport	Aircraft Movements
SBGR	Guarulhos - Governador André Franco Montoro	271.237
SBSP	Congonhas	223.989
SBBR	Presidente Juscelino Kubitschek	158.507
SBGL	Galeao – Antonio Carlos Jobim	127.092
SBRJ	Santos Dumont	118.149
SBKP	Viracopos	112.772
SBCF	Tancredo Neves	100.593
SBPA	Salgado Filho	83.377
SBSV	Deputado Luis Eduardo Magalhaes	81.700
SBRF	Guararapes - Gilberto Freyre	79.169

SBCT	Afonso Pena	71.638
SBGO	Santa Genoveva	66.247
SBFZ	Pinto Martins	56.747
SBFL	Hercilio Luz	50.082
SBVT	Eurico de Aguiar Salles	49.201
SBBE	Val De Cans - Julio Cezar Ribeiro	47.968
SBBH	Pampulha - Carlos Drummond De Andrade	45.218
SBEG	Eduardo Gomes	38.921
SBRP	Leite Lopes	34.024
SBCG	Campo Grande	33.997
SBNF	Ministro Victor Konder	31.600
SBUL	Ten Cel Aviador César Bombonato	30.013
SBLO	Governador José Richa	28.875
SBMO	Zumbi Dos Palmares	18.481
SBPJ	Brigadeiro Lysias Rodrigues	13.001
SBFI	Cataratas	12.831
SBSL	Marechal Cunha Machado	12.724
SBJV	Lauro Carneiro De Loyola	10.802
SBUR	Mario de Almeida Franco	6.331
SBAE	Bauru/Arealva	below de 5.000
SBAR	Santa Maria	below de 5.000
SBAU	Estadual Dario Guarita	below de 5.000
SBAX	Romeu Zema	below de 5.000
SBBV	Atlas Brasil Cantanhede	below de 5.000
SBCA	Coronel Adalberto Mendes Da Silva	below de 5.000
SBCB	Cabo Frio	below de 5.000
SBCH	Serafin Enoss Bertaso	below de 5.000
SBCN	Nelson Rodrigues Guimaraes	below de 5.000
SBCP	Bartolomeu Lisandro	below de 5.000
SBCR	Corumba	below de 5.000
SBCX	Hugo Cantergiani	below de 5.000
SBCY	Marechal Rondon	below de 5.000
SBCZ	Cruzeiro Do Sul	below de 5.000
SBDB	Bonito	below de 5.000
SBDN	Presidente Prudente	below de 5.000
SBDO	Dourados	below de 5.000
SBFN	Fernando De Noronha	below de 5.000
SBIL	Jorge Amado	below de 5.000
SBIP	Usiminas	below de 5.000
SBIZ	Prefeito Renato Moreira	below de 5.000
SBJA	Regional Sul	below de 5.000
SBJE	Comandante Ariston Pessoa	below de 5.000
SBJI	Ji-Parana	below de 5.000

SBJP	Presidente Castro Pinto	below de 5.000
SBJU	Orlando Bezerra De Menezes	below de 5.000
SBKG	Presidente Joao Suassuna	below de 5.000
SBLJ	Lages	below de 5.000
SBMA	Joao Correa Da Rocha	below de 5.000
SBMG	Silvio Name Junior	below de 5.000
SBMK	Mario Ribeiro	below de 5.000
SBML	Frank Miloye Milenkovich	below de 5.000
SBMQ	Alberto Alcolumbre	below de 5.000
SBPF	Lauro Kurtz	below de 5.000
SBPK	Pelotas	below de 5.000
SBPS	Porto Seguro	below de 5.000
SBPV	Governador Jorge Teixeira De Oliveira	below de 5.000
SBQV	Pedro Otacilio Figueiredo	below de 5.000
SBRB	Plácido De Castro	below de 5.000
SWRD	Maestro Marinho Franco	below de 5.000
SBSG	Governador Aluizio Alves	below de 5.000
SBSM	Santa Maria	below de 5.000
SBSN	Maestro Wilson Fonseca	below de 5.000
SBSO	Adolino Bedin	below de 5.000
SBSR	Professor Eriberto Manoel Reino	below de 5.000
SBTE	Senador Petronio Portella	below de 5.000
SBTT	Tabatinga	below de 5.000
SBUG	Rubem Berta	below de 5.000
SBVG	Major Brigadeiro Trompowsky	below de 5.000
SBNM	Santo Angelo	below de 5.000

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Mutual influence on air transport routes network in the context of a liberalized aviation market. The case of Colombia

José F. Zeaa - jfzeac@gmail.com
Universidad Santo Tomás, Colombia.
Oscar Díaz Olariaga - oscardiazolariaga@usantotomas.edu.co
Universidad Santo Tomás, Colombia
Diana Tascón Hoyos - dianatascon@ustadistancia.edu.co
Universidad Santo Tomás, Colombia

Abstract

To investigate the mutual influence of the volume of traffic to an airport through the routes that serve the same airport and the effect of liberalization.

Linear mixed models (Pinheiro and Bates, 2000) and instrumental variables (Pearl, 2000) are used to quantify effects. The adopted methodology allows quantifies the influence of airport node traffic by means of a mixed linear model, this model incorporates routes as random effects and quantifying the effect of airport liberalization as a fixed effect. On the other hand, the endogeneity of the passenger flow of the routes connected with the nodes of a main route is dealt using instrumental variable. The main results reveal that an increase in a specific route has a positive effect on the number of passengers on the other routes that share an endpoint with the route. On the other hand, the liberalization of the air transport industry has a positive effect on the flow of passengers on routes that share extreme points with the route of interest.

Colombia has followed the regional trend (Latin America) in the management of airport infrastructure concessioning the operation of these infrastructures (Díaz Olariaga and Carvajal, 2016). Since the mid-1990s, in four temporary phases, called generations, Colombian government granted the operation of several airports in the country (19 airports to date), resulting in a better management, an expansion in operation, a biggest commercial exploitation and better maintenance of the most used air.

Keywords

Instrumental variables; Air transport network; Mutual influence; Domestic air passenger traffic

Mutual influence on air transport routes network in the context of a liberalized aviation market. The case of Colombia

Introduction

Colombia has followed the regional trend (Latin America) in the management of airport infrastructure concessioning the operation of these infrastructures [1]. Since the mid-1990s, in four temporary phases, called generations, Colombian government granted the operation of several airports in the country (18 airports to date), resulting in a better management, expansion in operation, a bigger commercial exploitation and better maintenance of the most used air terminals [2].

First phase was the entry of private air operators into the market with FSC (Full-Service Carrier) business model. This happened very soon after the liberalization of the sector (mid-1990s) [3]. In second phase occurred the entry of low-cost airlines or LCC (Low-Cost Carrier) into the market some years after the liberalization (end of the 2000s). The market share of the LCCs is still very low, not higher than 16% (between the three existing LCCs) and mainly domestic [4] [5]. Finally, since 2012 Colombian air fares (ticket prices) are liberalized, airline operators must only inform the public regulator about their rates.

This paper investigates the mutual influence of the volume of traffic to an airport through the routes that serve the same airport and the effect of liberalization. Linear mixed models [6] and instrumental variables [7] are used to quantify effects. Different models reveal that an increase in a specific route has a positive effect on the number of passengers on the other routes that share an endpoint within the route. Furthermore, the liberalization of the air transport industry has a positive effect on the flow of passengers on routes that share extreme points with the route of interest.

Literature review

There is extensive literature on the analysis of air traffic / air transport from the point of view of network. The majority of formal network research on airline/air traffic networks has focused on their complex network topology [8] [9], and with three features in particular [10] [11] [12] [13] [14] [15] [16] [17] [18]; small-world structure [19], scale-free degree distributions [20], and modular community structure [21] [22] [23] [24].

However, there is very little literature that analyzes the mutual influence of air passenger traffic between the different airports (nodes) of the network, and determines the factors that affect said mutual influence. The only related work found is Doi [21] that investigates the mutual influence of traffic volumes across routes serving the same airport. Regression analysis using the data of Japan's domestic air transport market reveals that an increase in passengers on a given route has a positive effect on the number of passengers on other routes that share an end point airport with the given route. However, Doi [21] does not determine mathematically what are the factors that influence the results found.

This paper quantifies the influence of airport node traffic by means of a mixed linear model. This model incorporates routes as random effects and quantifying the effect of airport liberalization as a fixed effect. On the other hand, the endogeneity of the passenger flow of the routes connected with the nodes of a main route is dealt using instrumental variables methodology [22].

Methodology

The analysis calculates and determines the mutual influence of traffic passenger volumes across routes serving the same airport through linear regression and two-stage least squares (2SLS) estimation with the use of instrumental variables. The analysis is bounded to routes involving regular (commercial / scheduled) flights and for 15 main Colombian airports and its respective routes, including the country's main airport and hub, Bogotá-El Dorado International Airport (BOG) [4]. Two indicators are considering in the analysis:

- Q_{rt} as the number of passengers on route r in year t,
- Qot_{rt} as the total number of passengers on routes to or from the endpoint airports of route r, excluding route r itself.

Table 1. Descriptive Statistics Q_{rt} and Qot_{rt}Source: Authors.

	Observations	Mean	Std. dev.	Min	Median	Max
All Routes						
Q_{rt}	2055	90965.5	262964.47	0	6313	2941788.0
Qot_{rt}	2055	2166984.5	2199231.80	49528	1478510	13563765.0
Routes serving BOG						
Q_{rt}	323	444883.7	525608.41	2	267338	2941788.0
Qot_{rt}	323	5750559.0	2752802.52	2764555	4425569	13563765.0
Other routes						
Q_{rt}	1732	24963.4	54142.34	0	2776	592716.0
Qot_{rt}	1732	1498685.1	1219144.11	49528	1179444	8447792.0

In order to quantify the effect of the number of passengers on routes to or from the endpoint airports of route r (Qot_{rt}) in the number of passengers on route (Q_{rt}), we develop a linear regression controlled by the next covariables:

- pop_{rt}: natural logarithm of the geometric mean of the populations of the departments in which the endpoint airports of route r are located (natural logarithm of POP_{rt}).
- inc_{rt}: natural logarithm of the geometric mean of the per-capita incomes of regions (administrative departments) associated to route r.
- Year

The first empirical model is as follows:

$$q_{rt} = \alpha qot_{rt} + \beta' x_{rt} + R_r + e_{rt}$$
(1)

where q_{rt} denotes natural logarithm of the number of passengers on route r in year t (the natural logarithm of Q_{rt}); qot_{rt} denotes natural logarithm of the total number of passengers on routes to or from one of the endpoint airports of route r, excluding route r itself (natural logarithm of Qot_{rt}), x_{rt} denotes a vector of control variables and includes pop_{rt} that denotes natural logarithm of the geometric mean of the populations of the departments in which the endpoint airports of route r are located (natural logarithm of POP_{rt}), c_{rt} denotes natural logarithm of the geometric mean of the per-capita income of those departments (the natural logarithm of C_{rt}), year (it is considered as continuous variable in order to reduce the number of parameters), R_r represents the route-specific fixed effects; e_{rt} is the error term with mean zero. is the error term with mean zero.

A second model is carried on based on the time-demeaned:

$$q_{rt} = \alpha \widetilde{qot}_{rt} + \beta' \widetilde{x}_{rt} + \widetilde{e}_{rt} \tag{2}$$

where $\alpha \widetilde{qot}_{rt} = \sum_t y_{rt}/T_r$ where Tr is the number of observations of route r in the sample.

Covariables $\widetilde{x}_{rt}$ and $+\widetilde{e}_{rt}$ are transformed in analogous way.

A third model is adjusted due to the endogeneity of $\widetilde{qot}_{rt}$. The error term $\widetilde{e}_{rt}$, is likely to contain short-run demand shocks for an airport, such as a vogue for a sightseeing spot around the airport, which may affect all the routes from the airport. It is therefore expected that $\widetilde{qot}_{rt}$has a positive correlation with the error term and that the ordinary least squares (OLS) estimation will result in a positively-biased estimate of α.

To deal with this endogeneity problem a third model is adjusted. We use the variation in $\widetilde{qot}_{rt}$that comes not from unobserved shocks but from the changes in population and income. Specifically, we estimate (2) by a two-stage least squares (2SLS) estimation with the following two variables as instrumental variables for $\widetilde{qot}_{rt}$. One is $\widetilde{pop}_{rt}$, and is $\widetilde{inc}_{rt}$, the demeaned values of the average of the population and income , writing the model through the ivreg function of AER package:

```
iv1 = ivreg(Qrt_C ~ q0trt_C + Year | pop_C + inc_C , data = query)          (3)
```

The method of instrumental variable is used to estimate causal relation in non-controlled experiment. This methodology is used when it is required that one or more variables induce changes in the explanatory variables but they do not have an independent effect on the dependent variable, in this it is possible to extract the effect of the explanatory variable on the dependent variable [22].

Data

We restrict the analysis for routes involving regular flights. Due to restriction in economic information we work with 15 main airports of Colombia, which represent nearly 85% of total of passengers in 1992 - 2015 period. Flights of two Medellín airports (Olaya Herrera - EOH and Jose María Cordoba - MDE) are aggregated. The airports we consider in this study are show in Table 2.

Table 2. Colombian airports considered in the study. Source: Authors.

Municipality	IATA Airport Code
Medellín	EOH
Rionegro	MDE
Barranquilla	BAQ
Cartagena	CTG
Valledupar	VUP
Quibdo	UIB
Montería	MTR
Bogotá	BOG
Rioacha	RCH
Santa Marta	SMR
Cúcuta	CUC
San Andrés	ADZ
Bucaramanga	BGA
Corozal	CZU
Cali	CLO

A database with the number of passenger of every route (two way flights) is organized for the main 15 airports between 1992 and 2015 (105 routes are considered). Ten of the fifteen main routes involve the Bogotá Airport (BOG), another important routes involve Medellin (MDE) and Cali (CLO) airports. It is important to highlight the growth that the main routes have presented since 2008 (Fig. 1).

In Fig 2 we can observe main routes (excluding country's main hub - BOG), whose routes represent roughtly 75% of the domestic passenger traffic mobilized in the country. The routes that involve the airport of the Colombian second largest city (Medellin, MDE) stand out. To a lesser extent, the routes linked to the airport of Cali (CLO) and Barranquilla (BAQ) (third and fourth largest cities in the country respectively), have a significant amount of passengers. Routes associated to tourist cities of Cartagena (CTG) and San Andrés (ADZ) are very important in terms of traffic of passengers. The growth of the routes that do not involve the main hub airport of the country has been considerable in recent years but without being as prominent as the growth presented in the routes associated with this hub.

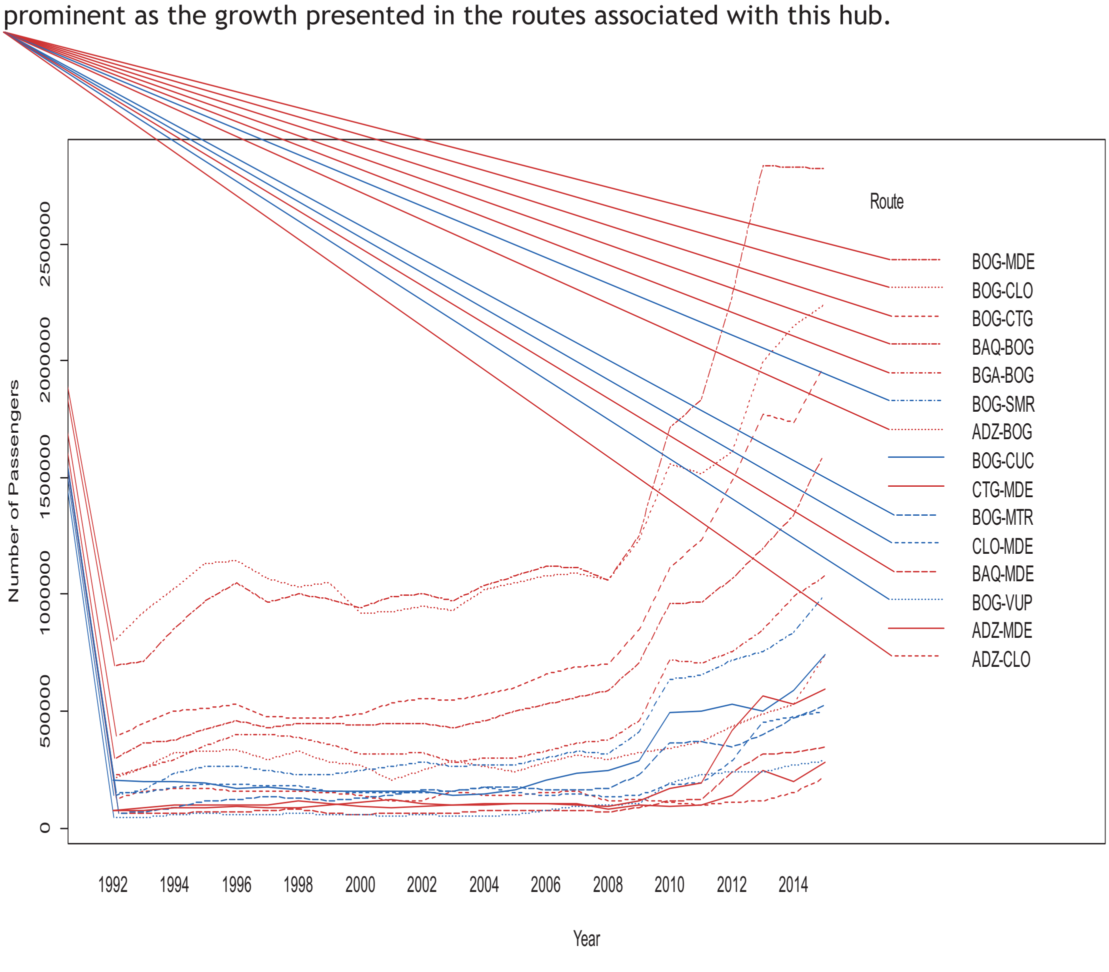

Figure 1 - Top Colombian routes by number of passengers (1992- 2015). Source: [4].

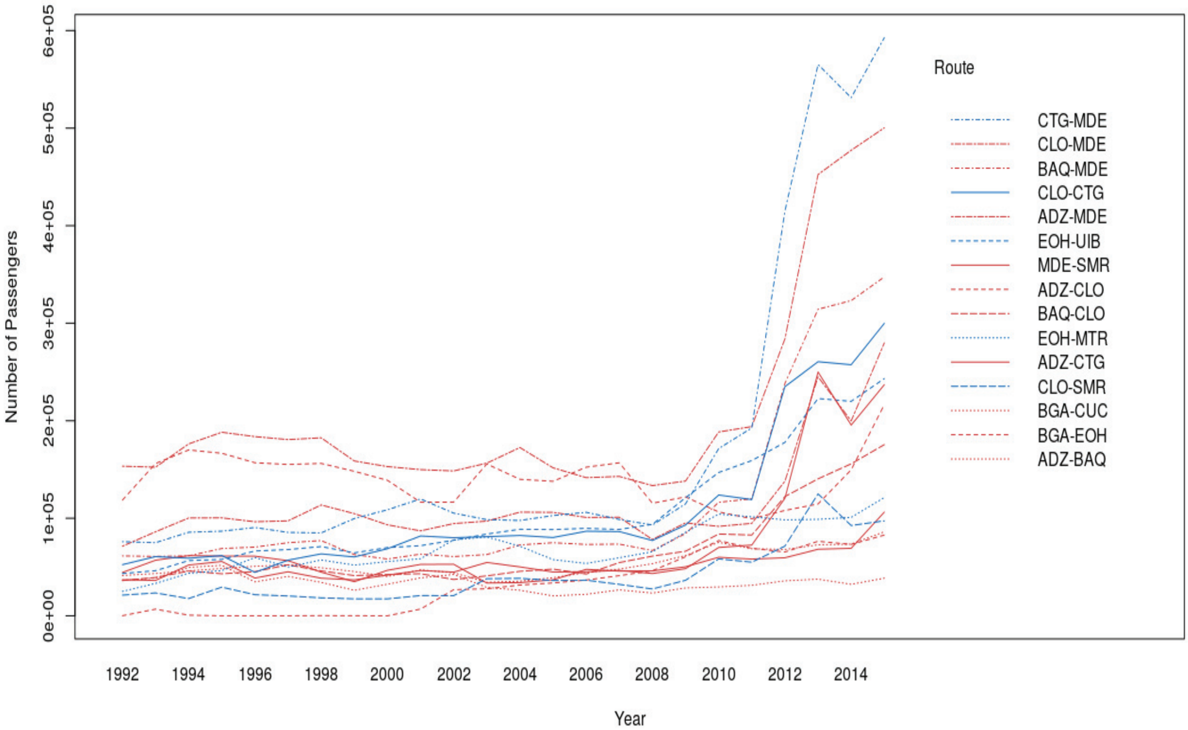

Figure 2 - Top Colombian routes by number of passengers (1992- 2015) – Excluding Bogotá Airport (BOG). Source: [4].

In order to get the influence of the number of passengers of the routes involving the endpoints of a given route (A-B) over the volume of passenger of this route, we will give some definitions [21]:

- Q_{rt} as the number of passengers on route r in year t. In Fig. 3, we consider r as route A-B, it is the sum of passengers from airport A to airport B and form airport B to airport A in a specific time t.

- q_{rt} total number of passengers on routes to or from the endpoint airports of route r, excluding route r itself. It is the sum of passenger from route A-C (include flight in two-ways), B-C, and every route that involves endpoints (A and B), except route A-B itself. In the Fig. 3, it corresponds to passengers of dashed lines (in both ways) in a specific time t.

- pop_{rt} is the natural logarithm of the geometric mean of the population of the departments associated to the routes to and from the endpoint of route r, excluding route r itself. In Fig. 3, inc_{rt} corresponds to natural logarithm of geometric mean of population departments associated to endpoints of dashed lines in a specific time t.

inc_{rt} is the natural logarithm of the geometric mean of the per capita income of the departments associated to the routes to and from the endpoint of route r, excluding route r itself. In Fig. 3, inc_{rt} corresponds to natural logarithm of geometric mean of per capita income of departments associated to endpoints of dashed lines in a specific time t.

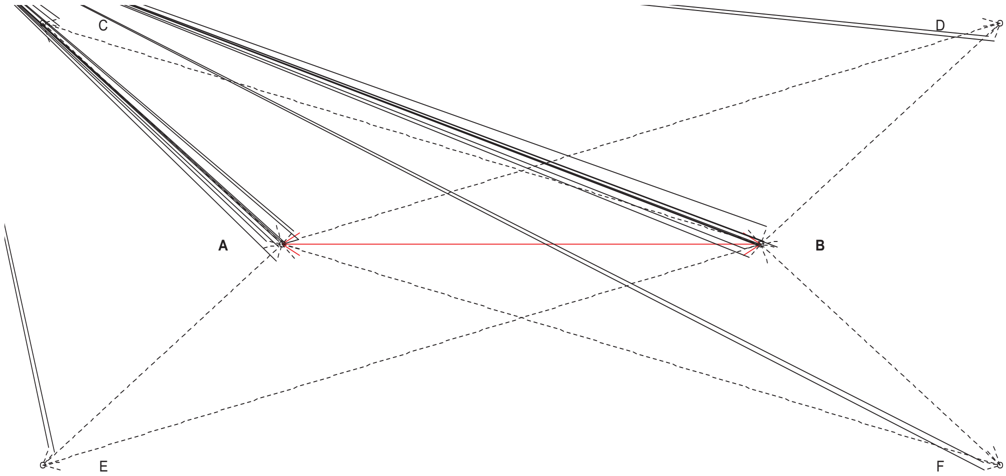

Figure 3 - Scheme of route A-B (red and solid line) and routes connected with end-points (black dashed lines, A-C, B-C, etc.). Source: Authors.

We will quantify how it is influenced the number of passengers in a specific route by the number of passengers of routes that involved the endpoints, i.e. the influence of q_{rt} over Q_{rt}. For example, we examine how the number of passengers in Bogotá - Cartagena (BOG-CTG) route is influenced by the number of passengers on other routes to or from Bogotá airport (BOG) or Cartagena airport (CTG) (for example routes such as Bogotá – Cali, BOG-CLO).

The model

We begin with regression estimator (OLS model):

$$Q_{rt} = \beta_0 + \beta_1 q_{rt} + Year_t + e_{rt} \tag{4}$$

Both the dependent and independent variables are random, besides q_{rt} is correlated with the error term in a regression model, which makes the OLS method inappropriate [21]. In the model the variable *Year* is considered as exogenous variable. To remedy the problem of endogeneity of q_{rt} we use of instrumental variables methodology (often called "two-stage least squares"), which are variables that do not directly influence the response but are correlated with the endogenous variable (Wooldridge, 2012). We consider as instrumental variables pop_{rt} and inc_{rt} which are highly related to q_{rt} but it is not expect to be highly correlated with the number of passengers in route r in time t, Q_{rt}. To evaluate the suitability of this instruments we develop test for verify if instruments are weak (Hausman test for endogeneity and Sargan-Hansen test for overidentification) [23].

The null hypothesis of weak instruments test is H_0: all instruments are weak, in this test the null hypothesis is rejected meaning that at least one instrument is strong as is shown in Table 3.

Wu-Hausman test is used to verify if q_{rt} is an endogenous variable (the null hypothesis is that error is uncorrelated with q_{rt}). Table 3 shows that null hypothesis is rejected indicating that $q_{rt}$is marginally endogenous. Finally, Sargan test shows that all instruments are valid.

Table 3. Endogeneity test for model (1). Source: Authors.

Diagnostic tests	df1	df2	statistic	p-value	
Weak instruments	2	2228	311.149	< 2,00E-16	***
Wu-Hausman	1	2228	35.716	2.65e-09	***
Sargan	1	NA	0.565	0.452	

Signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Table 4 shows the effect of the number of passengers of routes sharing endpoints of a given route over the number of passengers of a route is positive and statistically significant (second column, 0.1012). For every 1000 passengers in routes with endpoints A or B there is nearly of 101 passengers in route A-B. This result implies that a change in policy for an airport influences routes which do not serve the airport.

Table 4. Estimated parameters of OLS and IV model (all routes included). Source: Authors.

	Dependent variable: Q_rt	
OLS and IV models compared	OLS	IV
Constant	7835421***	14437648***
	(1296903)	(1650994)
q_{rt}	0.0739***	0.1012***
	(0.0021)	(0.0045)
Year	-3945.411***	-7269.02***
	(648.1599)	-827.1335
Observations	2232	2232
Multiple R-Squared	0.3793	0.33
Adjusted R-squared	0.3787	0.3294

The same analysis is carried on excluding Bogotá (BOG), routes involving Bogotá constitutes nearly 75% of total of passengers. First, model (1) is carried on with pop_{rt} and inc_{rt} as instrumental variables, test for endogeneity suggest that one of the instrumental variables is not necessary (Table 5).

Table 5. Endogeneity test for IV model without country's main hub (BOG) routes. Instrumental variables: pop_{rt}, inc_{rt}. Source: Authors.

Diagnostic tests:	df1	df2	Statistic	p-value	
Weak instruments	2	1892	27.708	1.38e-12	***
Wu-Hausman	1	1892	0.194	0.6597	
Sargan	1	NA	4167	0.0412	*

Signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

A second model considered as instrumental variable pop_{rt}, the endogeneity test shows a suitable model (Table 6).

Table 6. Endogeneity test for IV model without Bogotá routes. Instrumental variables: pop_{rt}. Source: Authors.

Diagnostic tests:	df1	df2	Statistic	p-value	
Weak instruments	1	1892	29.040	7.98e-08	***
Wu-Hausman	1	1892	5.113	0.0239	*
Sargan	0	NA	NA	NA	

Signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

The effect of the number of passengers of routes sharing endpoints of a given route over the number of passengers of a route (q_{rt}) is positive and statistically significant but is considerably lesser (0.0139) than the effect that is obtained with all routes (including Bogotá-BOG) (Table 7). An increase in the passengers of other routes sharing an endpoint of a specific route has little effect in the traffic in the routes not involving Bogotá. This is an evidence of a weak connection in the networks routes different to Bogotá.

Table 7. Estimated parameters of OLS d and IV model (all routes included). Source: Authors.

	Dependent variable: Q_rt		
OLS and IV models compared	OLS	IV	IV (2)
Constant	2022894***	1546772***	-460229.9
	(314847)	(951884.9)	(1453506)
q_{rt}	0.0292***	0.0263***	0.0139***
	(0.001)	(0.0056)	(0.0088)
Year	-1018.951***	-779.246***	231.1841***
	(157.4932)	478.8917	731.5223
Observations	1896	1896	1896
Multiple R-Squared	0.3483	0.3451	0.2618
Adjusted R-squared	0.3476	0.3444	0.261

Conclusions

In this research, the influence of the routes related to the terminal points in the domestic passenger traffic between the routes is quantified, controlling possible problems of bias in the estimates through the use of instrumental variables (demographic and socioeconomic). The model allows to understand the dynamics of the behavior of the network in terms of passenger traffic and to analyze the connectivity of the network indirectly through the model of instrumental variables.

The influence of the routes related to the terminal points on the passenger traffic between routes is positive and of an important magnitude. Nevertheless, if we consider routes not involved the country's main hub, this effect is much lower, which is an evidence that there is a huge influence in the network by country's main hub. The particularity of this air transport market is that in the case where the country's main hub is not included there is a very small effect of the routes that involve the nodes of a route on the traffic of the same route. This effect is approximately 1000% smaller than the effect observed when performing the same analysis including the country's main hub. The results allow to conclude that the network analyzed has a strong heterogeneity. A great effort is required to strengthen other airports to generate a greater volume of traffic in the Colombian air transport network.

Finally, the results show a strong increase in recent years in the routes that involve the country's main hub, this is especially noticeable since the total deregulation of air fares (2012).

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Air transport forecast in post-liberalization context: A Dynamic Linear Models approach

Yesid Rodriguez - heivarrodriguez@usantotomas.edu.co
Universidad Santo Tomás, Colombia
Wilmer Pineda - wilmerpineda@usantotomas.edu.co
Universidad Santo Tomás, Colombia
Oscar Díaz Olariaga - oscardiazolariaga@usantotomas.edu.co
Universidad Santo Tomás, Colombia
Diana Tascón Hoyos - dianatascon@ustadistancia.edu.co
Universidad Santo Tomás, Colombia

Abstract

To perform a formal and statistically rigorous traffic forecast (passenger, air cargo and operations or movements) for Bogota-El Dorado International Airport, (BOG), in the short term.

Dynamic Linear Models (DLM) will be used, this has the following advantages with respect to the usual forecast calculation methodologies: it detects stochastic tendencies that are hidden in the time series (West and Harrison, 2006) and it detects structural changes that allow estimating the variable effect over time of exogenous shocks without increasing the number of parameters (Honjo et al., 2018).

The growth of air traffic in Colombia has been reinforced since the 1990s by a public policy of liberalization of airspace in the domestic and foreign markets, and by redirecting public and private investment towards the modernization and updating of airport infrastructures, giving in concession the country's busiest airports (Díaz Olariaga, 2016). As a result of public and investment policies in the last two and a half decades, passenger transport in Colombia grew by 863%.

Both the master plans of BOG and several technical studies estimate an increase in demand that the current airport capacity (and future, since no further expansion is planned) will not be able to accommodate. Then, the formal and (statistically) rigorous development of a traffic forecast (passenger, air cargo and operations or movements) for BOG in the short term is considered of interest, although there are a large number of publications on various aspects of air transport liberalization.

Keywords

Air traffic forecast; Liberalization; Dynamic Linear Models; Airport

Air transport forecast in post-liberalization context: A Dynamic Linear Models approach

Introduction

Air transport in Colombia has been developing at an accelerating and dynamic pace for about two and a half decades. This period coincides with the beginning of a continued implementation of public policies, designed specifically for the sector of air transport to drive and promote it. The growth of air traffic in Colombia has been strengthened since the 1990s by the public policy of liberalization of airspace in both domestic and international markets and by the re-orientation of public and private investment toward modernizing and updating airport infrastructure through concessioning the busiest airports in the country [1]. The first generation of airport concessions was implemented in the mid-1990s and since that time three additional generations have taken place [2]. In the commercial aviation sector, the national airline was privatized during the same period and new (private) air carriers entered the market, including low-cost carriers (LCC). Since 2012, airfares are completely deregulated [3].

As a result of public policies, both of privatization and public investment in airport infrastructure (together with deregulating policies in the commercial aviation sector), passenger transport in Colombia has increased 863% [4] during the last decades and a half. This significant growth rate has been boosted and led by the main airport in Colombia, Bogotá-El Dorado International Airport (hereafter BOG), in the country's capital city. However, the master plans for BOG, as well as several studies/reports, not necessarily rigorous (from the statistical viewpoint) consider some growth in the demand, which implies that the airport's present capacity (and in the future, as no expansion is contemplated) will not meet the anticipated demand. This situation prompted the public sector to approve the construction of a new airport in the city outskirts, which is supposed to start operating in 2025/2026.

Therefore, the goal of this article is to carry out a forecast for BOG (passengers, air cargo, and air operations or movements) in the short term. To this end, and as a calculation methodology (novel for this type of analysis of air traffic), Dynamic Linear Models (DLM) will be used, which, in comparison with usual methods for forecast calculation, presents the following advantages: it detects stochastic trends hidden in time series [5], as well as structural changes that allow estimating the variable effect in time of exogenous shocks without increasing the number of parameters [6]. Furthermore, the structure of conditional independence, on which the state dynamics is based, allows considering forecasts through a recursive algorithm [7].

Literature review

There is much research that deals with different aspects of liberalization of aviation / air transport. Many studies address such topics as spatial effects in deregulating connectivity and accessibility [8], market competition and consolidation [9], configuration network structures ([3] [10]), price of air tickets [11], and airline alliances [12]. Other studies focus their attention on the analysis of different situations (e.g. the behavior of demand) within the post-liberalization context in some given countries or regions [13]. On the other hand, Rolim et al. [14] analyze the development of demand in recently privatized airports, as in the case of Brazil. The changes in traffic concentration in airports as a result of liberalization have also been discussed [15].

As regards the research that is presented in this paper, there are not too many contributions in this field. For instance, Sun and Schonfeld [16] use stochastic programs to estimate, on the one

hand, traffic future demand, and, on the other hand, how to optimize decision making about the future development of an airport (investments in capacity), where uncertainty in traffic forecast is considered. All this is applied to markets or countries where air transport is completely liberalized [17], by using systems dynamics they carry out a forecast of transport demand of air cargo to determine the capacity of the cargo terminal and its expansion (the study included a set of airports in Taiwan). Singh et al. [18], through an econometric model, conduct a forecast study of both air traffic and investment in airport capacity for a 20 years period for the airport system in India and within the context of post-liberalization in the air traffic industry. Scarpel [19] uses expert models to forecast air passenger demand in the Sao Paulo Airport (Brazil), in the context of both liberalization of air transport and airport privatization. Díaz Olariaga et al. [20] estimated the effects that airport privatization in Colombia has on the future passenger demand, by using the Box–Jenkins method and ARIMAX models. Finally, Carmona-Benítez et al. [21] use a dynamic econometric model to estimate passenger demand, through a case study of the air transport system in Mexico.

Methodology and data

In any statistical application, a crucial and sometimes difficult step is to carefully specify the model. The first strategy is a static model, where the effect of time does not play an important role. For this research, Dynamic Models (DMs) have been chosen because, unlike the case of static models, some of the elements that participate in the construction of the model do not remain invariable, but are considered as functions of time, describing temporal trajectories [22].

Dynamic Models (DMs) have the advantage of having “dynamics” in the model’s parameters, thereby rendering the parameters not fixed, but changing or dependent on time. Their main application is the analysis of time series. They also have the advantage of being useful to perform sequential analyses because the updating of parameters is carried out based on the data that have been obtained sequentially.

The development of forecasts is usually based on models of the autoregressive type, moving averages or their combination. However, such models have a complicated verisimilitude function and, therefore, the final distribution of parameters inherit the same difficulty. Based on the aforementioned, Dynamic Linear Models (DLMs), which are a particular case of Dynamic Models (DMs), are used for modeling time series in order to carry out forecasts by distributions of stochastic variables that influence observations in time. One of their advantages is that by using them one realizes that they are more simple models, powerful enough to adjust and forecast data and they may include explanatory variables in a simple way [23] [24] [25] [26] [27] [28]. DLMs are defined under the following structure for each time t [29] [30] [22] [31]:

Observation equation: $\mathbf{Y_t} = \mathbf{F_t}'\boldsymbol{\theta}_\mathbf{t} + \mathbf{v_t}\,, \mathbf{v_t} \sim \mathrm{N}(\mathbf{0}, \mathbf{V_t})$
System equation: $\boldsymbol{\theta}_\mathbf{t} = \mathbf{G_t}\boldsymbol{\theta}_{\mathbf{t-1}} + \mathbf{w_t}\,, \mathbf{w_t} \sim \mathrm{N}(\mathbf{0}, \mathbf{W_t})$

where:
$\mathbf{F_t}$ is a matrix of a known dynamic regression.
$\mathbf{G_t}$ is a matrix of a known state.
$\mathbf{V_t}$ is a matrix of a known observational variance.
$\mathbf{W_t}$ is a matrix of known evolution.
$\boldsymbol{\theta}_\mathbf{t}$ is a vector of parameters.

In time 0 an a priori distribution is postulated for $(\theta_0|D_0)$ where D_0 represents available information until time zero. West and Harrison [5] suggest $(\theta_0|D_0) \sim N(m_0, C_0)$, where m_0 and C_0 are the vector of averages and the matrix of variances and covariances, respectively.

The observation equation defines the observational model for an answer Y_t and its relation with p covariables or explanatory variables F_t. The first explanatory variable is generally a constant or intercept that represents the level of the series. As F_t is univariate, then θ_t is a vector of the form $(\theta_{0t}, \theta_{1t}, \dots, \theta_{p-1t})'$. It is possible to consider Y_t as multivariate, in which case θ_t is a matrix of dimension m x p.

The system equation presents the evolution of the parameters in time. If the model includes p changing coefficients, it will result in the evolution to be defined as a transition matrix G_t of dimension p x p.

Finally, DLMs present errors v_t and w_t with variances dependent on time V_t y W_t that denote the matrix of observational variance and the evolution of variance, respectively.

When dealing with temporal series, it is sufficient to consider that for DLMs a source of variability that works for representing errors in the observation equation and in the system's equation is known as a vector of permanent effects. Even though it appears to have more limitations, some classical models of time series are presented as a particular case, especially ARMA models. They are dealt with through Kalman's filter, when the error terms in the observation equation follow a normal distribution, they are independent and are distributed identically in average 0 and known variance.

In order to determine the strength in numerical terms of the proposed model, Mean Absolute Percentage Error (MAPE) will be used, which measures the size of error (absolute) in percentage terms. The fact that the magnitude of percentage error is estimated, it renders it an indicator frequently used by forecast developers due to its easy interpretation. A small MAPE value indicates that forecasts are accurate and that they will have a higher likelihood of being accurate forecasts [32] [33].

There are data available about the air traffic in the airport under study (passengers, air cargo and operations or air movements) during the last four decades (1979-2017) [34]. Likewise, socioeconomic data are available as regards the city where the airport is located (GDP, GDP/per capita, population, etc.) [35] [36]. According to the chosen variables as covariables, a short-term forecast will be presented due to the changing economic conditions and their effects on air traffic. For that purpose, the years 2018 to 2022 will be forecast. To achieve such forecast, first forecasts should be carried out using ARIMA models [37] on the covariables chosen in order to include these new variables in the selected model, thereby attempting to obtain a relatively low MAPE.

Application case

In Colombia, the aviation industry has been liberalized since the beginning of the 1990s and airfares are completely deregulated since 2012. Within the national context, the case of Bogotá-El Dorado International Airport (IATA code: BOG; OACI code: SKBO) is chosen. This is the main airport in the country and main country hub, situated in the city of Bogotá (capital of Colombia, and with more than 8 million inhabitants), about 7,5 miles from the city center. The airport is public property but it has been concessioned to the private sector since 2007 [2], a year when the airport developed a first (and significant) expansion in infrastructure and facilities (with an investment of USD 650 million), which finished in 2013. In 2015 a second expansion began, which finished at the end of 2018. About 25,000 people work at the airport. BOG is the third terminal for passenger transport and the first for air cargo in Latin America [1].

Results

In the case of the variable “national (or domestic) passengers” Consumer Price Index (CPI) was used as an auxiliary variable to estimate the future forecast. Figure 1 shows the result.

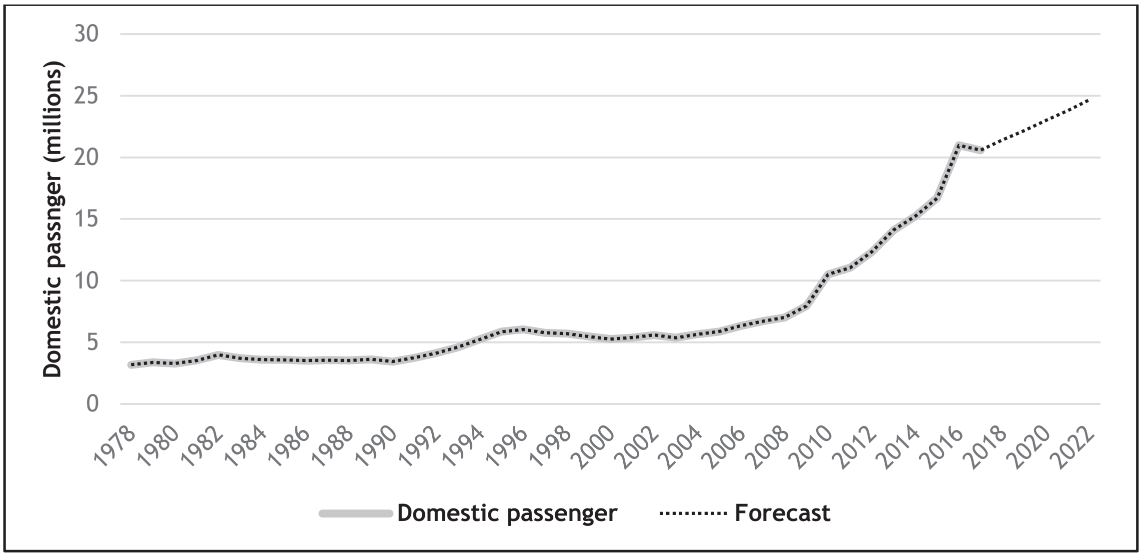

Figure 1 - Model 1, forecast for the variable “domestic passengers”. Source: Authors.

In Fig. 1 Model 1 is presented, where the behavior of estimated values for the chosen model is shown. These values overlap with the behavior of the original values. 1,08% MAPE can also be observed (see Table 1). To estimate the forecast, ARIMA (2,1,0) model was used in the variable CPI in order to carry out 5 years forecast and for it to be included in the variable of national passengers.

Table 1. Comparison of MAPE values for Model 1. Source: Authors.

Modelo	MAPE	Variables
1	0,01082	National passengers, CPI
2	0,01630	National passengers, GDP per capita
3	0,02560	National passengers, national passengers with delay t-1
4	0,02884	National passengers, per capita GDP, CPI

In the case of the variable “international passengers” GDP, Population and Currency Exchange Rate (in Spanish TRM) were used as auxiliary variables to estimate the future forecast, thereby obtaining the results shown in Model 2 (see Fig. 2).

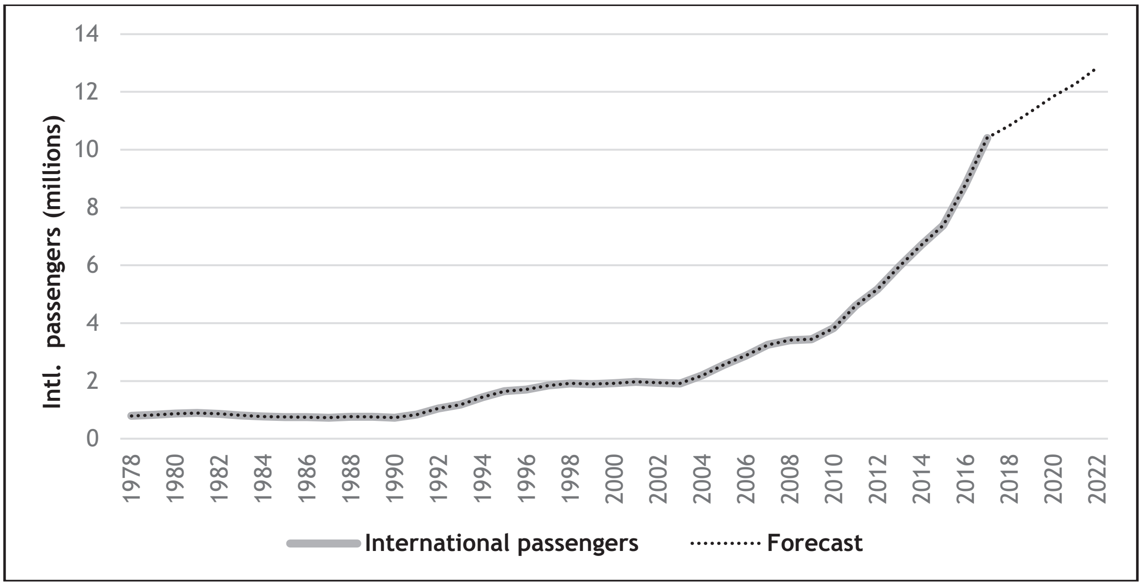

Figure 2 - Model 2, forecast for the variable "international passengers". Source: Authors.

In Fig. 2 Model 2 is presented, where the behavior of estimated values for the model chosen is shown. These values overlap with the behavior of the original values. 0,97% MAPE can also be observed (see Table 2). To estimate the forecast, ARIMA (3,1,0) model was used in the variable GDP, ARIMA(1,1,0) model in the variable population, and ARIMA(2,1,0) model in the variable TRM in order to carry out 5 years forecast and for it to be included in the variable of international passengers.

Table 2. Comparison of MAPE values for Model 2. Source: Authors.

Model	MAPE	Variables
1	0,0097555	International passengers, GDP, population, TRM
2	0,0111818	International pasengers, TRM
3	0,0114201	International passengers, population
4	0,0122443	International passengers, GDP
5	0,0137127	International passengers, GDP, TRM
6	0,0156288	International passengers, GDP, population
7	0,0163126	International passengers, GDP
8	0,0195899	International passengers, international passengers with delay t-1

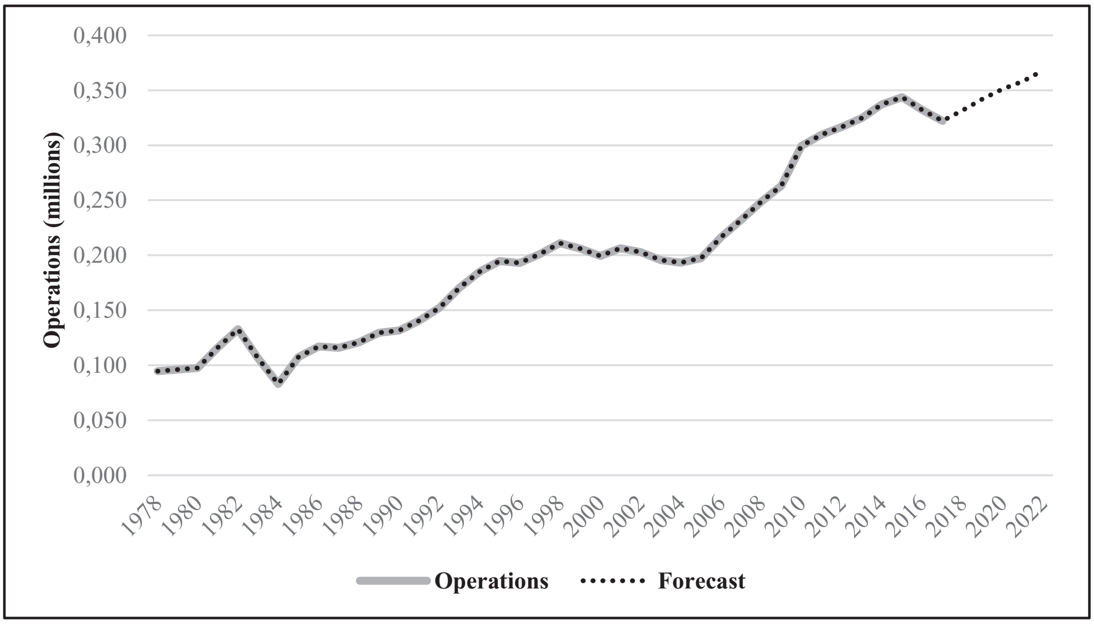

Figure 3 - Model 3, forecast for the variable “operations (or movements)” (total: national + intl.). Source: Authors.

In the case of the variable “operations” (take-offs/landings, where national and international operations are included), GDP per capita, Population and Currency Exchange Rate (in Spanish TRM) were used as auxiliary variables to estimate the future forecast, thereby obtaining the results shown in Model 3 (see Fig. 3). In Fig. 3 Model 3 is presented, where the behavior of estimated values for the chosen model is shown. These values overlap with the behavior of the original values. 0,24% MAPE can also be observed (see Table 3). To estimate the forecast, ARIMA (3,1,0) model was used in the variable GDP per capita, ARIMA(1,1,0) model in the variable population, and ARIMA(2,1,0) model in the variable TRM in order to carry out 5 years forecast and for it to be included in the variable of operations.

Table 3. Comparison of MAPE values for Model 3. Source: Authors.

Model	MAPE	Variables
1	0,00245412	Operations, GDP per capita , population, TRM
2	0,00259602	Operations, population, TRM
3	0,00266953	Operations, GDP per capita , TRM
4	0,00418937	Operations, TRM
5	0,00439192	Operations, Operations with delay t-1
6	0,0047898	Operations, GDP per capita
7	0,00646659	Operations, GDP per capita, population
8	0,00839123	Operations, population

In the case of the variable “national (or domestic) air cargo”, GDP a per capita and population were used as auxiliary variables to estimate the future forecast, thereby obtaining the results shown in Model 4. In Fig. 4 Model 3 is presented, where the behavior of estimated values for the chosen model is shown. These values overlap with the behavior of the original values. 0,42% MAPE can also be observed (see Table 4). To estimate the forecast, ARIMA (3,1,0) model was

used in the variable per capita GDP and ARIMA(1,1,0) model in the variable population in order to carry out 5 years forecast and for it to be included in the variable national air cargo.

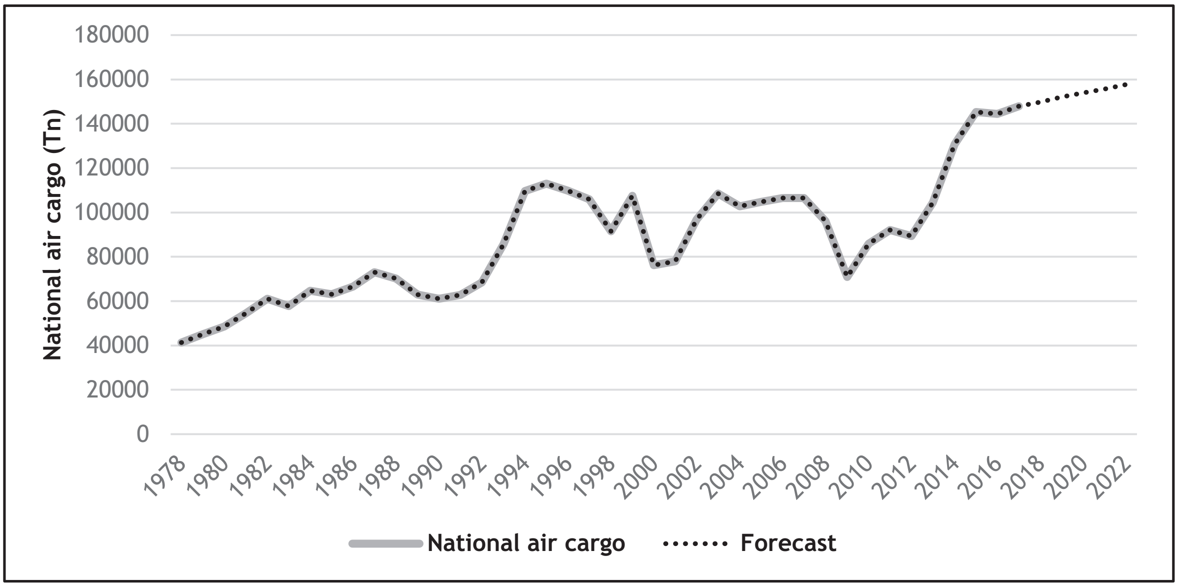

Figure 4 - Model 4, forecast for the variable "national (domestic) air cargo". Source: Authors.

Table 4. Comparison of MAPE values for Model 4. Source: Authors.

Model	MAPE	Variables
1	0,0042948	National air cargo, GDP per capita , population
2	0,00438331	National air cargo, population
3	0,00951284	National air cargo, GDP per capita
4	0,01479821	National air cargo, national air cargo with delay t-1

In the case of the variable "international air cargo", GDP and international trade (imports and exports) were used as auxiliary variables to estimate the future forecast, thereby obtaining the results shown in Model 5 (see Fig.5).

In Fig. 5 Model 5 is presented, where the behavior of estimated values for the chosen model is shown. These values overlap with the behavior of the original values. 0,63% MAPE can also be observed (see Table 5). To estimate the forecast, ARIMA (3,1,0) model was used in the variable GDP, ARIMA(1,1,0) in the variable imports, and ARIMA (1,1,0) model in the variable exports in order to carry out 5 years forecast and for it to be included in the variable international air cargo.

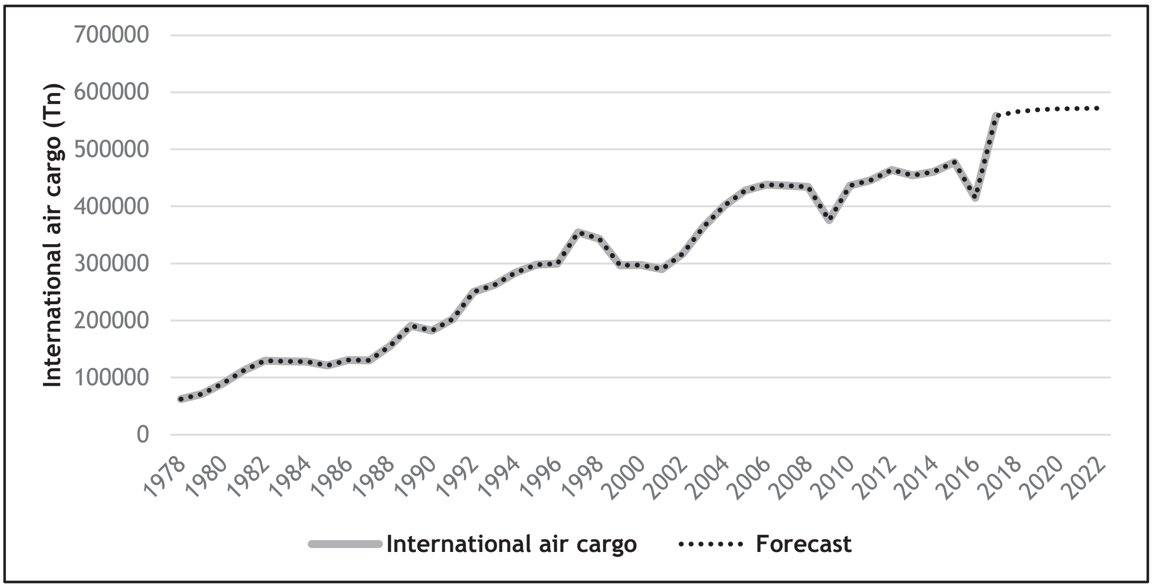

Figure 5 - Model 5, forecast for the variable “international air cargo”. Source: Authors.

Table 5. Comparison of MAPE values for Model 5. Source: Authors.

Model	MAPE	Variables
1	0,00633563	International air cargo, imports, exports
2	0,00750094	International air cargo, GDP, exports
3	0,00762745	International air cargo, GDP, imports, exports
4	0,00840434	International air cargo, GDP, imports
5	0,00891068	International air cargo, international air cargo with delay t-1
6	0,01684195	International air cargo, exports
7	0,02385259	International air cargo, imports
8	0,02820351	International air cargo, GDP

Conclusions

Considering the advantages of using DLMs in the forecast of time series, an initial description of variables was made, which revealed a growing behavior as well as strong correlations in time with the covariables. As regards the covariables present in the models, an ARIMA model was used to carry out their future forecast and for those values to be included in the model chosen. The result of the application of DLMs presents MAPE values below 1%, which ensures high predictability forecasts. On the other hand, it could be verified that when the model chosen is contrasted with models that compared the variable with delay t-1 (which is equivalent to AR(1) models), DLMs showed the best performance as alternative models to develop reliable forecasts in air transport (or air traffic prognosis), at least in the short term.

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Air Transportation Sustainability Strategies: Technological, Operational, Economic, Social and Environmental.

Airports Operational Strategies

Military Aircraft Life Cycle - A holistic perspective of how sustainability can be exploited

José Lourenco da Saúde - lourenco.saude@icloud.com
UBI

Abstract
To address the issue of military aircraft with regard to life extension and other system options as the most relevant option that today exists in terms of contribution to sustainability.
The research process is essentially a document research in terms of open sources that provide data in terms of programmes information of military aircraft that over the years have been submitted to upgrades and life extension.
A demonstration that military aircraft whose service life has been extended including upgrade of systems have been positive contributors to the sustainability of aviation from an economic, environment and technology perspectives.
The originality comes will be two fold, that is, it is estimated that military aviation also contributes to aviation sustainability: Portugal has also taken options in terms of the Air Force by promoting upgrade and life extension of some of the aircraft.

Keywords
military aircraft; life extension; aircraft sustainability

Military Aircraft Life Cycle - a holistic perspective of how Sustainability can be exploited (

1. INTRODUCTION

Unlike civil aircraft that tends to change Operator after had concluded a leasing period, which is in average of the order of 10-12 years, the military aircraft permanence at a single Defence Operator in certain cases exceeds more than 30 years.
Figure 1 gives a perspective of how the in service life can be long for certain types of aircraft [1].

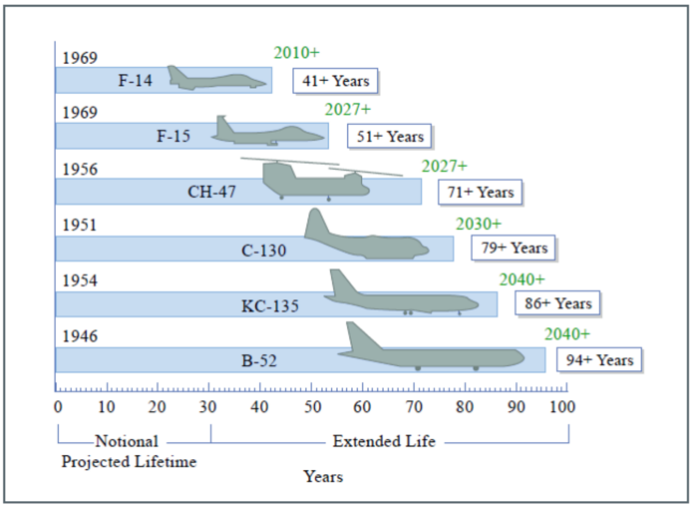

Figure 1 – Example of life service span of military aircraft

Source: [1]

In this context, Portugal is no exception, being examples of 56 years of operation for the helicopter Alouette III or 42 years of life of the C130H. Both are still in carrying on military activities fulfilling the applicable missions.

Many reasons could explain the success of long life spans of many military aircraft currently in operation vis a vis the civil units.
Without having to make specific assumptions, it is clear to say that if military aircraft can continue to fly that is possible because they have not yet reached the limit of the applicable fatigue life.
Among other reasons, discussed below, fatigue is the most critical factor that from a material perspective dictates the capacity to continue to operate.

In fact, it is not the fatigue itself rather its consumption or in other words the rate of expenditure towards the applicable limit.

In other words, for a similar period of time, military transport aircraft although with more variety of operations [ranging from transportation to tactical flights including just standing in alert to conduct specific activities such as SAR or eventually Air Defence operations] fly less

which means less pressurization cycles of the cabin thus the rate of fatigue consumption is more favourable to them.
The explanation for this, for the same period of time civil aircraft perform more landing/take -off cycles which means more fatigue consumption resulting from more pressurization cycles.

Also explaining why it is possible to successfully continue to fly old aircraft is the fact they are able to respond to specific requirements which *inter alia* encompass operational and ATC capacities which over the years have been evolving not only in the military domain but also in the civil spectrum of activities.

This means that the avionics system of aircraft that have been in operation for more than 40 years were modified to absorb new functionalities such as TCAS, RVMS, GPS etc, etc, allowing them to comply with the progress of the ATC [1],procedures.

The same applies in the military segment, where onboard systems have been introduced in terms of navigation, communications and in the domain of electronic warfare [2] (also known as self defence or auto-protection systems).

In other words, the existent aircraft are old in terms of airframe however as they have been submitted to modifications over the years these actions have permitted the aircraft to continue to be effective in terms of operation and capacity to respond to the continuous progress of the ATC environment.

By taking this option, the life of the aircraft has been extended which at the end corresponds to improve the sustainability of the aircraft.

This provides an additional perspective of the aircraft life cycle, as traditionally sustainability is centered in terms of its contribution to the environment, by mainly involving actions towards reducing gas emissions (being the main pollutants Carbon Dioxide (CO_2), Nitrogen Oxides (NO_x), Sulphur Dioxide (SO_2), Volatile Organic Compounds (VOCs) and Carbon Monoxide (CO)), noise reduction, fuel efficiency and materials.

This approach typically encompasses most of the times design and development of new civil aircraft with more efficient engines and new material, measures that as Whitelegg & Cambridge [2, p. 39] define allow to:

- contribute to achieving reductions in greenhouse gases and eliminating or reducing the negative consequences of climate change;
- reduce the size of the ecological footprint of nations;
- protect human health.

On the contrary, military aircraft tend to increase its sustainability by introducing modifications that extend the life service operation while keeping the original structure. In other words, as consequence those modifications extend the original life cycle.

2. METHODOLOGY AND RESEARCH DATA

The approach associated to this work relies essentially on the utilization of open sources, with bibliographic research and analysis in view of providing evidence that military aircraft also pursue a different perspective of sustainability that include updates during the life span

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[1] TCAS = Traffic Collision Avoidance System; RVSM = Reduced Vertical Separation Minima; GPS = Global Positioning System; ATC = Air Traffic Control.

[2] This type of systems includes passive and active capacities. The today's technology for the passive functions mostly include Radar Warning Receiver and Missile Warning Approach capacities; as for the active functions these include jammers and chaff and flares, to react to threats related to radar illumination and to incoming missiles, respectively.

encompassing modernization of existent fleet instead of phasing out and then scrapped or parked hot desert.

3. THE CONCEPT OF LIFE CYCLE - RELEVANCE

The life cycle (LC) is a well known concept defined in at least three standards, that is, ISO 15228 [3] – initially oriented for the development of software engineering; in the AAP 20 [4] standard dedicated to the development of defence systems of any type, that is land, sea and air; and in NASA Systems Engineering Handbook - devoted to mainly to aerospace however they are applicable to any kind of system – from a global perspective.
The next paragraphs address briefly life cycles under standards ISO 15228, AAP 20 and NASA Systems Engineering Handbook.

Figure 2 [5] summarizes ISO 25288 graphically the life cycle of a system. As shown it encompasses five stages (concept, development, production, use/support and disposal).

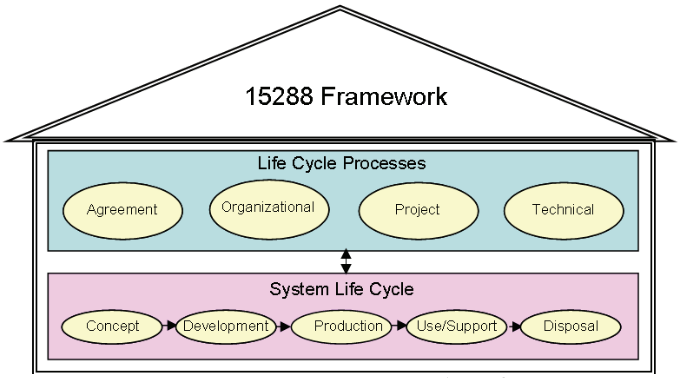

Figure 2 - ISO 15288 System Life Cycle
Source: [5]

Figure 3 presents NATO AAP 20 system life cycle with an additional stage (pre-concept) which in essence it is a phase of feasibility study.

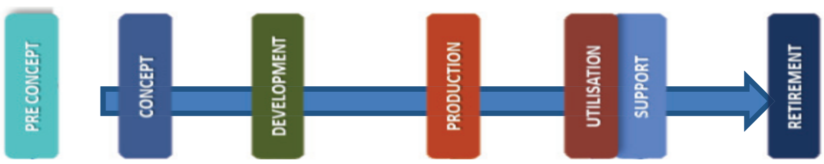

Figure 3 - NATO AAP 20 System Life Cycle
Source: [4]

Finally, the standard NASA System Engineering Handbook exhibits its vision of the systems life cycle as shown in Figure 4.

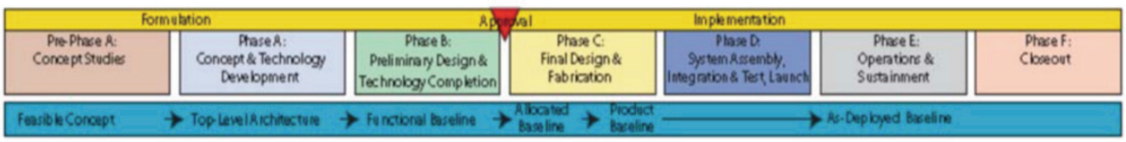

Figure 4 - NASA System Life Cycle
Source: [6]

In general terms, despite the fact NASA approach has more details and the difference in terminology among the discussed standards, all three standards encompass similar stages of the life span of (any) system from inception until operation is stopped/disposed/retired.

As it results from the above figures, the LC concept relies on the fact that although it does not establish a finite timeframe for the duration of the life cycle of each system, it is relevant to state that it does not also explicitly addresses the need to upgrade the aircraft during its life in order to ensure capacity to continue to operate.

In practical terms, although the existent LC is a reliable manner to describe the sequence associated to life span of an aircraft, the sustainment included (NASA phase E – see Figure 4) is linked to sustainability. In other words, it is not possible to ensure sustainability if the aircraft is not sustainable.

To close this part of the discussion, the central aspect of the aircraft sustainability is in fact how the aircraft manufacturers – on in concrete the entities owning the design type certificate (known as OEM) either civil or military approach it in the LC.

In concrete, the approach of sustainability of the civil aircraft apparently is addressed differently when compared to the military aircraft process.

The practice of sustainability by the OEM of civil aircraft is oriented, as expressed before, towards the design and production phase[3] by incorporating solutions related to design options for Products and Operations [7] [8] [9] [10] aiming at noise reduction, waste reduction, recycling materials and fuel efficiency, that is to say environmental driven.
This means that if a civil Operator wants to operate a better efficiency aircraft then the alternative is to acquire a new aircraft exhibiting better sustainability factors.

The above allows to conclude that from a LC approach for a civil aircraft that sequence can be considered frozen in the sense it does not incorporate a specific stage to revisit the characteristics of an aircraft to improve sustainability [4] [11].

A way that Operators have to improve aircraft sustainability is through cost reduction and meeting specific environmental aspects as described in PWC report [12, p. 6 ss] namely by controlling fuel efficiency and carbon emissions levels with different indicators.

On the contrary, (some) military aircraft suffer upgrades during their life cycle keeping the original structure and enhancing specific characteristics, namely in various domains, such as, communication, navigation, electronic walfare, being examples of this options [13] [14] [15] [16]:

- Bombers B21, B1, B2, B52;
- Transport/tactical C-17, C-5, C-130
- Tankers KC-135, KC-10, KC-46
- Other VC-25
- Fighter F16, F18 and F22

[3] Although IS0 15288 and NATO AAP 20 include separated phases for Design and Production in real terms the design process can not be concluded without producing the system. As such the phases are not in sequence but in parallel that is design stars first and then once the first production data specifications are available then procurement for manufacturing and assembly starts.

[4] The conversion of passengers transport aircraft into cargo aircraft by extending the operational life can be considered as an improvement of sustainability businesswise.

This approach leads to separate sustainability in two components, that is, the external or the Environmental; and internal or in terms of operational life span of the aircraft.

With regard to the Sustainability from the Environmental perspective, the Operators are limited to improve this type of Sustainability, because that depends on the overall efficiency of the acquired and/or leased aircraft they operate.

To this end, any intention of the airline Operator to modify their aircraft to improve this type of Sustainability is a process outside of the Operators regulatory privileges, because they are not supposed to hold capacity to perform extensive and complex modification of the operated airplanes.
In concrete terms, this type of services is restricted to the owner of the type certificate of the aircraft or it can be done by an entity holding EASA Part 21 (or equivalent) together with an adequate aircraft design organization [5].
As a consequence of these regulatory-design conditions, the available option for the airline Operators to improve the sustainability of their aircraft is mainly by addressing it through the efficiency of operation, namely by defining processes leading to the reduction of fuel consumption and waste management.

Unlike the environment sustainability the sustainability related to the life span or operation can be modified by defence Operators namely by upgrading the aircraft in the aspects that once incorporated the airplane can continue operation, extending it thus the sustainability.

This is seen in fact as corresponding to an improvement of the sustainability process of the aircraft.

The next section deals with the aspects that need to be taken in consideration for expanding the life span of military aircraft in terms of sustainability.

4. AGEING AND OBSOLESCENCE VS SUSTAINABILITY

Unlike civil Operators that exhibit more flexibility to change aircraft and procure more efficient units (in both sustainability components) the defence sector faces more complex sustainability[6] aspects because the sustainment challenges are dependent upon a number of factors as described by GAO [17] :

- Delays in acquiring replacement aircraft;
- Unexpected replacement of parts and repairs;
- Delays in depot maintenance;
- Shortage of deport maintenance personnel;
- Parts obsolescence; Diminishing manufacturing sources.

The first factor limiting sustainability is related to the prolonged timeframe required to change from existent aircraft with new units able to respond to modern capacities.

As concluded by Riposo, McKernan, & Kaihoi Du [18, p. pg XI] there are a number of reasons that as result of it make acquisition programmes with extensive duration whose reasons are shown in Figure 5.

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[5] This means a set of capacities that involve among various aspects, engineering resources to carry on conceptual and detailed design and production – see NASA System Life Cycle – but and mostly it requires knowledge of the aircraft design characteristics .

[6] In this text sustainability and sustainment although not synonyms are used expressing common meaning that is a system to have sustainability needs to be able to sustained. As such the sustainment is the essential contributor for aircraft sustainability.

Regarding the duration of the aircraft design, development and production (all hereinafter called the project) it is common to observe that unlike the aircraft civil programmes the project of military units tends to take more than one decade.
Many examples could be given, such as, the A400M, the KC390 and the F22 referred in the next paragraphs.

The A400M originally started the first requirements in the 1982 being initially denominated FIMA (Future International Military Airlifter with Aeroespatialle, MBB). Later in 1989 Lockheed withdraws whilst the name is converted into Euroflag (European Future Large Aircraft Group with new partners - Aeritalia and CASA).

Finally, in 1999 BAE Systems, Daimler Chrysler Aerospace (DASA), France's Aerospatiale Matra and Spain's Casa establish Airbus Military Company to develop the A400M – the present denomination. After contract signature in 2003 the long-awaited maiden flight took place on 11 December 2009 [19].

Area	Possible Reason
Requirements development, generation, and management	Infeasible or unrealistic requirements
	Unstable requirements (e.g., engineering requirements, readiness requirements, reliability and support requirements)
	Inefficiencies in the process (e.g., serial nature of process and requirements evolution)
Managing technical risk	Excessive technical, manufacturing, or integration risk (general) or program complexity
	Unanticipated design, engineering, manufacturing, technical difficulty, or technology integration issues
	Overly optimistic assumptions/expectations (technical risks, performance goals, system requirements, or design maturity)
	Immature technology
	Concurrency in complicated programs
	Prototyping
	Deficient test planning or testing inefficiencies
	Inadequate funds for testing
Resource allocation	Funding instability or budget cuts
Defense acquisition management	Lack of focus on schedule or inadequate schedule management (e.g., underutilization of integrated master schedule)
	Overly optimistic assumptions/expectations in general, including insufficient contingency funds in program budgets
	Overly optimistic assumptions/expectations in cost and schedule estimates
	Personnel issues
	Competition
	Use of undefinitized contract actions
	Contractor performance and inadequate incentives
	Inadequate tailoring of the acquisition process
Other	Delays in obtaining necessary data

Figure 5 – Reason for long duration for aircraft Programmes
Source: [18]

Similarly, the KC390 was formally announced for the first time 2007 with roll-out in 2014 with a forecast of Initial Operating Capacity by the end of 2019 followed by series production - [20].

Finally, as also an example of the duration of military programmes is F22 Raptor where in October 1985 the USAF proposes the Advanced Tactical Fighter that resulted in 1997 in the first flight of the F22.

Associated to this is the fact the most of the funds/budgets available for military programmes run on a financial year, meaning that sometimes as also referred by authors the funding is unstable or suffer from cuts, because they are managed on a yearly basis, which means that if they are not properly and continuously financed they will prolong their project.

As consequence of extending the life of the aircraft the “old” units are seen as legacy. In this respect Figure 6 gives examples of extended life of various type of aircraft.

As referred by USAF [21]:

> “Maintaining aircraft that are nearing the end of their design service lives requires an enterprise effort to maintain airworthiness, mission capability, and effectiveness for these aircraft.
> This is being done today, but only by extensive repair and remanufacture of the aircraft component by component. It also requires that upgrades be implemented to retain warfighting capability for fighters and bombers or fuel efficiency for transports and tankers.”

Figure 6 - Legacy Aircraft
Source: [17, p. 7]

In this long process to obtain a new aircraft it must considered the turnkey solution, i.e., the acquisition of aircraft that have already entered in series production meaning they have already received the type certificate (or equivalent).

This solution is the traditional one, either for the civil and military market, where Operators define requirements and select the aircraft that are already in operation under commercialization.

In the military sector the turnkey option adds more time to the full process to obtain a new aircraft as the acquisition process of units with type certificate only occurs after it has been granted.
The procurement process encompasses the necessary preparation for the invitation to tender all the whole steps that ends in acquiring the aircraft [22]

Parallel to the discussed long acquisition process is the excessive downtime of depot maintenance recognized, conclusion that comes from analyzing the sustainability of aging aircraft [23, p. 61], mostly related to critical factors namely the capacity to respond to the Technical Challenges for Operators of Aging Aircraft, that is fatigue, corrosion, materials and systems obsolescence [24, pp. 23-33].

From a different perspective, to continue operation of the ageing aircraft it is necessary to overcome the elements that prevent the sustainability, being critical to resolve the obsolescence of systems that prevent the sustainment and creates limitations to operation.

As mentioned before, the effectiveness of the operations can be dependent in terms of the capacity of the aircraft to respond not only to specific operational requirements but also to ATC requirements.
This imposes to the existent aircraft new features in terms of integration in the complex process of ATC operations, namely [25] in two domains that will interfere with the aircraft (either civil and military). i. e., Remote Control Towers ((…) replacing traditional tower buildings with a control room that can be built almost anywhere) and “Space-Based ADS-B” ((…) that allows an aircraft to access satellite navigation systems to determine its position and then broadcast it, enabling it to be tracked (…)”

The next section deals with options taken by the Portuguese Air Force for some of its weapons systems, in a description combining aging and obsolescence with the need to keep sustainability.

5. THE PORTUGUESE AIR FORCE – SUSTAINABILITY CASE STUDY

In view of the above, looking for the sustainability in terms of military aircraft regarding capacity to continue to be operated, and example of the approach that have been a solution by the Portuguese Air Force is the F16.
The next paragraphs describe briefly the sustainability approach that have been in place for aforesaid weapon system.

F16 Sustainability

The Portuguese F16 aircraft first units entered into service in 1994 [26, pp. 4-12] and over the years have performing the essential mission, that is air defence.

Although already in service after almost 25 years, the F16 of the Portuguese Air Force have been successfully operating because conscient of the limitations associated to the process of replacing aircraft which, as previously mentioned can take more than one decade, decision was taken in 2000 by Portugal to joint a multination programme.

This initiative known as MNFP (F-16 Multinational Fighter Program) is a reference in the military environment, that “(…) saw light on June 10, 1975 when the Ministers and Secretary of Defense from the United States, Belgium, Holland, Denmark and Norway signed a Memorandum of Understanding (…)” that In 1980 the MNFP agreement evolved and gave birth to a Mid-Life Update” process an opportunity to modify the basic F16 characteristics known as “(…) Block[7] 10 &15 and bring them to a near Block 50 capability including the integration of a glass cockpit and a mission computer (…)” [27].

After the acquisition of the F16 by Portugal the Portuguese authorities aware of the relevance to be part of the MNFP agreement on June 9, 2000 signed a memorandum of understanding with the founders of said programme thus becoming the sixth nation.

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[7] Block is a terminology used by the manufacturer of the aircraft Lockheed – Martin represent variants of the of the first F16 that was produced (note of the author)

The decision taken by Portuguese Air Force in 2000 for the MNFP as also member of the European Participating Air Force (EPAF)[8] has allowed the take advantage from the available financial resources, applying them to be more efficient and have access to advanced operational features [28, p. 8].

In practical terms the sustainability approach by the Portuguese Air Force for the F16 was aimed mainly at:

- Ensuring evolutionary strategy based on cost sharing for the upgrades to be implemented (to reach higher blocks);
- Improve the operational sustainability by participating in operational training with EPAF members.

This solution taken in 2000 was preventive, in the sense as Santos [28, p. 9] referred in reducing the exposure to obsolescence and also it enabled to share solutions for the structure of the aircraft that inevitably faced aging and accumulation of more cycles of fatigue, namely as the result of the MLU process that introduced new armament (with GPS capacity) with targeting pods.

Likewise, should Portugal had not taken the solution enabling the improvement of the sustainability of the F16 by joining the MNFP/EPAF programme the risks and costs (non-recurring and recurring) would have been such that result would have been the progressive lack of capacity of sustainment.

As mentioned by JAPCC [29, p. 7] partnership is essential to ensure sustainability of aircraft because that realises “(…) savings by creating and jointly manning (…) to manage and consolidate common enabling aspects, including logistics, maintenance and training. Common standards, policies, syllabi, and procedures (…)”.

Notwithstanding the above the picture is not all rosy as the F16 sustainability process under the MNFP programme is not unlimited as the solution will not last forever.

In this particular case, the F16 is aimed at 8000 flying hours [28, p. 9], with means that the continuation of sustainability process requires continuous intervention to ensure that aircraft is permanently updated to meet the capacity for the combat scenario where it is operated in the international environment of NATO and of the United Nations and of the European Union operations.

Participation in the MNFP, in view of increased sustainability, has allowed the introduction of a modular mission computer, upgraded radar and other systems [30].
This permitted capacity to ensure interoperability with NATO partners, detection of long-range aerial and ground targets, operation in any weather conditions day and night, electronic identification of other aircraft and integration into battlefield management networks.

6. CONCLUSION AND PROSPECTING THE FUTURE –A NATIONAL APPROACH

The issue of sustainability is traditionally approached from an environmental perspective namely covering civil aircraft, in this case trying to reduce mainly noise and pollution footprints.

Howeve , parallel to this there is the reality of military aircraft that need to be seen as systems that require sustainability including in the domain of operational capacity.

[8] EPAF is composed of Royal Norwegian Air Force, Royal Netherlands Air Force, Royal Danish Air Force, Belgian Armed Forces Air Component and by the Portuguese Air Force.

In other words, there are a number of military types of aircraft that have prolonged life, which means that to reach that circumstances nations had to put in place specific approaches to resolve critical issues that have to be resolved or taken into consideration, that is:

- Long processes to replace aircraft with new units with better survivability factors;
- Obsolescence of systems;
- Fatigue;
- Corrosion;
- Excessive maintenance depot downtime.

To overcome this need to ensure the capacity to sustain thus the sustainability, examples exist that combine two essential aspects, that is, continuous upgrade of aircraft and partnership sharing costs and risks.

In this environment, Portugal is not immune to the need to improve the sustainability of its Air Force aircraft which led to the participation in an international programme involving the F16.

This initiative, given the knowledge required to modify an aircraft, the non and recurring costs associated to modify an airplane is not an option to be exercised by only one nation.

So far, the involved nations in this joint sustainability programme known as an Mid-Life Upgrade programme has been successfully managed in the sense that the F16 fleet belonging to the various nations continue to be operated under the very demanding operation requirements applicable to the missions F16 perform.

Without prejudice for the level of sustainability already reached by the F16, there are threats to this, mainly the fact that if one or more partners of this joint exercise decides to exit then the whole process is put at risk because recalculation of risks and costs may dictate ending of the process thus the sustainability of the aircraft.

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A-CDM description and operational implementation challenges

Omar Daniel Martins Netto - omar.netto@ubi.pt
University of Beira Interior, Covilhã, Portugal
Jorge Silva - jmrs@ubi.pt
Universidade da Beira Interior, Covilhã, Portugal; CERIS, IST, University of Lisbon
Maria E. Baltazar - mmila@ubi.pt
Universidade da Beira Interior, Covilhã, Portugal; CERIS, IST, University of Lisbon

Abstract

The purpose of this research is to discuss a subject that, today, is a significant challenger of all the International Civil Aviation Organization (ICAO) signatory countries: the implementation of the Performance Improvement Areas preconized in the Global Air Navigation Plan (GANP).

To achieve the objective of providing a better understanding of Airport Collaborative Decision Making (A-CDM) processes the strategy chosen was to present the vision and implementation of the main entities representing the aviation area, such as the didactic form as the article is sequenced and the case studies discussed will present solutions for countries that aren't so advanced in the implementation of their A-CDM operational processes. Also, the article will act as a guide for all stakeholders. The contribution of the research will be to provide further support to all stakeholders in the air transport sector, regarding basic knowledge and more technical approaches of compliance with the recommended guidelines for the next decades in GANP. ICAO. In this specific case, regarding Performance Improvement Area: Airport Operations and the A-CDM module.

Keywords

Airport Operations; Global Air Navigation Plan (GANP); Airport Collaborative Decision Making (A-CDM); Performance Improvement Areas

A-CDM description and operational implementation challenges

1. INTRODUCTION

Among the areas of performance improvement advocated by International Civil Aviation Organization (ICAO) in the Global Air Navigation Plan (GANP), to be implemented in the coming decades, and to integrate the projects of each signatory country, Airport Operations and Airport Collaborative Decision Making (A-CDM) appear as items of significant importance for Air Traffic Flow Management (ATFM). The A-CDM concept started more than a decade ago in Europe and its equivalent to Surface-CDM in the USA, established a new way to optimise operations at airports through a more efficient collaboration between all interested parts. This innovative approach, based on transparency and sharing of information, is now a well-documented, strongly supported concept, and accepted worldwide by concrete results at various airports.

A-CDM is a process that provides a positive response to the problem of congested airports. It is supported by the International Civil Aviation Organization (ICAO), Civil Air Navigation Services Organization (CANSO), International Airport Council (ACI), and International Air Transport Association (IATA). Today, manuals dealing with Future Air Navigation Systems (FANS) such as the Single European Sky Air Traffic Management Program (SESAR), the USA's Next Generation Air Transportation System (NextGen) and Japan's Collaborative Actions for Renovation of Air Traffic Systems (CARATS), already incorporate several variants of A-CDM. Each of these organisations and projects has developed a vision according to their specific needs and context. The A-CDM is a mindset, and working methods change to improve the airport operations performance and provide better overall predictability, allowing the stakeholders to work together as a team for mutual benefit. The process is based on transparency and information sharing among key stakeholders, starting with the establishment of collaborative work methods and practices [1].

In the current Air Traffic Management (ATM) concept, when the demand for traffic exceeds available capacity at airports or air traffic control units, aircraft are retained at the airport, these actions cause a lot of delays and ATFM slots troubles. A-CDM is a new process in the air traffic system using the concept of proactive decision-making, which aims to replace the current centralised system of air traffic management with collaborative decision making in respect to the airport's airside operations. To establish such a system, it is necessary to include, in the air transport system, all stakeholders and deliver timely information to all users. The main stakeholders in this system are the Air Traffic Controller (ATC), Airports and Airlines [2].

The A-CDM approach, which involves ATC and Airports, is one of the fundamentals contained in the GANP that will guide aviation in the coming years. This knowledge is of vital importance for those in the air sector, especially occupants of management positions in the air traffic services, airports and airlines operational areas so that they can interact operationally with the air traffic control agencies and airport operations areas. Thus, a set of performance improvements processes to achieve the objectives are suggested, such as in Airport Operations, this theoretical basis is essential, as well as the understanding of the importance, diversity and flexibility of its application [3].

This paper describes and highlights the main characteristics and points that include the operationalisation of an A-CDM, bringing the vision of the leading system implementers today, such Europe and the USA, air sector associations representatives, such as CANSO and IATA, and academics. Also, considers the contribution that the academy has given in the field of decision support, and collaborative decision using studies by [4], as well as the work of [5], which allowed us to measure the effectiveness of the operational and decision-making processes.

This paper has practical, scientific, methodological, social and personal relevance. In practice, the results of this study can clarify and mark actions to air sector members and serves as the primary theoretical basis for those who should start working with Aviation System Block Upgrades Methodology (ASBU) and A-CDM. Scientifically provides support for future academic research in the field.

2. LITERATURE REVIEW

2.1 Methodologies

Multiple Case Study was adopted for the preparation of this paper to facilitate the understanding, illustrating and giving more credibility, to the Case Study methodology, which will allow presenting some analysis and solutions already performed at the international level. According to [6], case studies can cover multiple cases and then draw a unique set of cross-case solutions. The same author considers that in some areas, multiple case studies have been considered a different "methodology" than single case studies.

However, to illustrate in this paper, it is interesting to highlight one of the most appropriate methodologies in studies and processes implementation, such as the one studied. The characteristics of the aviation sector and, more particularly, the airports and the air traffic control services, always recommends collaborative actions applications. Moreover, the Collaborative Decision-Making (CDM), now widely adopted by ICAO, is a recommended process to be applied by managers and stakeholders.

2.2 The GANP and ASBU Understanding

According to GANP 2016-2030 [7], the ASBU methodology is an approach that aims to facilitate and enable each state to move forward in their air navigation capabilities based on each of their specific operational needs. Such a block system will allow the sector to achieve global harmonisation, increase capacity and improve environmental efficiency - improvements that are requirements imposed by the air traffic growth in all regions of the world. Considering these needs, ICAO has developed a comprehensive system of block improvements, mainly to ensure that aviation safety is maintained, improved and ATM programs can be effectively harmonised and not put any barrier to future aviation efficiency. Moreover, environmental gains and a reasonable cost of implementation efficiency. The primary foundation of the concept is linked to four specific issues and interrelated areas of performance improvement (Figure 1):

a) Airport operations;
b) Interoperable systems and data at the global level;
c) Optimum capacity and flexible flights; and
d) Efficient flight paths.

The technologies and procedures for each Block were organised into Single Modules, based on their respective Performance Improvement Areas. In systems engineering developed by ICAO for its Member States, they only need to contemplate and adopt, the Modules suitable to their operational needs. Not all States will have an obligation to implement each Module. ICAO will be working with its Member States to support and guide, and to determine, precisely according to their operational requirements, which capacities they should have in each of their systems.

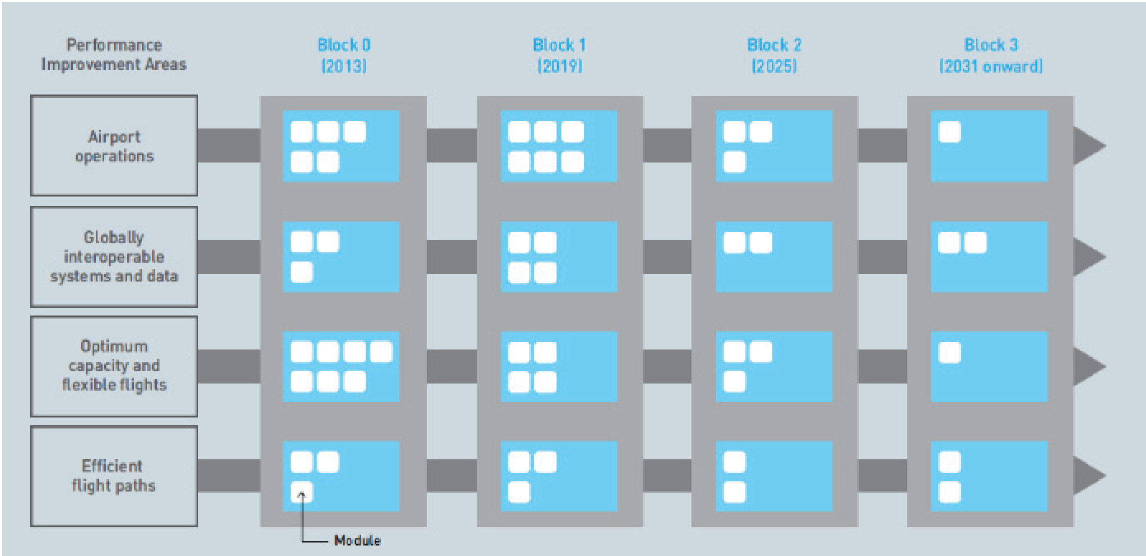
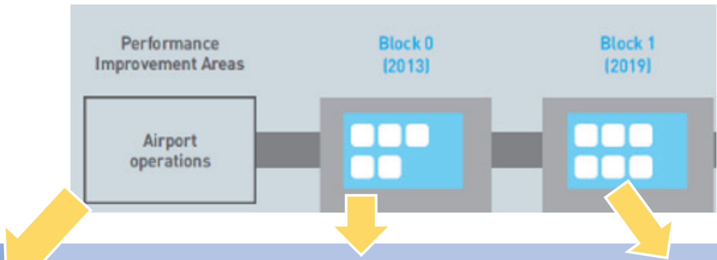


Figure 1: The ASBU standard.
Source: [7]

These four performance improvement areas showed in Figure 1, and the so-called ASBU modules associated with each one was organised into a series of four blocks (Block 0, 1, 2 and 3) based on timelines for the variable, which is contained, as illustrated in Figure 2 (Blocks 0 and 1).



Performance Improvement Area	BLOCK 0 (2013-2018) (5 modules)	BLOCK 1 (2019-2025) (6 modules)
<u>Airport Operations</u>	Optimisation of approach procedures including vertical guidance	Optimised airport accessibility
	Increased runway throughput through optimised wake turbulence separation	Increased runway throughput through dynamic wake turbulence separation
	Improved traffic flow through runway sequencing (AMAN/DMAN)	Improved airport operations through departure, surface and arrival management
	Safety and efficiency of surface operations (A-SMGCS levels 1-2) and enhanced vision system (EVS)	Enhanced safety and efficiency of surface operations - SURF
	Improved airport operations through A-CDM	**Optimised airport operations through A-CDM total airport management**
		Remotely operated aerodrome control

Figure 2: ASBU - BLOCK 0 and 1 – MODULES focused in A-CDM
Source: Own elaboration based on the ASBU standard [7]

ASBUs are not comprehensive, nor are they an umbrella system, but remain flexible modules that can be used by States according to their individual operational needs. One of the hallmarks of ASBUs is that they define technologies and procedures that are calculated to improve operational performance, mainly when the need came for an operational problem to be solved. The goal is to achieve global harmonisation and interoperability of air navigation [9].

2.3 Collaborative Decision-Making (CDM)

The A-CDM concept is based on a general idea about collaborative actions, called CDM. From this concept, the ICAO starts to apply it in aviation.

According to Steiner, Stimac and Melvan [2], the implementation of Airport-CDM involves a change in procedures and a cultural change in all the interested parties involved. The author's further state that the system is based on two main elements:

a) Predictability of events - which would result in the optimisation of each process related to aircraft and airport operations; and
b) On-time performance of operations - which would influence the increase in capacity of the airport and ATC on one side and, more directly, the efficiency of airlines and the use of aircraft on the other.

CDM at congested airports has demonstrated that considerable improvements could be gained at airports by air transportation agents, without sacrificing internal objectives and the means for different operators to achieve them. The goals of A-CDM are to reduce delays and improve system predictability while optimising the utilisation of resources and reducing environmental impact. An airport is ready to be considered a CDM airport only when A-CDM Information Sharing (ACIS), Turn-Around Process (CTRP) and Variable Taxi Time Calculation (VTTC) concept fundamentals are useful at the coordinated airport. In Europe, airport CDM has been implemented successfully at several airports and are expanding. Collaborative Air Traffic Management is now a key component in both SESAR and NextGen [10].

2.3.1 CDM – ICAO Overview

According to ICAO documentation DOC 9971 dealing with the subject [11], CDM defines a process focused on how to decide on a course of action articulated between two or more community members. Through this process, members of the ATM community share information related to that decision, interact, establish everyday choices and apply the approach and principles of decision making. The overall purpose of the process is to improve the performance of the ATM system while balancing the needs of individual members of the ATM community.

2.4 Airport Collaborative Decision Making (A-CDM)

Collaborative decision-making at airports is a process that provides a concrete response to the problem of congested airports. It has become essential in recent years, a process supported by the International Civil Aviation Organization, the International Airport Council, the International Air Transport Association and the Civil Air Navigation Organization.

2.4.1 A-CDM. The ICAO Normative Measures

Collaborative decision making at the airport is a set of philosophy processes of collaborative decision-making applying in aerodromes operations

The A-CDM allows airport and aircraft operators, air traffic controllers, ground handling agents, pilots, and traffic flow managers to exchange operational information and work together to manage aerodromes, A-CDM can also improve the planning and management of en-route operations. The A-CDM defines the rules and procedures used by aerodrome participants to share information and collaborate. The A-CDM enables all stakeholders to streamline their operations and decisions in a collaborative environment, considering their preferences, known constraints, and the predicted situation. The decision-making process is facilitated not only by the sharing of accurate and timely operational information through a standard set of tools but also by the application of agreed procedures and procedures. The primary objective of the A-CDM is, therefore, to generate a shared situational awareness that will foster better decision-making. The A-CDM, however, does not weak or eliminate the responsibilities associated with decisions. Decisions are still made, and A-CDM partners remain accountable for their actions. They are, however, taken collaboratively and, as a result, are better understood and applied [11].

2.4.2 A-CDM. The IATA Overview

According to IATA [12], A-CDM is designed to improve overall airport and network efficiency through improved turnaround processes, harmonising sequencing, surface and departure management. IATA supports common objectives and performance metrics between all A-CDM stakeholders, based on mutually agreed targets:

a) Airport Operations;
b) Aircraft Operators;
c) Ground Handling;
d) Air Traffic Services; and
e) Air Traffic Flow Management.

2.4.3 A-CDM. The EUROCONTROL / SESAR Overview

According to Eurocontrol [13], an airport is ready to be considered a CDM Airport when information sharing, milestone approach, variable taxi time, pre-departure sequencing, adverse conditions and collaborative management of flight updates elements are successfully implemented at the airport. The future European ATM system depends on the full integration of airports as nodes into the network.

This above Eurocontrol report, indicates enhanced airport operations, ensuring an all-in-one process through collaborative decision-making (CDM), in normal circumstances, and through the further development of collaborative recovery procedures in adverse conditions. In this context, this feature addresses the enhancement of runway throughput, integrated surface management, airport safety nets, and total airport management. It also introduces some initial concepts, above which, are basic definitions to guide the implementation of the operational concepts, which are meticulously explained in the 363 pages of the Airport CDM Implementation – Manual.

2.4.3.1 Eurocontrol MANUAL (basic definitions)

According to Eurocontrol [13], Airport Collaborative Decision Making is the concept which aims at improving Air Traffic Flow and Capacity Management (ATFCM) at airports by reducing delays, improving the predictability of events and enhancing the utilisation of resources. Implementation of Airport CDM allows each Airport CDM Partner to maximise their decisions in teamwork with other Airport CDM Partners, knowing their preferences and constraints, and the actual and predicted situation. The decision making by the Airport CDM Partners is facilitated by the sharing of accurate and suitable information and by adapted procedures, mechanisms, and tools. The Airport CDM concept is divided into the following elements:

a) Information Sharing;
b) Milestone Approach;
c) Variable Taxi Time;
d) Pre-departure Sequencing;
e) Adverse Conditions; and
f) Collaborative Management of Flight Updates.

2.4.4 A-CDM. The FAA / NextGen Overview

The traffic management CDM between flight operators and the FAA has been in existence since the mid-1990s. Recent surface traffic management projects have confirmed the potential efficiency and environmental benefits that can be realised from counting other aviation stakeholders, including airports, into the CDM process. The CDM activities in airports have become active, and they have found it valuable in managing aircraft movements, gate management, de-icing operations, ground service equipment coordination, special events, tarmac delays, and Irregular Operations (IROPS). ACDM is thought to be a means of coordination and a tool through technology that is only valid and achievable by the larger airports; though, it can be used by smaller airports as it assists all size airports with their situational awareness. Smaller airports can be significantly impacted during IROPS, and it is their ability to have information quicker that allows them to activate their plan sooner and presumably more effectively with the least amount of impact on the airport's operations or the affected passengers [14].

According to U.S. *Airport Surface Collaborative Decision Making (CDM) Concept of Operations (ConOps) in the Near-Term* [15]: the Surface Domain is a Core Element of the NextGen Implementation Plan (NGIP) AND, the Surface Collaborative Decision Making (CDM) concept will enable U.S. airports to make optimum use of available airport capacity. Thus, increasing traffic management efficiencies across the National Airspace System (NAS). The concept describes the need for timely sharing of relevant operational data among Surface CDM Stakeholders to improve situational awareness and predictability, through a shared understanding of "real" airport demand and predicted imbalances between the demand and public airport capacity. At the core of this concept is a set of well-defined capabilities and procedures, which facilitate the proactive management of surface traffic flows and runway departure queues, via the continuous assessment of airport capacity and demand. The skills and processes are expected to improve the efficiency of surface traffic flow at U.S. airports while reducing environmental impacts. It is understood that Surface CDM capabilities and corresponding procedures must be transparent, flexible, agile, and, equally important, capable of supporting the distinct needs of individual U.S. airports and the unique business models of different Flight Operators.

3. A-CDM OPERATIONAL IMPLEMENTATIONS AND CHARACTERISTICS

3.1 Framework

The planning and operation of an A-CDM should always consider a preliminary assessment of the current operational constraints and which critical implementation milestones, and corresponding milestone should be adjusted to mitigate such restrictions, thus improve the aerodrome and air traffic flow operating conditions.

An airport is considered as *CDM* airport when *A-CDM Information Sharing (ACIS)*, *Turn-Round Process (CTRP)*, and *Variable Taxi Time Calculation (VTTC)* concept elements are applied at the airport. CTRP describes the flight progress from the initial planning until take-off by defined '*milestones*' to allow close monitoring of significant events. Flight Update Messages (FUMs) and Departure Planning Information (DPI) are in place to inform all participating CDM partners about the flight progress. Monitoring the flight between the period of milestone that defines aircraft landed, and aircraft off-block milestone is a complex task because situational awareness has to be established across various

subsystems of different organisational and operational structures having their causal and intentional domain constraints. ‘Subsystems’ here refer to actors who include airport operator, airline company, air traffic control, ground handler, and Central Flow Management Unit (CFMU). Additionally, all terminal and ramp processes have operational interdependencies, e.g. methods can typically not be parallelised, as well as legal requirements, e.g. one side of the aircraft must be clear of obstructions to ensure that firefighting access is always possible [16].

3.2 Stakeholders Recommendations

Corrigan et al. [17] state some consolidated overview recommendations that were accepted by the stakeholders at the airport in the A-CDM implementation:

a) Appoint a dedicated A-CDM coordinator in all stakeholder organisations (airport, ground handling, airline, ATC, fuel, cleaning, catering etc.) that can attend all project meetings;
b) Each coordinator develops a communication strategy for their respective organisations. Create a project team to develop an overall airport-wide communication strategy;
c) Create a sense of collective leadership across all actors to ensure a win-win attitude for all actors;
d) Clearly define and agree on objectives and key performance indicators at global and individual stakeholder organisations;
e) Prioritise the visiting of other stakeholders’ operational space regularly. Make this a fundamental tool for ensuring a common operational picture between stakeholders. This kind of action may be developed into a regular programme of cross-training;
f) Develop an agreed strategy for rewarding collaborative behaviour and discouraging non-collaborative practice;
g) Develop a dedicated training programme to deal with the softer issues of communication and collaboration; and
h) Address the issue of what communication support and methods are required to support the turnaround process operations.

3.3 The Eurocontrol Milestone Approach Concept Element

According to Eurocontrol [13], in the processes of A-CDM, it is common to use the term Milestone, widely used in Project Management. It originates from the stones used to mark the distances at the edge of a road or path. In the cases of A-CDM are used as determinant milestones of each activity (termination of some stage and changes of phase, transition or completion of steps within the process).The milestone approach element describes the progress of a flight from the initial planning to take off by defining Milestones to enable close monitoring of significant events. The aim is to achieve an everyday situational awareness and to predict the forthcoming events for each flight with off-blocks and take off as the most critical events.

A total of 16 basic Milestones have been defined. The list of Milestones is indicative; more milestones may need to be included to cover for extra information updates on critical events, such as de-icing. Local procedures may dictate that some milestones may not be required and are therefore considered as not highly recommended. For each milestone, there are Time References, previously defined or that vary according to each airport, which should be presented and systematically updated to all stakeholders (Table 1).

Table 1
Milestones Descriptions
Source: Own elaboration based on Airport CDM Implementation [13].
*Highly Recommended (HR) or Mandatory; and Recommended (R) or Optional Milestone.

N. °	MILESTONES	DESCRIPTION
1/HR	ATC Flight Plan activation	The ICAO flight plan is submitted to the ATC. At this time the flight is activated on the Airport CDM Platform, and all available information is processed. Usually, this occurs 3 hours before the EOBT. However, it may be later. In many cases, a repetitive flight plan (RFPL) is already in the database covering daily or weekly flights.
2/HR	Estimates Off-Block Time (EOBT): - 2 hs before	At EOBT -2 hr most flights will be known in the Airport CDM Platform including if they are regulated or not. If the flight is regulated, a Calculated Take Off Time (CTOT) is issued at EOBT –2h.
3/HR	Take Off from outstation	The Actual Take Off Time (ATOT) from the outstation (Departure Aerodrome - ADEP). The outstation provides ATOT to the Network Operations and Aircraft Operator.
4/HR	Local radar update	The flight enters the FIR (Flight Information Region) or the local airspace of the destination airport. This information usually is available from the Area Control Centre (ACC) or Approach Control Unit that is associated with an airport. The radar system can detect a flight based upon the assigned SSR code when the flight crosses a defined FIR/ATC boundary.
5/HR	Final approach	At the destination airport, the flight enters the Final Approach phase. This information usually is available from ATC. The radar system detects a flight based upon the assigned SSR code and identifies when the flight crosses either a defined range/position or passes/leaves a predetermined level.
6/HR	Landed	ALDT – Actual Landing Time. It is the time that an aircraft touches down on a runway. Provided by ATC system or by ACARS from equipped aircraft.
7/HR	In-block	AIBT - Actual In-Block Time. It is the time that an aircraft arrives in blocks.
8/R	Ground handling starts	Commence of Ground Handling Operations (ACGT). Specific to flights that are the first operation of the day or that have been long term parked. For flights that are on a normal turnaround, ACGT is considered to commence at AIBT.
9/R	Final confirmation of TOBT	The time at which the Aircraft Operator or Ground Handler provide their most accurate TOBT considering the operational situation. The information is provided *(t) minutes before EOBT. Where *(t) is a parameter time agreed locally).
10/HR	Target Start-Up Approval Time issue	The time ATC issues the Target Start-Up Approval Time. The information is provided (t) minutes before EOBT, where (t) is a parameter agreed locally.
11/R	Boarding starts	The gate is open for passengers to physically start boarding (independent of whether boarding takes place via an air-bridge/pier, aircraft steps or coaching to a stand).
12/R	Aircraft ready	The time when all doors are closed, boarding bridge removed, push back vehicle connected, ready to taxi immediately upon reception of TWR instructions.
13/R	Start-Up request	The time that the start-up is requested.
14/R	Start-Up approved	This is the time that an aircraft receives its Start-Up approval.
15/HR	Off-block	AOBT – Actual Off-Block Time. The time the aircraft pushes back/vacates the parking position (Equivalent to Airline/Handler ATD – Actual Time of Departure ACARS=OUT).
16/HR	Take off	ATOT – Actual Take Off Time. This is the time that an aircraft takes off from the runway.

3.4 The FAA Operational Approach

3.4.1 Implementing CDM at Airports

According to Guidebook for Advancing Collaborative Decision Making (CDM) at Airports (Vail et al., 2015), to perform ACDM either as a leader or partner, airports will be required to commit financial and staff resources to the effort. A-CDM is also a process that may require expanded communications and enhanced communications/outreach programs. Thus, it is desirable for the airport to assign specific staff to lead and track A-CDM activities. During the implementation of A-CDM, it is essential that airport staff understands management's goals and objectives and the airport's commitment to A-CDM. Not unlike most complex programs and efforts, such as the implementation of Safety Management Systems (SMSs), A-CDM is a change in the way airports do business and will require staff training to assure effectiveness. In other words, airport staff will need to be trained on A-CDM background and procedures before it can successfully be deployed. They recommend three necessary steps to start an A-CDM project:

a) Step One - Problem Identification;
b) Step Two - Developing the A-CDM Approach; and
c) Step Three - A-CDM Implementation.

3.4.2 The FAA Milestones

The U.S. Airport Surface Collaborative Decision Making (CDM) Concept of Operations (ConOps) in the Near-Term [15] considers three key milestones to be found in the operation of a Surface CDM (A-CDM) that need to be completed before a flight can depart.
These milestones are:

a) Flight Planning
    - Relative to the filing a flight plan, network-wide resource planning, it enables a Flight Operator to achieve maximum utilisation of its resources by adapting to changing conditions based on accurate, timely information. For example, Flight Operators may use airport aircraft surface surveillance data, integrated with airspace and National Airspace System (NAS) status data, to detect and understand the nature of any demand/capacity imbalances affecting airport surface traffic.
b) Pushback
    - Relative to the pushing back from a gate/parking stand, it is anticipated that the participating Stakeholders will share the following information: *Scheduled Off-Block Time (SOBT); Earliest Off-Block Time (EOBT); Updated flight intent information; Operating limitations affecting the departure of an aircraft; Actual Off-Block Time (AOBT); and Access to pushback and other specified event data.*
c) Taxiing on the Airport Surface
    - *Taxiing to a Holding Area* - A gate may be needed for an arrival, making it necessary to push back a departure earlier than otherwise would be required. In such cases, Ramp Control and ATC coordinate as essential to taxi the aircraft to the designated holding area. Using surface surveillance and flight intent information, Surface CDM monitors current and predicted the capacity of the holding areas.

A-CDM is as a process, not as a project, a process that when implemented brings unique operational advantages to air operators, airports and airspace control, consequently to the final customer, the passenger, who is the biggest beneficiary of the improvements implemented. Economic and environmental factors are also huge components favourable to deployment (Figure 3).

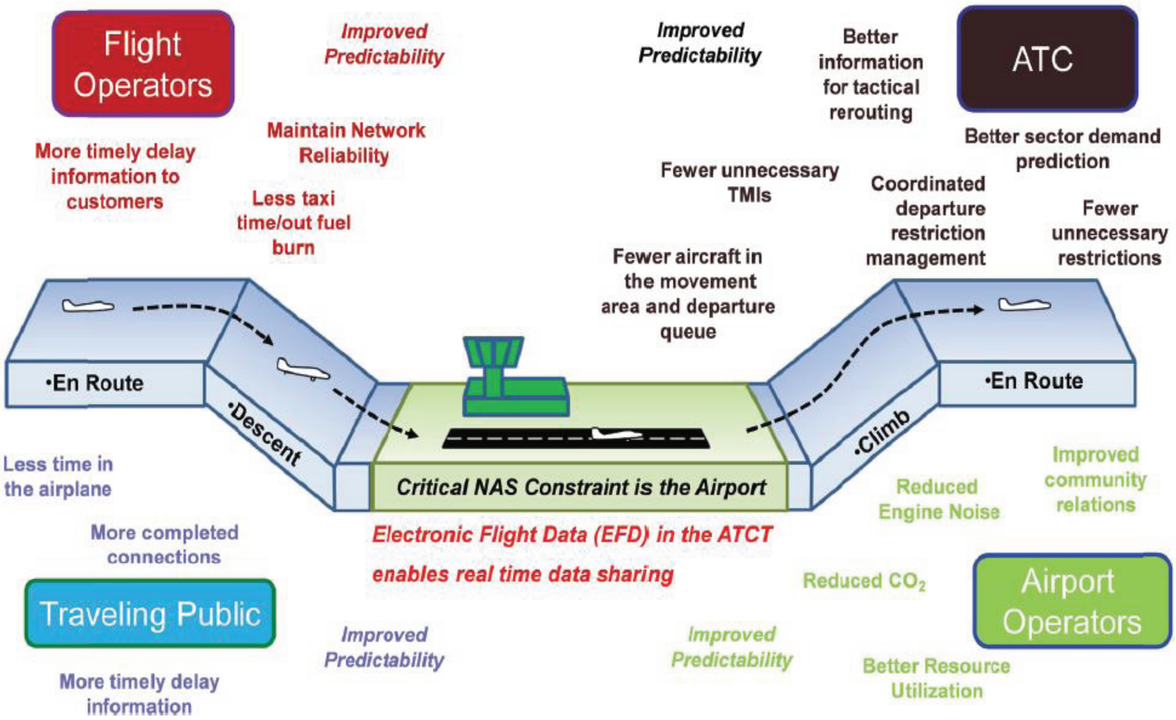


Figure 3: A-CDM efficiency benefits.
Source: Guidebook for Advancing Collaborative Decision Making (CDM) at Airports [14]

4. CONCLUSIONS

The complexity of a CDM deployment at large airports, receives several approaches from signatory countries and their ATM Systems, based on the recommendations of the ICAO Global Air Navigation Plan. In all these airports, especially those of greater importance, we have seen confluent points that, regardless of airport size, should always be part of A-CDM processes. The process will always involve three significant stakeholders: airport, air traffic control and air carriers, all connected around a regulatory entity and the application of the Operational Concepts (ConOps) they recommend, applicable for each state.

In the A-CDM creation, it is possible to depict integrating factors, practically mandatory, in the implanting in large airports: the stakeholders that will be involved; the milestones - which the FAA points to in three broad groups and divides them after, in a systematic way. The milestones that Eurocontrol points out in 16 major brands, of which ten are Highly Recommended.

The process, now implemented in almost a hundred airports around the world, will require later interaction with smaller airports as well. This is because they are also feeders of the system. For the gears to function correctly, they must also have processes for control and transfer of information and data, in a systematic and integrated way to the big world air traffic system.
It is, therefore, a matter for discussion that the next steps to be taken in the global A-CDM processes are aimed at airports with lower aircraft and passenger movement capacity that are currently A-CDM. It is a challenge for future research work from the global airline industry as to how this complex process could be simplified to apply it quickly and on a smaller scale as reducing the number of stakeholders and compacting the milestones now recommended in airports of lower movement and always considering CDM in a general way.

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Analysis of airport efficiency in liberalized aviation industry. A DEA approach

Luis Pulido - luis.pulido@usantotomas.edu.co
Universidad Santo Tomás, Colombia
Oscar Díaz Olariaga - oscardiazolariaga@usantotomas.edu.co
Universidad Santo Tomás, Colombia
Diana Tascón Hoyos - dianatascon@ustadistancia.edu.co
Universidad Santo Tomás, Colombia

Abstract

To evaluate and measure the efficiency of privatized airports in Colombia, and to fill the gap in the scientific literature on the subject at a geographical level.

The evaluation of airport efficiency has been a research area booming in recent years. These evaluations are important for all players in the industry, airport operators (public and private), regulatory agencies, governments (local, regional and national), and airlines. For this reason, a large number of articles on airport efficiency have been published in the last 15-20 years (lo Storto, 2018; Gutierrez and Lozano, 2016; Wanke et al., 2016). As for the specific techniques adopted in the research, it is expected to perform a Data Envelopment Analysis in a context of liberalized air transport market (where the most important airports in the country were privatized), including the complete deregulation of air fares, a significant level of global investment in airport infrastructure, public and private, and high growth maintained in the last two decades (Díaz Olariaga and Zea, 2018; Díaz Olariaga, 2016).

The research fills the gap in the scientific literature on the subject at a geographical by taking as case study for the measurement of airport efficiency a set of airports in Colombia, it is of great interest to know and measure the efficiency of privatized airports in Colombia. And the methodology used to carry out the study is the Data Envelopment Analysis (DEA).

Keywords

Airport privatization; Efficiency; Data Envelopment Analysis; Governance

Analysis of airport efficiency in liberalized aviation industry. A DEA approach

Introduction

The evaluation of airport efficiency has been a research field that is booming in the last years. These assessments are useful for all actors in the industry, airport operators (public and private), regulating agencies, governments (local, regional, and national), and airlines. Thus, during the last 15-20 years many articles about airport efficiency have been published [1] [2] [3] [4]. As regards specific techniques used in the research, Data Envelopment Analysis (DEA) [5] is one of the most frequently used, beginning with the work by Gillen and Lall [6], one of the first studies in the field.

Therefore, this research, which has set as one of its goals to fill the gap in the scientific literature on this topic, specifically at the geographical level (both regionally and locally), will take a set of airports in Colombia as a case study to measure airport efficiency. They are the most important airports in Colombia, including the ones with private governance. All this within the context of a liberalized market of air transport (where the most important airports of the country were privatized), together with the complete deregulation of airfares, the high level of global investment in airport infrastructure, public and private, and the high rate of growth during the last two decades [7]. Ultimately, it is very interesting to know and to measure the efficiency of privatized airports in Colombia. The methodology used to conduct the study is the Data Envelopment Analysis (DEA). The variables used are the following: technical (related to existing infrastructure), air transport (passengers, cargo, movements), supply and coverage (airlines and destinations), operation/exploitation (number of employees), financial (aeronautical and non-aeronautical revenue), and the behavior of passenger demand (load factor).

Literature review

During the last two decades, researchers have investigated worldwide the impact of different forms of property on the efficiency of airports [1] [8] [2] [3] [4] [9]. From the methodological viewpoint, Data Envelopment Analysis (DEA) has become the most popular tool to analyze and measure efficiency.

Some studies find clear evidence of the influence of governance on the efficiency of airports; others do not show any relevant effect, and still others indicate that the effect of governance on the efficiency of airports depends on many other factors, related to the market and the competitive environment, the government structure (of the airport's operator), the type of concession, and even the airport's capacity to generate economies of scale. Researchers have used different samples, variables, periods of time, and research methods [1]. Some discrepancies in the results found in the research are due to differences in the research approach. Contradictory results may be found for airport samples that are the same or similar in different time frames [10] [11] [12] [13]. Sample heterogeneity and the sets of data render comparative studies problematic and may strongly bias the efficiency analysis because the operative environments of airports are very different [14] [15].

Most research that measures and analyzes airport efficiency are focused on a country (or sometimes include continental regions), and as a result, one finds studies of several countries/regions in the world. However, it is worth mentioning that for the Latin American region there is not much literature; a study by Perelman and Serebrisky [16] stands out, where airport efficiency was analyzed in several airports in the region; Barros [17] also examined the technical efficiency of airports in Argentina, specifically within the context of the economic crisis during the 2003-2007 period; and, finally Wanke [18], and Pacheco and Fernandes [19] measured the airport efficiency in Brazil.

Application case

As regards the management of airport infrastructure, Colombia has followed the regional tendency of concessioning the management of such infrastructure to the private sector [20] [21] [22], as are also the cases of Brazil [23], Peru [24], Chile [25], Argentina [26], Mexico [27], among others. Thus, since the mid-1990s, and in several periods known as generations, the Colombian government has concessioned several airports in the country, a total of 19 until now, including the largest and most important ones, which manage most of the air traffic in the whole network [28] [29] [30]. As a result of the public policies, both of privatization and public and private investment in airport infrastructure, together with deregulating policies in the airline business sector, where airfares are completely liberalized since 2012 [7], passenger transport (total) has increased 863% [31] during the last two and a half decades.

Moreover, it can be asserted that air transport in Colombia is almost unrivaled (domestically) in relation to other means of transportation, especially for medium and long distances due to two crucial factors: first, the country's complex geography (going across south east to north east through three mountain ranges of the Andes), and second, the deficiency (regarding coverage, capacity, and technology) of ground communication systems (there are no high capacity highways), and railway systems (there is no railway system/network) [32]. And, finally, on account of the geographical distribution of airports in the country and due to the structure (or system) of airport concessions [28], there is virtually no intra-airport competition. Thus, Table 1 shows information about privatized airports that have been included in this research.

Table 1. Data about airports with 100% private governance. Source: [33].

Airport city	IATA Code	Year of privatization	PAX (2017)
Carepa	APO	2008	205362
Medellín	EOH	2008	1070158
Rionegro	MDE	2008	7325740
Barranquilla*	BAQ	2015	2576253
Cartagena	CTG	2010	4590151
Valledupar	VUP	2010	387634
Quibdó	UIB	2008	372618
Montería	MTR	2008	938460
Bogotá	BOG	2007	24694288
Riohacha	RCH	2010	149980
Santa Marta	SMR	2010	1686025
Cúcuta	CUC	2010	875519
Providencia	PVA	2007	71091
San Andrés	ADZ	2007	2328104
Barrancabermeja	EJA	2010	128895
Bucaramanga	BGA	2010	1565482
Corozal	CZU	2008	82675
Cali	CLO	2000	4858057

* The airport of the city of Barranquilla (BAQ) is not included in the study, for it was recently privatized (and there are not enough historical records for the analysis).

Methodology

Theoretical foundations

The methodology of Data Envelopment Analysis (a result of Rhodes' PhD dissertation [34] and an extension of Farell's work [35]), which is used in this research, is considered a non-parametric solution to estimate productivity of input factors in a system and the results of its transformation in a process with the use of linear programming [5] [36]. The first DEA model, proposed by Charnes, Cooper y Rhodes [5], known as DEA-CCR, had an input orientation and assumed the existence of constant returns to scale. The second DEA proposed, known as DEA-BCC [37], presents the hypothesis

of variable returns to scale. Charnes et al. [5] say in their work that, faced with a set of units considered as productive and which can be compared with each other because their process of resources transformations is similar (and, thus define a framework for comparison), they name these productive units DMU (Decision Making Units) and define three types of efficiency to achieve this comparison:

(a) Technical efficiency: the unit with the highest productivity between units of the same size is chosen as a unit of reference.
(b) Scale efficiency: reflects the ability of DMU to use resources or factors in optimal proportions.
(c) Global efficiency: the unit with the highest productivity of those under study is chosen as a unit of reference.

The efficiency relations are measured with the coefficient obtained between the output results (outputs) of the system and the resources supplied at the beginning (inputs) with the following criteria [38]:

(a) Oriented Inputs: seek, given the level of outputs, the maximum proportional reduction in the vector of inputs, while it remains on the border of production possibilities. A unit is not efficient if it is possible to reduce any input without altering its outputs.
(b) Oriented Outputs: seek, given the level of inputs, the maximum proportional increase of outputs, while remaining within the border of production possibilities. A unit is not efficient if it is possible to increase any output without increasing any input and without reducing any other output.

Methodological conceptualization

This research considers "global efficiency" as the ability of any analyzed airport to use productively its input resources, regardless of its size in comparison to other units in the study. To begin calculating the global efficiency of airports in this study, and according to existing literature, a decision was made that each airport would be measured as a DMU (productive unit) and for each of them, some variables were defined, which would be considered in the analysis as input and output variables. Table 2 presents the variables used in the research. The time scenario or period for the study is set in six consecutive years, 2012-2017.

Table 2. Definition of input and output variables for the analysis. Source: Authors.

DMU	INPUTS	OUTPUTS
Airports (17): ADZ, SMR, CTG, PVA, MDE, CLO, APO, MTR, VUP, RCH, BOG, CZU, UIB, EJA, BGA, EOH, CUC.	1. Number of runways. 2. Length of runways. 3. Number of aircraft parking positions on the platform. 4. Built area in passenger terminal building. 5. Apron area. 6. Number of airlines. 7. National destinations. 8. International destinations. 9. Number of employees	1. Operations (take-offs / landings) 2. Passengers carried. 3. Air cargo transported. 4. Load factor (ratio between available seats and passengers onboard). 5. Aeronautical revenue. * 6. Non-aeronautical revenue. *

* This variable will be used only for four airports (BGA, BOG, CLO y CTG), since it is not available for the rest of the airports.

Finally, and according to a tendency in the existing literature, the model DEA-CCR [5] will be used, which turns out to be the most frequently used in this type of studies. It also offers the possibility of obtaining returns on a comparative scale. Then, the model is presented as follows [39]:

$$Max_{u,v} \; ho = \frac{\sum_{r=1}^{s} U_r \, Y_{ro}}{\sum_{i=1}^{m} V_i \; X_{io}}$$

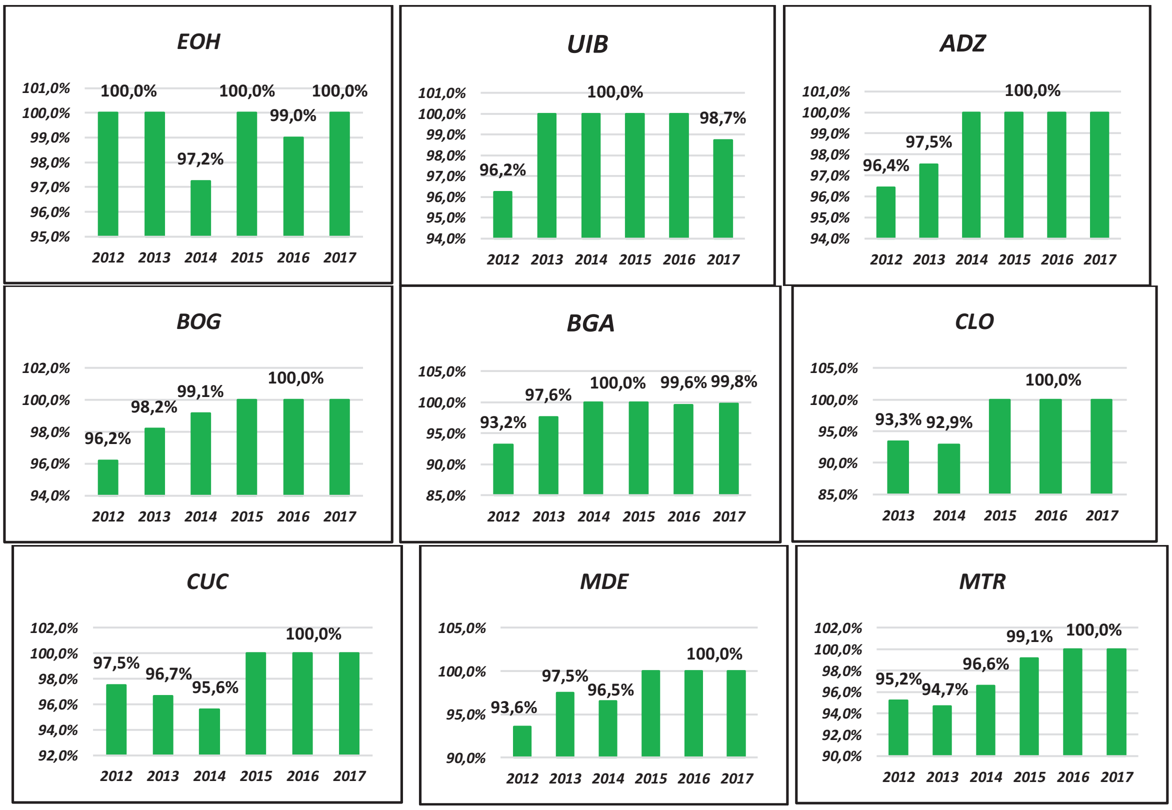
subject to:

$$\frac{\sum_{r=1}^{s} U_r\, Y_{rj}}{\sum_{i=1}^{m} V_i\, X_{ij}} \leq 1\ \forall\, j: 1..n$$
$$U_r, V_i\ \geq 0\ \forall\, r: 1..2 \qquad \forall\, i: 1 \ldots . m$$

where:
ho: Objective function. Measurement of efficiency.
Yrj: i-th output of j-th DMU.
Xij: i-th input of j-th DMU.
Vi,: weights of inputs respectively (program solutions).
Ur: weights of outputs respectively (program solutions).
r: i-th output
j: i-th input
s: total number of outputs
m: total number of inputs
n: total number DMU

Results

The results obtained are presented with information about inputs and outputs in 17 Colombian airports during the research period 2012-2017 (Figures 1, 2, 3, 4).



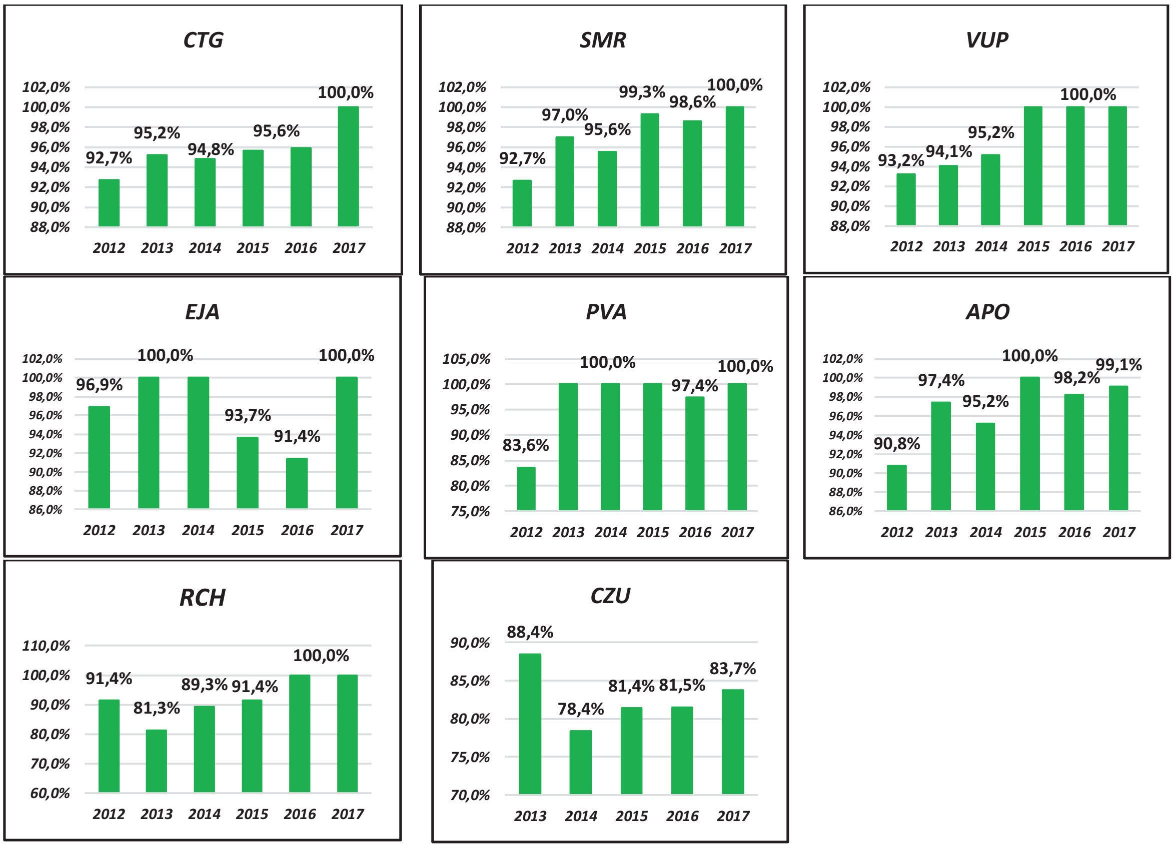


Figure 1. Values of efficiency in privatized airports, 2012-2017 period. Comment: only 4 outputs were considered in this measurement ("income" variables were not included). Source: Authors.

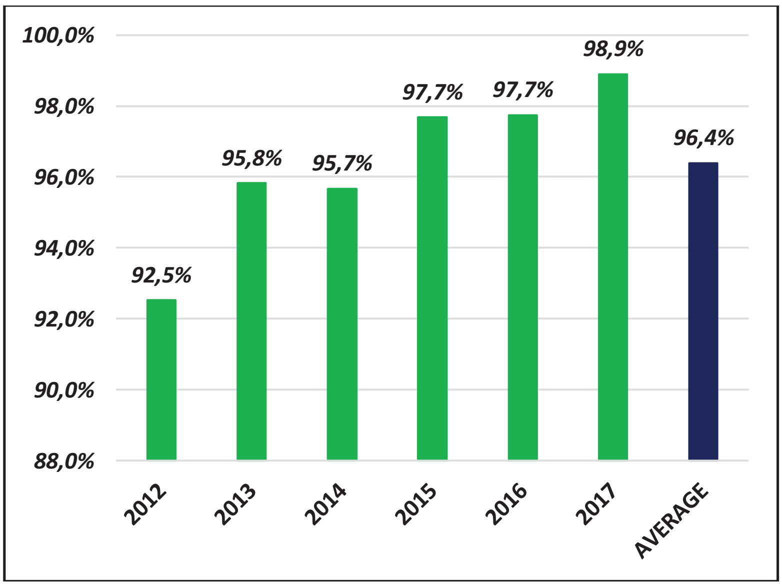


Figure 2. Evolution of efficiency of the set of privatized airports in the study (17), 2012-2017 period. Comment: only 4 outputs were considered in this measurement ("income" variables were not included). Source: Authors.

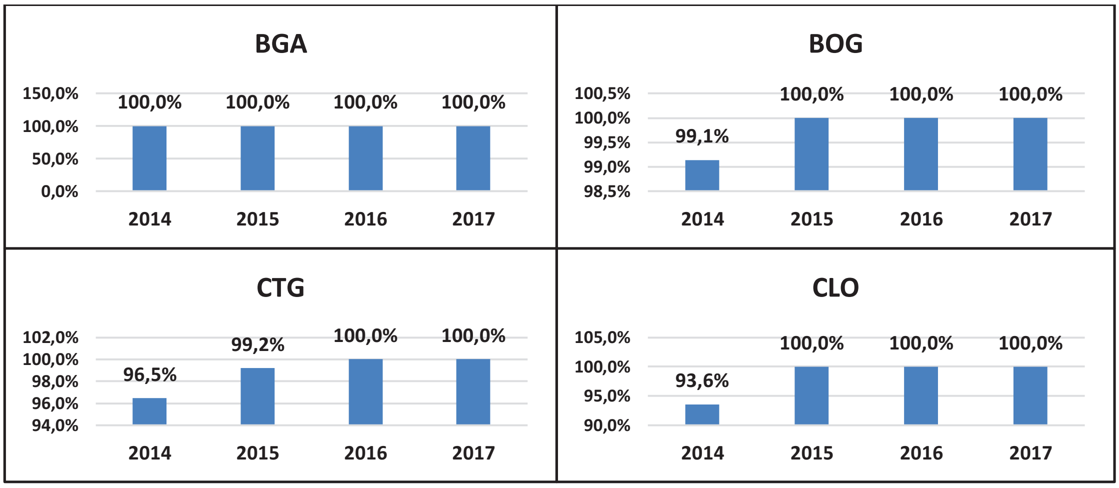


Figure 3. Measurement of efficiency in privatized airports, 2014-2017 period. Comment: all outputs were considered in this measurement (including “aeronautical income” and “non-aeronautical income”). Thus, the measurement is limited to only 4 airports (for which data on income are available). Source: Authors.

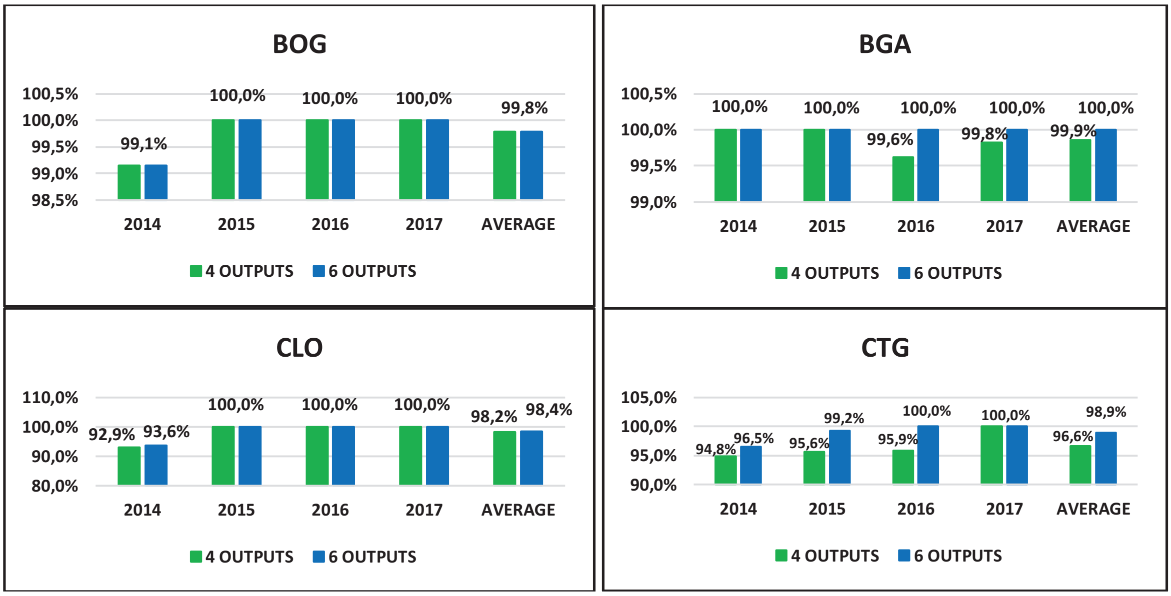


Figure 4. Comparison of efficiency in the measurement with and without “income” variables, 2014-2017 period; analysis only valid for 4 airports. Source: Authors.

The results presented here lead to the following statements:

a) The level (or index) of efficiency is independent of the size of the airport (measured as the volume of annual traffic managed). And even more relevant, the efficiency index is also totally independent of the geographical location of the airport (capital-city, interior or remote), of the economic status of the region (rich or poor), of the productive characteristic of the city / region (tourist, industrial, government, etc.) and the demography (population) of the city / region served by the airport (see Fig. 1).
b) Efficiency levels have increased during the analysis period, this indicates a solid consolidation of private management, or governance, of the airports (see Fig. 2).
c) In those airports in whose analysis or measurement the variables " revenues " (aeronautical and non-aeronautical) have been considered, the efficiency index shown is the maximum

(100%) (see Fig. 3).

d) Compared to the results in other similar studies (in Colombia) ([40] [41]), for the same airports and in similar time periods, the use of a greater number of variables (both inputs and outputs) in measurement increases the efficiency rates.

Conclusions

The analysis models presented in this work include one model with 9 a inputs and 4 outputs for 17 DMU (airports) in the 2012-2017 period and another model with 9 inputs and 6 outputs for 4 DMU in the 2014-2017 period. They were compared with the number of variables used in the estimation analysis of efficiency in airports by using the DEA methodology. In comparison with similar research, it could be said that this research is clearly the one that has used most variables (inputs+outputs) for measuring efficiency (see a comprehensive and detailed overview of similar research in Storto [1] and Wanke et al. [3].

When the results obtained in this research are compared with those of a previous study, where the same airports during the same period of time were analyzed but half of the variables were included [40], the estimation of average efficiency (for the same set of airports under study) obtained in this research shows an important (positive) difference, 96,4% as compared to 71% in the previous research. This result aims at the conclusion that increase in the number of input and output variables has an impact, at least in the sample analyzed, on the significant increase in the average global efficiency, which does not necessarily imply that the efficiency measurement is more accurate.

On the other hand, when efficiency is estimated considering the variable “income” and it is compared with the estimation that does not include it (analysis limited to only 4 airports), the results show a very small difference, which tends to increase if this variable is actually included. It should be pointed out that efficiency values in privatized airports have increased during the analyzed period under private governance and in a fully liberalized aviation market environment.

Finally, it is of interest to mention some relevant aspects of this research:

a) Following the line of many investigations cited here ([1] [2] [3] [4]), the objective of this work was to measure the technical efficiency of airports. There is not so much data available (and in detail), and all the airports simultaneously (and in similar time periods), as to be able to infer the nature, or cause, of its level of efficiency and to be able to make comparative evaluations with other airports (under the same conditions and time periods).
b) What it is possible to do is the comparison (only) of the level of efficiency between (Colombian) airports with public governance and with private governance (and comparison within each of these two groups), in equal time periods and using the same inputs and outputs But this research has already been carried out and published [40].
c) On the other hand, it is also possible to compare the efficiency of (Colombian) airports between their period of public governance and then in their period of private governance (once they were privatized), but this research was also already carried out and published [41].

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Caracterización del tráfico aéreo de la red aeroportuaria argentina

Ezequiel Burela - ezequielburela@gmail.com
Universidad Nacional de La Plata/ Grupo Transporte Aéreo – UIDET GTA-GIAI, Departamento de Aeronáutica, Facultad de Ingeniería
Rogelio Faut - rogelio.faut@ing.unlp.edu.ar
Universidad Nacional de La Plata/ Grupo Transporte Aéreo – UIDET GTA-GIAI, Departamento de Aeronáutica, Facultad de Ingeniería
Alejandro Di Bernardi - cadibern@ing.unlp.edu.ar
Universidad Nacional de La Plata/ Grupo Transporte Aéreo – UIDET GTA-GIAI, Departamento de Aeronáutica, Facultad de Ingeniería

Abstract
El presente tiene como objetivo caracterizar el tráfico aéreo comercial, regular y no regular, que se desarrolla en los aeropuertos del grupo A del Sistema Nacional de Aeropuertos.
A partir del registro de operaciones diarias de los aeropuertos bajo estudio, se procesa la información con el objetivo de cuantificar el tráfico aéreo de aeronaves, pasajeros y cargas, así como distintos indicadores que caracterizan el tráfico aéreo desarrollado en el 2017. Los resultados se presentan en mapas georeferenciados que facilitan la interpretación y la complementación con otros estudios.
El trabajo pretende detallar la estructura operativa del tráfico aéreo desarrollado en gran parte del Sistema Nacional de Aeropuertos, y resaltar la utilidad de estos estudios como herramienta en instancias de planificación de las infraestructuras e instalaciones de los aeródromos a nivel sistémico.
El trabajo pretende resaltar la necesidad de contar con un sistema de gestión de la información referida al tráfico aéreo, que asegure la fiabilidad de los datos, y permita el desarrollo de estudios tendientes a caracterizar una red aeroportuaria, buscando una herramienta útil para la toma de decisiones en etapas de planificación.

Keywords
Planificación; Tráfico aéreo ; Red aeroportuaria; RPK/ASK

Caracterización del tráfico aéreo en la red aeropor - tuaria argentina

Introducción

Bajo los mismos lineamientos planteados en el estudio de caracterización del tráfico aéreo en la red aeroportuaria argentina [1] considerado para el escenario 2017, este trabajo tiene como objetivo realizar un análisis similar. Contemplando los aeródromos de la red, se determina la mezcla y tipo de aeronaves de la flota operativa, tipo y cantidades de movimientos, pasajeros y carga.

Se verifica, además, la conectividad existente entre los elementos de la red, indicando las frecuencias asociadas a los corredores correspondientes.

A su vez, y extendiendo los parámetros del trabajo anterior, se introduce el análisis de los indicadores Pasajeros por Kilómetro Transportado (RPK) y Asientos Ofrecidos por Kilómetro Transportado (ASK). El primero como un indicador de la magnitud del servicio de transporte aéreo realizado y, el segundo, como estimación de la magnitud del servicio de transporte aéreo ofrecido.

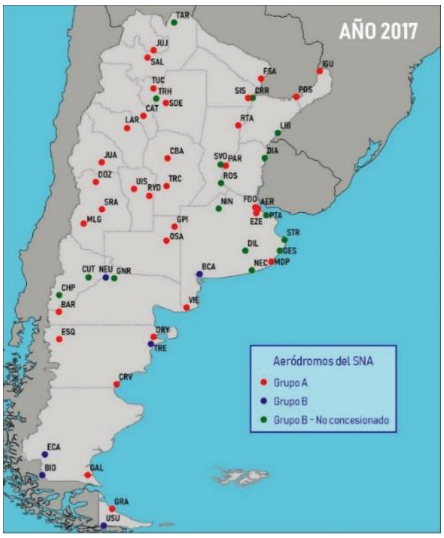
De esta manera se buscará contemplar una cantidad de variables que sirvan de apoyo en la planificación, que como justifica FAA resultan de relevancia en la toma de decisiones para asegurar la viabilidad del sistema de transporte aéreo nacional [2].

A este fin se confeccionan mapas georreferenciados en los cuáles se pone de manifiesto la influencia de cada variable analizada. A partir de estos mapas se orienta el trabajo y se extraen conclusiones relativas.

En función de los datos disponibles a la fecha, el análisis se basa en los aeropuertos del Sistema Nacional Aeroportuario (SNA) pertenecientes al Grupo A. El tipo de fuente utilizada fue: el registro todas las operaciones efectuadas durante 2017 en cada aeropuerto, por un lado y; los volúmenes mensuales de movimientos, pasajeros y carga por el otro.

Aeródromos del SNA

En este apartado se indican los campos de vuelo reconocidos como aeropuertos del SNA, con referencia en el mapa 1, construido con registros tomados de ANAC [3]. En el mismo se muestran los aeropuertos concesionados del Grupo A, los cuales son el sistema bajo estudio en este trabajo.



Mapa 1 - Aeródromos del SNA.

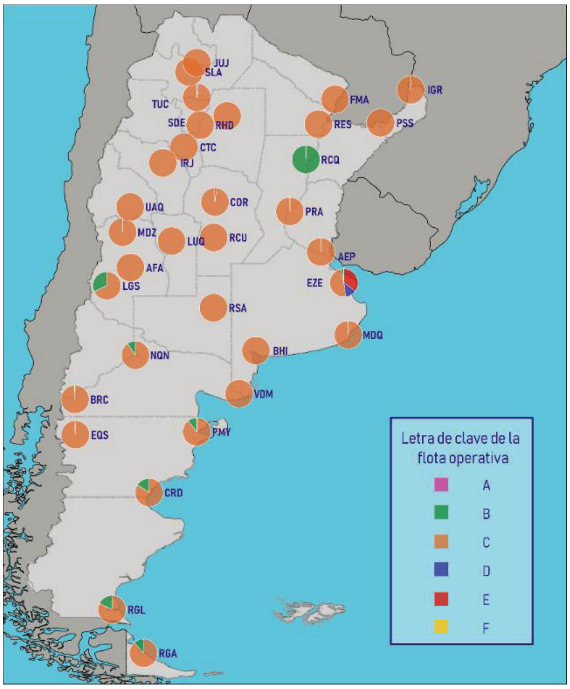
Fuente: Elaboración propia.

Análisis según aeronaves

En este primer apartado se analiza la red aeroportuaria a partir de datos referidos a las operaciones de las aeronaves.

Caracterización según clave de referencia de aeronaves de la flota operativa

En este apartado se analiza la composición de la clave de referencia de las aeronaves según flota operativa, definida según OACI [4], en cada aeropuerto, utilizando como referencia el mapa 2, construida a partir de los resultados extraídos del registro de operaciones.



Mapa 2 - Clave de referencia de aeronaves según flota operativa.
Fuente: Elaboración propia.

A partir del mapa 2 se puede observar que, en general, la clase de aeronave predominante es la de categoría C (envergadura de 24 a 36 m y distancia entre ejes de 6 a 9 m). Esto es, aeronaves de mediano porte con un alcance suficiente para unir cualquier destino en nuestro país.

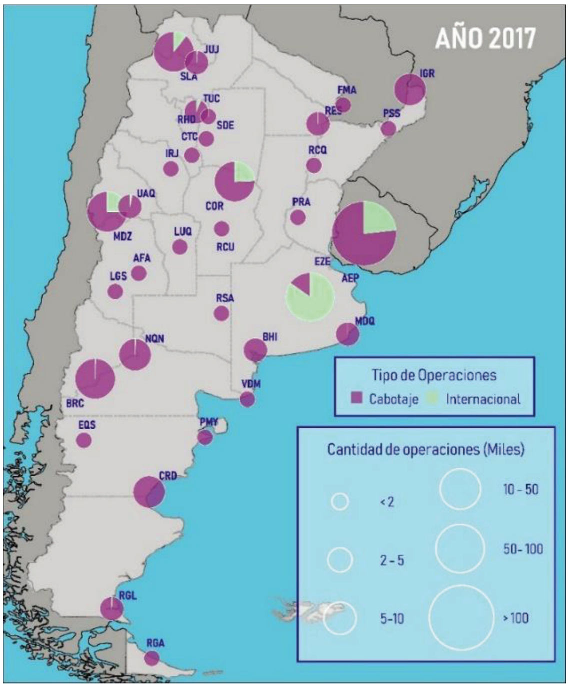
Las aeronaves clave A o B encuentran mayor preponderancia en aeropuertos del interior del país, con fuerte participación industrial y agrícola. De esta manera se identifica una participación mayor en la mezcla de este tipo de aeronaves en Santa Fe, Malargüe, Puerto Madryn, Comodoro Rivadavia, Neuquén, Río Gallegos y Río Grande.

En cuanto a las aeronaves clave D y E (envergadura de 52 a 65 m y distancia entre ejes de 9 a 14 m) se encuentran operaciones concentradas en Ezeiza, Córdoba, Mendoza, Salta y Tucumán. (La pequeña proporción de las claves D y E en los aeropuertos mencionados, no posibilita una adecuada lectura para el tamaño de los gráficos de torta representado).

Análisis según movimientos

Caracterización de movimientos según tipo vuelo

El segundo análisis abordado, es según operaciones de aeronaves internacionales y de cabotaje. El análisis de la composición del tipo de operación se evidencia en el mapa 3, construida en base a los resultados extraídos del registro de operaciones.



Mapa 3 - Movimientos según tipo de vuelo.
Fuente: Elaboración propia

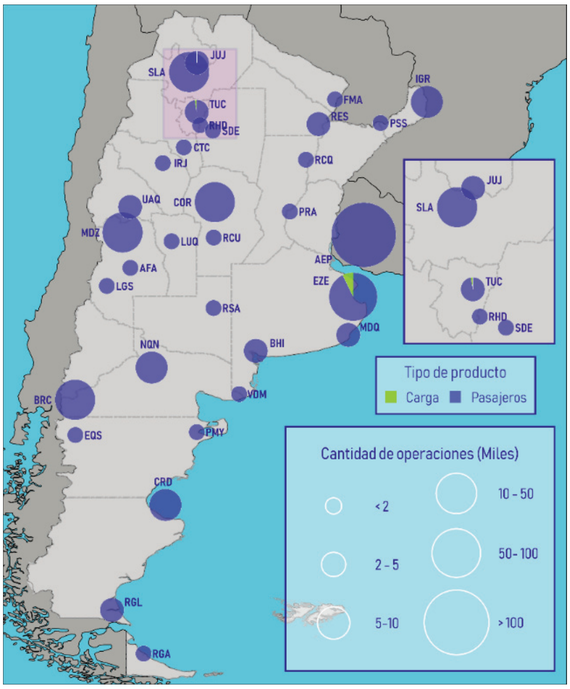
El mapa 3 demuestra la red caracterizada principalmente por operaciones de cabotaje, reflejando un incremento de las operaciones internacionales en la zona central del país y Salta y Tucumán. A modo contrario, Ezeiza, se muestra con una composición mayor de operaciones internacionales.

Respecto de las operaciones internacionales se observa la preponderancia de Ezeiza, principal hub internacional del país, superando las 53.000 operaciones. En el orden de la mitad Aeroparque de aproximadamente 27.000 operaciones y más reducido Córdoba con 6.000 operaciones.

Respecto de las operaciones de cabotaje, Aeroparque se sitúa como principal hub domestico de la red. En el mismo concentrándose el 43% de las operaciones con más 91.000 operaciones. En segundo lugar, se encuentra el aeropuerto de Córdoba con 8,7% de aproximadamente 19.000 operaciones, luego Mendoza con 4,5% superando las 12.000 operaciones.

Caracterización de movimientos según pasajeros o producto transportado

Una segunda clasificación se realiza según movimiento de aeronaves de pasajeros, aeronaves de cargas y otras aeronaves (grupo fuera de la clasificación de los primeros dos). El análisis de la composición del tipo de operación se evidencia en el mapa 4, construida en base a los resultados extraídos del registro de operaciones.



Mapa 4 - Movimientos según producto transportado.
Fuente: Elaboración propia.

En primer lugar, se destaca que las operaciones de pasajeros son las que dominan las operaciones aeronáuticas en nuestro país, relegando las operaciones de carga a valores insignificantes en términos porcentuales.

En el caso de las operaciones de pasajeros se puede discernir la preponderancia del área metropolitana (por encima de las 180.000 operaciones contabilizando Ezeiza y Aeroparque) donde más de la mitad de las operaciones realizadas se corresponden en esta zona. El orden se sigue por las ciudades de Córdoba, Mendoza, Bariloche y Salta. En tercera instancia Neuquén, Iguazú, Comodoro Rivadavia y Tucumán.

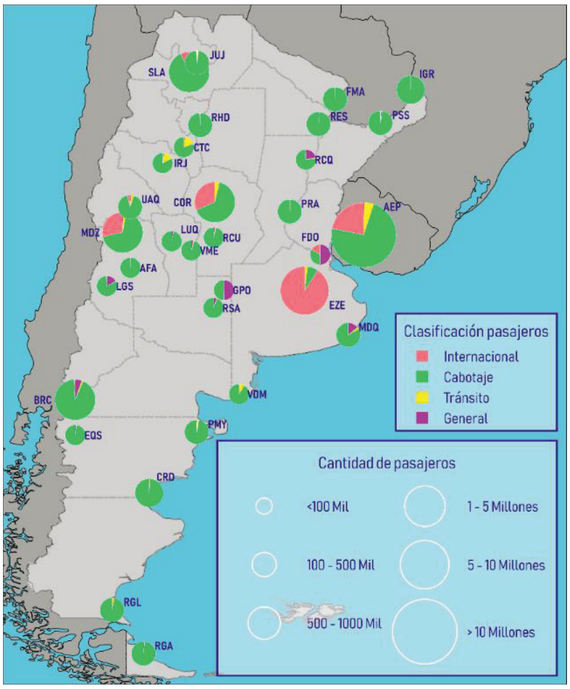
Por otro lado, se observa que Ezeiza concentra casi la totalidad de las operaciones de aeronaves de carga, con más de 4.300 operaciones.

Por último, destacamos como el grueso de operaciones totales de la red se extiende entre Aeroparque en primer orden excediendo las 130.000, Ezeiza en el segundo alcanzando casi las 67.000 y los aeropuertos de Córdoba con más de 26.000 operaciones, Mendoza de alrededor de 19.000 operaciones, Salta con 13.000 operaciones y Bariloche con 12.000 operaciones.

Análisis según pasajeros

Caracterización de pasajeros según tipo de vuelo

En este apartado se analiza la composición de los pasajeros en cada aeropuerto, utilizando como referencia del mapa 5, construida a partir de volúmenes mensuales.



Mapa 5 - Clasificación según pasajeros.
Fuente: Elaboración propia.

El mapa 5 evidencia la red caracterizada principalmente por pasajeros de cabotaje. Esta tendencia se atenúa en los casos de Mendoza, Córdoba y Ezeiza donde la composición de los pasajeros internacionales supera la cuarta parte, prevaleciendo para este último el 90% del total de los pasajeros.

Respecto de la cantidad de pasajeros internacionales, se esclarece la causa de Ezeiza como principal hub internacional de la red, al igual que en el caso de operaciones internacionales del apartado anterior, en cantidad de pasajeros, Ezeiza predomina acercándose a los 9 millones de pasajeros. Con una tercera parte precede Aeroparque transportando 3 millones de pasajeros y; Córdoba en menor medida con 900.000 pasajeros.

En cuanto a cantidad de pasajeros de cabotaje, se acentúa Aeroparque como principal Hub domestico de la red, interpretando la concentración de los pasajeros de cabotaje de la red como deviene también del análisis de operaciones nacionales. En términos porcentuales Aeroparque reúne el 28% de los pasajeros domésticos procesando más de 10 millones de pasajeros, desplazando a Córdoba en segundo lugar con el 5% y 1,8 millones de pasajeros y; en tercer lugar, Bariloche y Mendoza con el 3% y 1,2 millones cada aeropuerto.

En lo que refiere al volumen de pasajeros en tránsito, muestran una diferencia menos abrupta que en las clasificaciones anteriores, nuevamente Aeroparque y Ezeiza muestra predominando en la red, con 650.000 y 198.000 pasajeros respectivamente. En tercer orden sigue Córdoba aproximadamente 100.000 pasajeros.

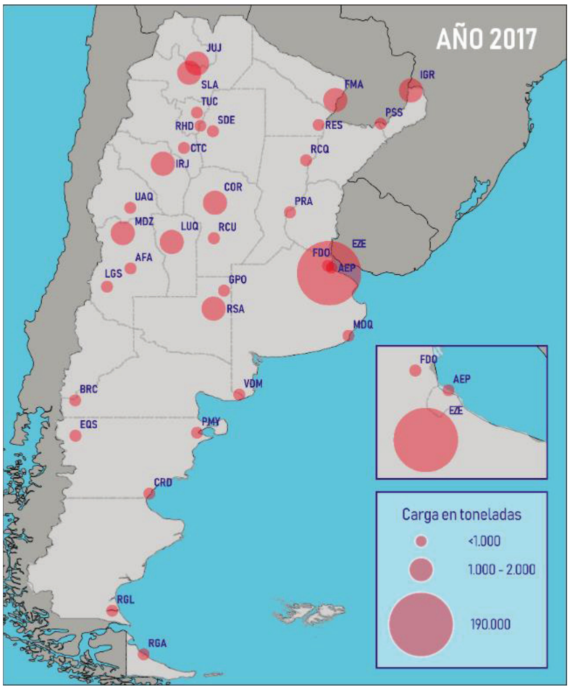
En otro punto el número de pasajeros de aviación General, revela una distorsión en el comportamiento de la red comparado con parámetros anteriores, donde surgen como relevantes Bariloche y Mar del Plata contabilizando alrededor de 73.000 y 47.000 pasajeros respectivamente. Próximamente por debajo, reaparecen Aeroparque con 46.000 pasajeros y San Fernando con 45.000 pasajeros.

Finalmente, la suma de pasajeros totales, revela un comportamiento similar a la de pasajeros de cabotaje con el aporte que agrega Ezeiza. Se observa la concentración total de pasajeros en el área metropolitana reuniendo más del 66% de la red, disponiendo en Aeroparque un total de casi 14 millones de pasajeros y Ezeiza por debajo de los 10 millones de pasajeros. Contabilizando cercano al

8% de pasajeros se posiciona Córdoba con 2,9 millones de pasajeros, en menor medida se suceden Mendoza, Bariloche, Salta e Iguazú todos superando el millón de pasajeros.

Análisis según carga

En este apartado se analiza la composición de los pesos del tipo carga según internacional, nacional y correo en cada aeropuerto, utilizando como referencia mapa 6, construida a partir de volúmenes mensuales.

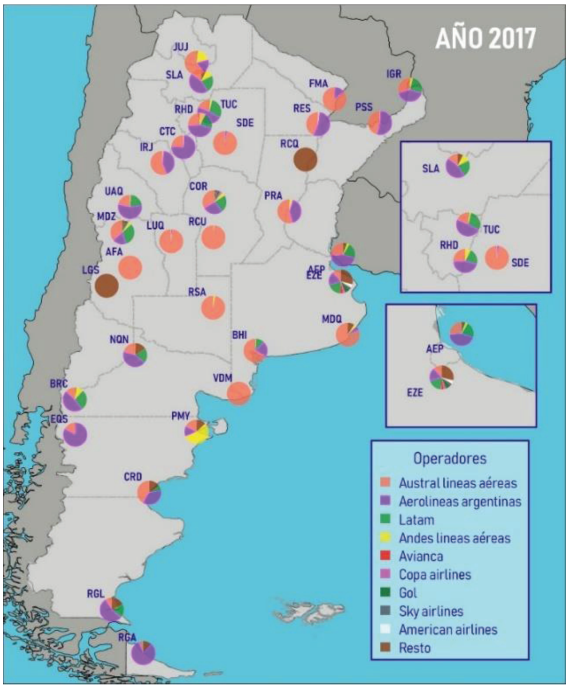


Mapa 6 - Carga
Fuente: Elaboración propia.

La figura presenta la concentración de cargas internacionales en el aeropuerto de Ezeiza, observando movimientos de este tipo en los aeropuertos de Córdoba, Tucumán, Aeroparque, y Mendoza.

Análisis según operador

En este apartado se analiza la composición de operadores según movimientos realizados, con referencia en el mapa 7, construida en base al registro de operaciones.



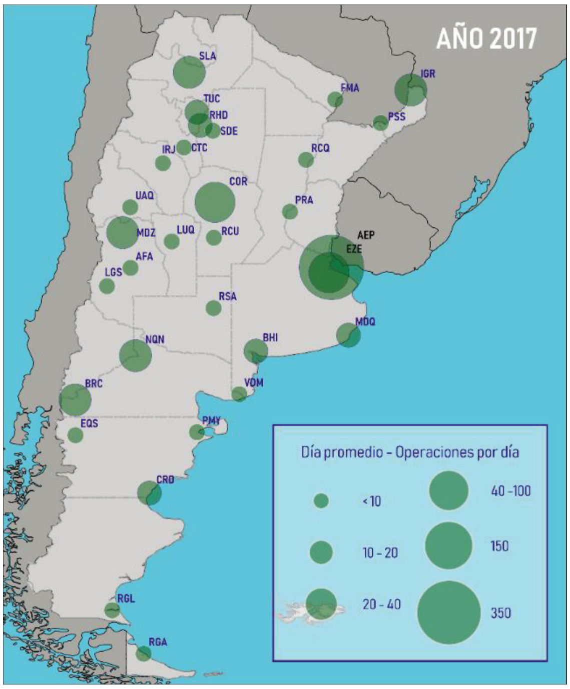
Mapa 7 - Distribución de operadores.
Fuente: Elaboración propia.

En el mapa 7 de distribución de operadores, se destacan con mayor presencia las dos aerolíneas estatales: Aerolíneas Argentinas, participando con el 35%, y Austral Líneas Aéreas, con el 26%. Con menor participación en la red se posiciona Latam con el 19%.

Como caso testigo de aeropuertos con un solo operador aéreo pueden identificarse los casos de Reconquista y Viedma. Esto indicaría que, si la aerolínea deja de operar o en un escenario hipotético la misma desaparece, ocasionaría un impacto fuertemente negativo para el aeropuerto, incluso provocando el cese operativo. En el caso opuesto, se observan los aeropuertos de Ezeiza, Aeroparque, Córdoba, Mendoza y Salta donde la variedad de operadores permite una mayor diversificación de la utilización del aeropuerto.

Análisis de día promedio

En este apartado se resume un análisis respecto a la distribución promedio de la cantidad de aeronaves diarias de cada aeródromo. La metodología empleada para la estimación del parámetro del día promedio, se basa en la media diaria de aeronaves en el mes punta del año. El valor de día promedio queda expuesto en el mapa 8 construido a partir del registro de operaciones.



Mapa 8 - Día Promedio.
Fuente: Elaboración propia.

En el mapa 8de día promedio se refleja una baja actividad en la que el 65% de la red registra una cantidad de aeronaves por día inferior a 10. En el extremo opuesto la región metropolitana muestra a Ezeiza y Aeroparque como los más densificados, obteniendo el primero cerca de 160 aeronaves/día y superando Aeroparque las 350 aeronaves/día. Por último, se identifica a Neuquén, Salta y Bariloche correspondidos con el promedio de 26 aeronaves/día en el conjunto de la red.

Análisis RPK

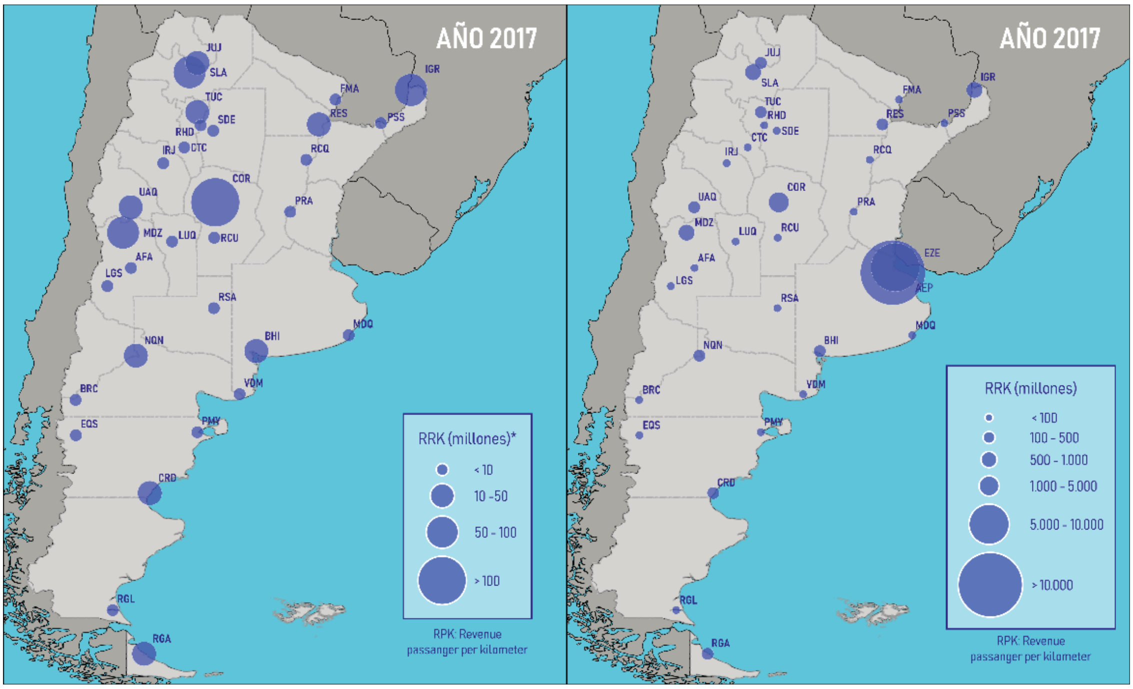
El indicar *RPK*, del inglés 'Revenue Passager per Kilometers', usualmente utilizado por las aerolíneas como un parámetro de comparación, representa una medida de la producción de una aerolínea calculada a partir de la *cantidad de pasajeros por kilómetros transportados* [5].

Si bien este texto no se enfoca en los operadores, la magnitud que se determina en este trabajo es para los elementos que conforman la red, es decir los aeropuertos. De esta manera para estimar el *RPK* de cada aeropuerto, se contabiliza la cantidad de pasajeros transportados a cada destino y conociendo la ubicación del origen del vuelo, la distancia recorrida se asume por la longitud ortodrómica que une ambos puntos. El procedimiento es un modelo de estimación, un modelo más preciso resultaría contemplando la distancia en kilómetros recorridos de la ruta de vuelo, modelo que, a falta del conocimiento de las rutas aéreas no pudo ser realizado.

La expresión utilizada en la estimación fue:

$$RPK = \sum \left(\sum Pasajeros\ por\ vuelo\ al\ destino \right) \times distancia\ lineal\ entre\ origen\ y\ destino\ (km) \quad (1)$$

El análisis del indicador *RPK* se realiza en referencia en el mapa 9, según los datos de volúmenes mensuales.



Mapa 9 - Distribución de *RPK*. Izq: Excluyendo Aeroparque y Ezeiza. Der: Incluyendo Aeroparque y Ezeiza.
Fuente: Elaboración propia.

Puede observarse que Ezeiza, Aeroparque y Córdoba son los aeropuertos con mayores índices RPK. Este parámetro da cuenta de modo indirecto del perfil de las operaciones que tienen lugar en este conjunto de aeropuertos, en donde se concentra la mayor distancia y mayor cantidad de pasajeros por kilómetro. Estos tres aeropuertos concentran el 90% del total de la red, fortaleciéndose respecto al resto de los aeropuertos del sistema en estudio.

Análisis ASK

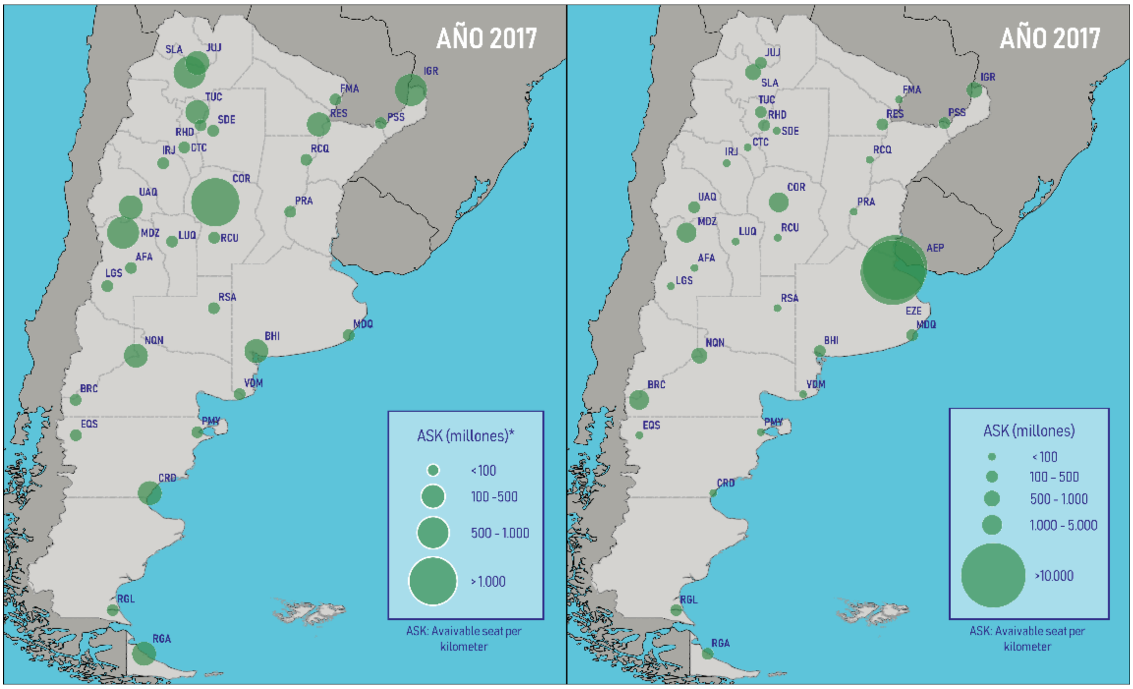
El indicador *ASK*, del inglés, 'Avaible Seat per Kilometer' también es un indicador de comparación utilizado por las aerolíneas como lo es el *RPK*. Representa una medida del producto ofrecido por una aerolínea a partir de la *cantidad de asientos ofertados por kilómetros transportados* [5].

En este apartado se busca estimar el *ASK* por aeropuerto en el mismo sentido que se lo realiza en el apartado anterior. Para la estimación, se procedió contabilizando cada una de las aeronaves definidas para el destino particular, la cantidad de operaciones de la aeronave asignada y asumiendo una capacidad promedio de asientos disponibles.

El cálculo del parámetro fue realizado en función de la siguiente expresión:

$$ASK = \sum \Big(\sum Asientos\ ofrecido\ por\ destino\ \ por\ aerolinea \times cantidad\ de\ vuelos\ al\ destino\ por\ aerolinea \Big) \times distancia\ lineal\ entre\ origen\ y\ destino\ (km) \qquad (2)$$

El análisis del indicador ASK se realiza en referencia en el mapa 10, según los datos de volúmenes mensuales.

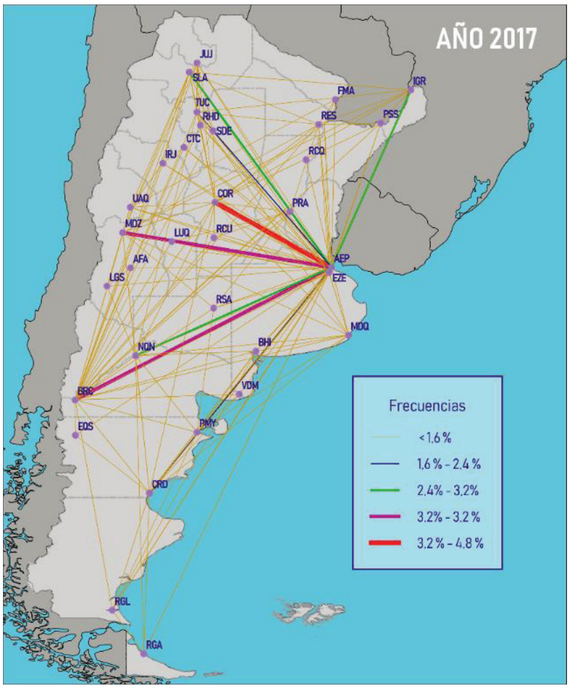


Mapa 10 - Distribución ASK. Izq: Excluyendo Aeroparque y Ezeiza. Der: Incluyendo Aeroparque y Ezeiza.
Fuente: Elaboración propia.

Este factor mantiene relación con el mostrado anteriormente, aunque se destaca también la incorporación a un primer grupo de aeropuertos al aeropuerto de Mendoza, junto con Ezeiza, Aeroparque y Córdoba. El parámetro indica que se ofrecen más cantidad de asientos a mayores distancias desde estos aeropuertos que del resto del país. El subconjunto destacado absorbe el 89% de los *ASK* estudiados en el sistema, reproduciendo el comportamiento que se menciona en el análisis de *RPK*.

Corredores

En este apartado se evidencia la conectividad de la red y las frecuencias en las que son utilizados cada uno de los corredores. Las conclusiones de este apartado son generadas tomando como referencia en el mapa 11, construida en base a los registros de operaciones.



Mapa 11 - Corredores.
Fuente: Elaboración propia.

En primer lugar, se destaca el entramado radial que presenta la red, con la confluencia de las principales rutas en el área metropolitana de Buenos Aires. Incluso los trazos más gruesos, que representan mayores frecuencias, son convergentes hacia esta zona.

Analizando los aeropuertos del área metropolitana las frecuencias se reparten 42% para Aeroparque y 4% para Ezeiza, mostrando un comportamiento poco menos intenso para Córdoba con el 8,5% y Mendoza con el 5,5%. Este elemento es relevante a efectos de la planificación del transporte multimodal, en virtud de integrar el transporte aéreo con otros medios para completar el ciclo de transporte.

Las frecuencias que no involucran a la región capital representan menos del 24%, con lo que evidencia una subestimación de la posibilidad de conexiones interurbanas sin intermediar en la zona metropolitana de Buenos Aires.

Por último, y del contraste entre el análisis de frecuencias respecto a [1], si bien se observa un aumento de las frecuencias de las ciudades más pobladas, el incremento es mayor en el resto de los aeropuertos referentes de la red tales como los aeropuertos de Bariloche, Iguazú, Neuquén y Salta, por nombrar los más beneficiados. Así también puede encontrarse la existencia de nuevos corredores explotados, sobre todo en la región norte como Patagónica. Este comportamiento, nos conduce a evidenciar una leve tendencia a descentralizar las operaciones fuera del cordón principal que conforman Buenos Aires- Córdoba- Mendoza, como se propone en [6].

Discusión sobre los resultados

El presente trabajo reúne indicadores en relación al transporte aéreo de los principales aeropuertos del Sistema Nacional Aeroportuario.

Se elaboraron indicadores para el movimiento de aeronaves, de pasajeros y de carga por aeropuerto. También se presentó la utilización de parámetros habitualmente aerocomerciales (RPK y ASK) para evaluar el desempeño de los aeropuertos dentro de la red. También se presentan resultados respecto al peso relativo de cada corredor aéreo en la red aeroportuaria analizada.

A continuación, se destacan las principales conclusiones referentes a cada ítem estudiado:

1. Movimientos de aeronaves: Se pudo observar cómo aeronave característica de la red la aeronave Embraer 190 con el 35% de participación en las operaciones realizadas, resaltando también la aeronave Boeing 737-700 con gran influencia. Las aeronaves características de la flota operativa de la red responden al tipo de clave C según la clasificación de OACI.
2. Movimientos de pasajeros: Los movimientos de pasajeros reflejan el grueso de las operaciones de la red, concentrando en el área metropolitana más del 80% de los movimientos para este tipo de vuelo
3. *Movimientos de carga*: Las operaciones de carga quedan acotadas a una componente relegada en el sistema, aun así, la red plantea a Ezeiza como principal hub de operaciones de carga, reuniendo más del 90% de los volúmenes transportados.
4. *RPK* y *ASK*: Propuesto Ezeiza como principal hub de movimentos para tipo de vuelos internacionales; y a propósito ofreciendo los destinos más alejados de la red; el mismo dispone con el valor más elevado para el indicador *RPK*. Observando el indicador *ASK* muy cercano a el valor de *RPK*, esto conduce a afirmar un factor de ocupación elevado para este aeropuerto. No obstante Aeroparque, no deja de perder relevancia como un actor importante en términos de *RPK* y *ASK*, siendo este el aeropuerto con mayor volumen de pasajeros transportados.
5. *Corredores aeroportuarios*: La conectividad de la red se ve fuertemente dependiente a la zona metropolitana, donde lo corredores concluyentes se reparten la mitad de los movimientos realizados. Por otro lado, si bien se evidencia bajas frecuencias de utilización en los corredores, la baja posibilidad de conexión entre los distintos puntos de la red, sin intermediar la ciudad capital, puede discreparse una leve tendencia hacia una red de carácter más federal.

Conclusiones

El trabajo brinda elementos para el análisis de la utilización del transporte aerocomercial en sus distintas variantes (pasajeros, carga o aviación general) como parte de un esquema integrado con otros subsistemas (carreteras, ferroviario, marítimo y fluvial, etc.).

La explotación de la red aeroportuaria nacional presenta perspectivas favorables de crecimiento, aprovechando en principio la capacidad instalada actualmente en conjunto con un plan de desarrollo que lo potencie.

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2016 Brussels Bombings: Air Traffic Analysis

Alejandro Hernández Rubio - ahernandezr1996@gmail.com
Universitat Politècnica de Catalunya
Pol Mesalles Ripoll - pol.air1@gmail.com
Universitat Politècnica de Catalunya
Ramiro Balado Ordax - baladoramiro@gmail.com
Universitat Politècnica de Catalunya

Abstract
The Gatwick airport drone incident has been the largest disruption on the air transport network since the 2010 eruptions of Eyjafjallajökull. Studying this incident, we intend to gain insight about the vulnerability of air transport networks to spatial hazards.
Robustness of complex networks is usually analysed through simulation of removal of vital elements (edges and nodes). The Gatwick incident allows us to analyse the impact of a real incident on air transport operations. We will use airport network and navigation network representations, and real data from operations during the event, to obtain a more realistic picture of robustness of air transport network.
The Gatwick drone incident lead to disruptions affecting 140,000 passengers and 1,000 flights. This impact is larger than the expected from analysis of robustness of the European airport network. The analysis of this event allows us to consider the impact of the spatial distribution and temporal scheduling of flights on the effects of a real-world incident.
The air transport network is known to be resilient to random errors and vulnerable to intentional attacks. Events like the Gatwick Airport drone incident have a much larger impact on the European transport network than the predicted in the literature. Our research extends the literature of robustness of the air transport network taking into account the spatial and temporal dimensions of air traffic.

Keywords
Air transport networks; Network robustness; Spatial Hazards

2016 Brussels Bombings: Air Traffic Analysis

Abstract

In this study, the results from an in-depth data analysis of the effects the 2016 Brussels bombings had on the European sky are presented. Even though the attack is found to not have had a major impact on the European air traffic as a whole, it did result in major losses for Brussels Airport that lasted for weeks even after the international airport reopened. The consequences of this event for nearby airports are also studied, and a significant spike in operations is detected in most of them. Finally, the most affected airlines operating in Brussels are listed.

Introduction

On Tuesday the 22nd of March, 2016, three suicidal terrorist attacks struck Brussels. Two of the explosions happened at 7:58am inside the main terminal of the Zaventem international airport (ICAO: EBBR, IATA: BRU), while the last blast struck the Maelbeek metro station in the city center an hour later [3, 2].
Following the incident, the airport closed until the 3rd of April, when it reopened again under a few restrictions. Many European countries reacted, including Germany, by stepping up security measures at points of high risk.
The attack, that took the lives of 32 people and injured 340 more, raised the terrorist threat levels to “Severe”, which symbolized a high possibility of attack.
This study presents the results of an in-depth analysis of the air activity before, during and after the incident, addressing the effects of the shutdown of Brussels’ only international airport, as well as the fear that the attack induced after it. All the data has been extracted from EUROCONTROL’s DDR2 platform, which includes information from all planned and flown European flight routes [1].

Air Traffic

On a European scale, this event had a moderate impact on the air traffic. Due to the fact that the Brussels airport closed, many flights were rerouted and many more were cancelled. The close proximity in time with the french ATC strike compounded these effects and made the impact significantly worse.
In this section, the impact of this terrorist bombing on the European and belgian air traffic is studied. In order to understand the data presented below, a bit of context is needed. Firstly, the European air traffic is very cyclic. Most of the flights occur between Monday and Friday, while the weekend sees a significant drop of flight numbers.
Secondly, March 20th signals the beginning of the Holy Week, with March 27th being Easter. This generates a significant increase of air traffic throughout Europe, most likely due to the combination of national holidays and good weather.

Brussels Airport

As it is expected and can be seen in Figure 1, the airport faced a severe decrease in air traffic, both in terms of arrivals and departures, after it reopened again. The traffic steadily increased during the first weeks after the reopening, but at a slow pace. On May 1st, the departures hall, which had sustained the most damage, partially reopened and marked the return of the airport to regular activity. Computing the mean, we obtain:

- Traffic before the attacks: 528 average daily flights (including departures and arrivals)
- Traffic after the attacks: 391 average daily flights (including departures and arrivals)

Overall, the traffic is reduced in a 26.1% following the tragic events. Further details of this comparison are presented in Figure 2, where the outer violin plot represents the flight density, while the inner box plot quantifies the distribution quartiles and the mean (diamond symbol). Bizarrely, despite the airport supposedly being closed from March 22nd to April 3rd, the number of flights during the days following the terrorist attack is non-zero. By taking a closer look at said flights, they appear to be from regular airlines. Some of them might be from cargo flights, but for some reason some of them seem short-haul routes, though they might have been special flights with no passengers.

Diverted Flights

On the day of the bombing, March 22nd, 2016, there were a total of 42 diverted flights that had intended to land on Brussels Airport.
On average, airlines actually saved 27.6 kg of fuel by diverting flights to airports closer to the origin point. These savings are so minimal that it had no appreciable effect either on the airlines costs or the environmental impact. However, costs related to those diverted flights such as compensations to passengers strongly outweigh those related to fuel consumption.
Figure 3 showcases the detailed routes followed by these flights as they were diverted. In some cases, the airlines decided to return to the point of origin, while in others they had to land in different airports, usually close to EBBR.

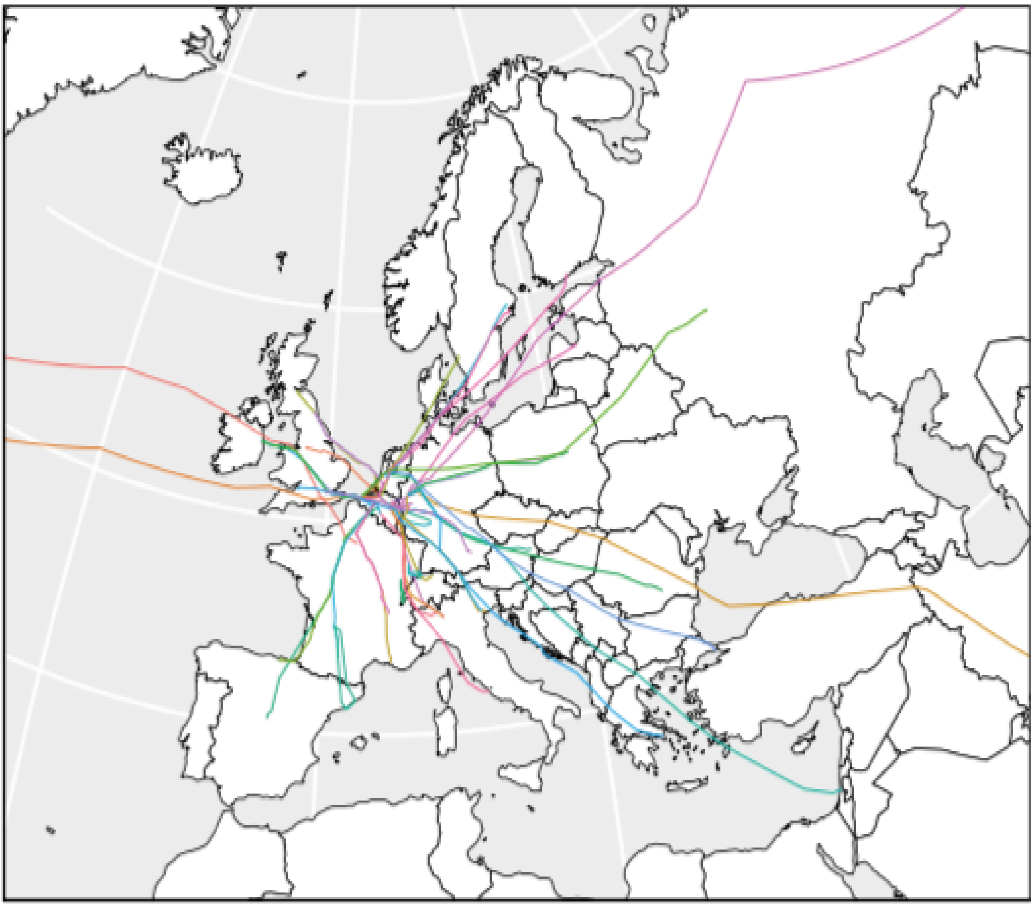

Figure 3: Map of all the diverted flights headed to EBBR

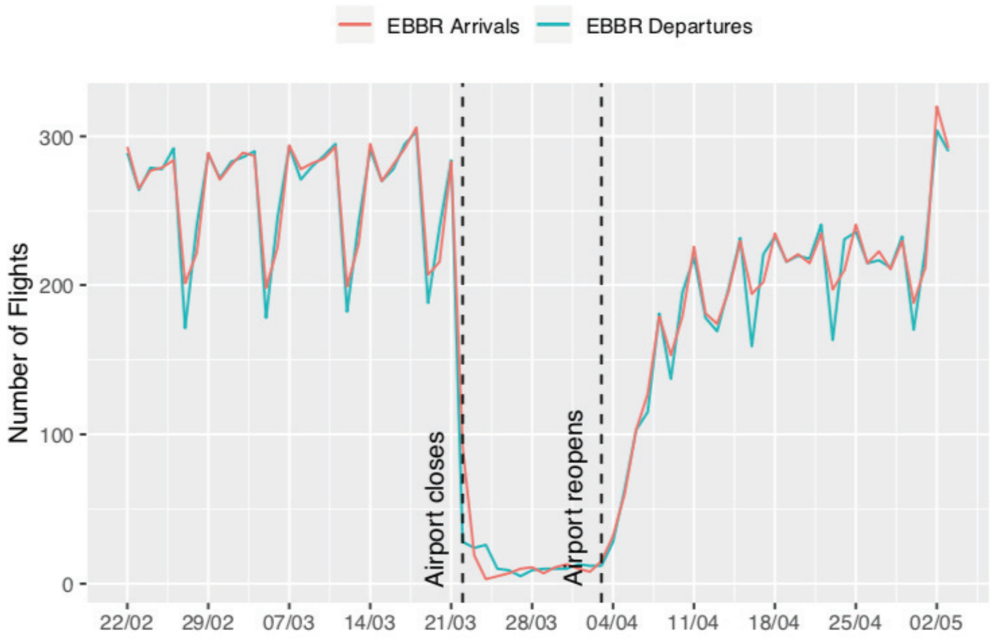

Figure 1: Air Traffic Evolution at EBBR

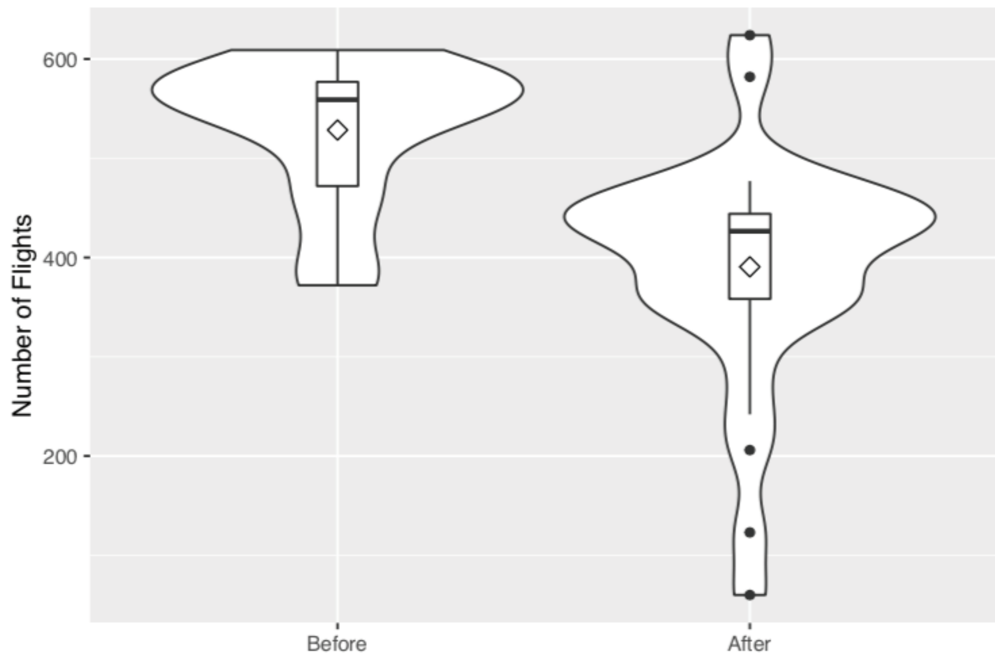

Figure 2: Average Daily Flights at EBBR

European Sky

The total number of daily flights registered by Eurocontrol is plotted in Figure 4. Overall, the effect over European air traffic is low, almost unnoticeable. This is due to the fact that the Brussels Airport does not control a large section of the European air traffic. This effect is even less noticeable taking into account the possibility of rerouting the planned flights through secondary airports. In fact, when analyzing the mean before, during and after the incident, we can see that the overall European volume of traffic actually increases:

- Average traffic before the attacks: 19451 flights per day
- Average traffic while EBBR was closed: 20345 flights per day (+4.6% with respect to before the attack)
- Average traffic after EBBR reopens: 22036 flights per day (+13.3% with respect to before the attack)

However, since the incident occurred around the Easter celebrations, the traffic was already expected to raise. This can be seen in airports such as Barcelona–El Prat Josep Tarradellas Airport (ICAO: LEBL, IATA: BCN), a typical tourism destination, which showed almost no reaction to the incident and kept the expected evolution (see Figure 5). In the case of Barcelona, the increase in traffic volume is significantly higher given the appeal of the city:

- Average traffic before the attacks: 666 flights per day (including departures and arrivals)
- Average traffic while EBBR was closed: 776 flights per day (including departures and arrivals; +16.6% with respect to before the attack)
- Average traffic after EBBR reopens: 830 flights per day (including departures and arrivals; +24.6% with respect to before the attack)

Therefore, we can conclude that the overall impact of the terrorist attack is higher than what can be interpreted directly from the European air traffic evolution, since the number of flights would have increased more if it weren't for the generated insecurity.

Airports

In this section, the arrivals and departures before, during and after the studied event both in the Zaventem airport and others nearby are discussed. Points of notorious relevance like traffic density, tendency and delays will be analyzed. The airports that have been considered to be close to Brussels and of relevance for this study are the following:

- Brussels South Charleroi (ICAO: EBCI), 50km down from Brussels
- Liège (ICAO: EBLG), eastern Belgium
- Antwerp (ICAO: EBAW), northern Belgium
- Eindhoven (ICAO: EHEH), southern Netherlands
- Lille (ICAO: LFQQ), northern France

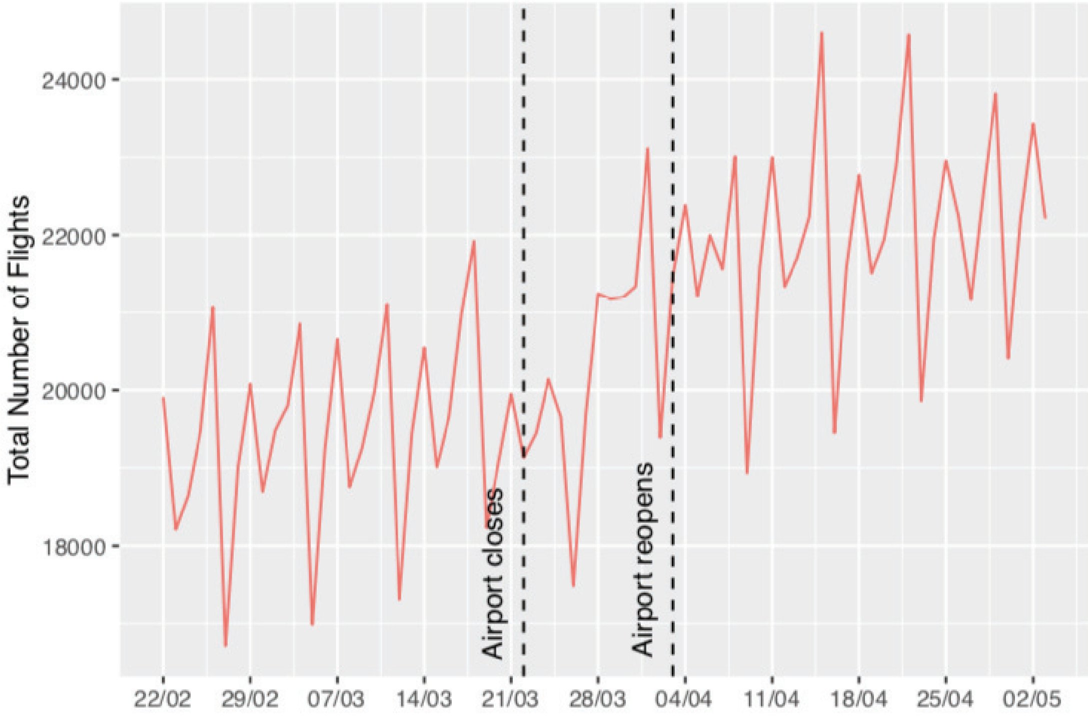

Figure 4: European Air Traffic Evolution

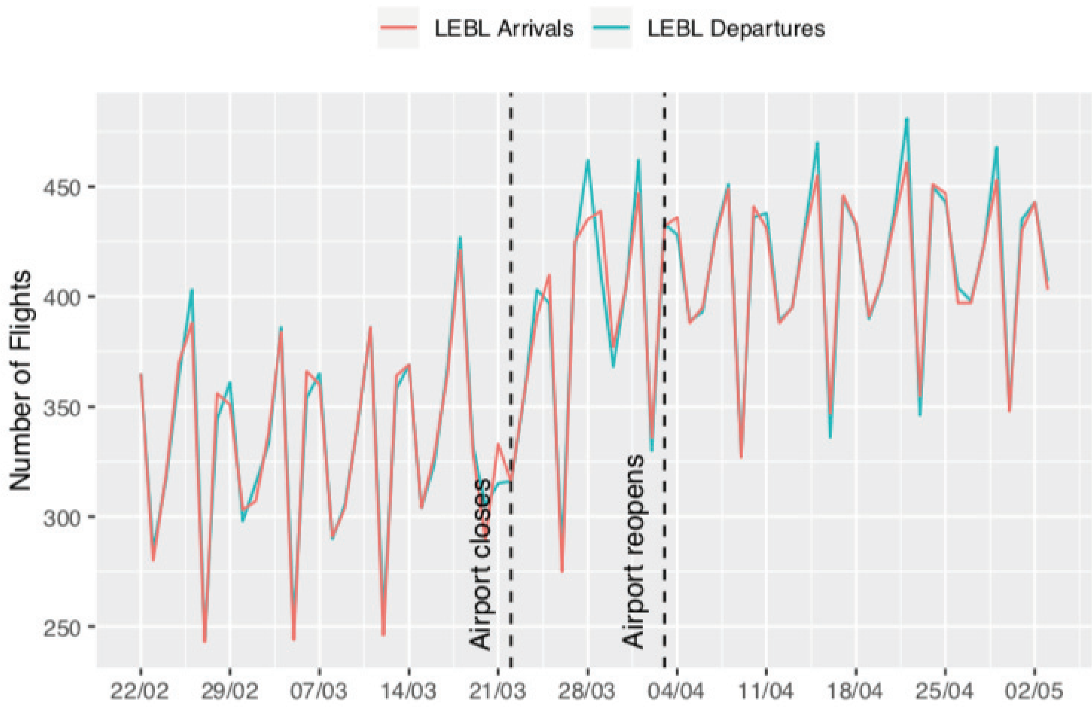

Figure 5: Air Traffic Evolution at LEBL

Traffic in nearby airports

To start, in Figure 6 we see how the traffic evolves in the five selected airports around Brussels, from one month before the attack to a month after the reopening of the airport. The plotted data can also be easily quantified by computing the mean:

- EBCI traffic:
  - +50.3% while EBBR was closed with respect to before the attack
  - +32.5% after EBBR reopens with respect to before the attack
- EBLG traffic:
  - +608.2% while EBBR was closed with respect to before the attack
  - +133.3% after EBBR reopens with respect to before the attack
- EBAW traffic:
  - +173.1% while EBBR was closed with respect to before the attack
  - +29.4% after EBBR reopens with respect to before the attack
- EHEH traffic:
  - +10.1% while EBBR was closed with respect to before the attack
  - +25.1% after EBBR reopens with respect to before the attack
- LFQQ traffic:
  - +57.7% while EBBR was closed with respect to before the attack
  - +75.2% after EBBR reopens with respect to before the attack

Finally, in order to obtain statistically significant figures regarding the distribution, box plots for each airport before, during and after the incident are drawn in Figure 7.

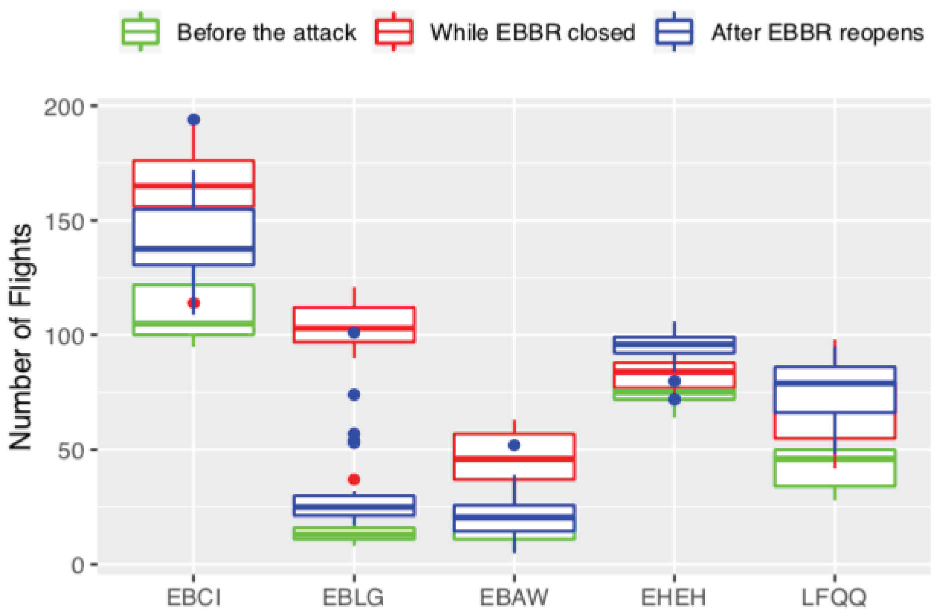

Figure 7: Average Daily Flights in Nearby Airports

We can see that right after the incident, there is a spike in both arrival and departure traffic density, due to the absorption of the traffic that Brussel's main airport can't take. The most notorious case is Liège (EBLG), where the traffic spiked by more than 600%. Following the opening of the main airport, the traffic slowly decreases as the Zaventem airport picks up the pace again. The one exception to this is Eindhoven (EHEH), which remains with its steady increase and appears unaffected by the incident.

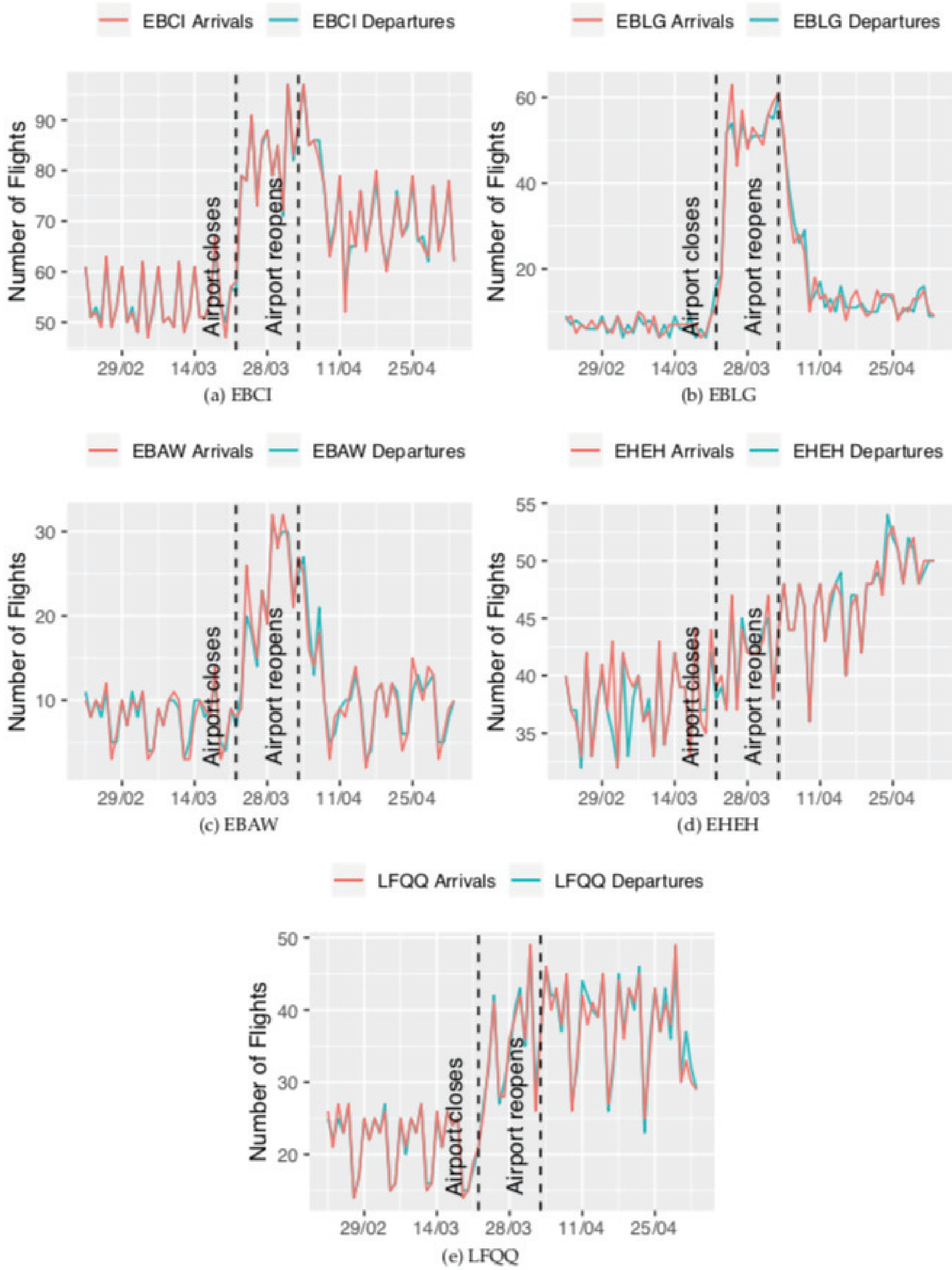

Figure 6: Air Traffic Evolution in Nearby Airports

Delays

In this section, the delays at Zaventem and nearby airports are studied. No relevant change in either arrivals or departures, during or after the incident is found. 1Note that there is a notable peak during the 20th of March. An air traffic control strike paralyzed the French airspace and caused numerous delays, but these are not related to the incident being analyzed. The data is mostly stochastic:

- EBBR delays:
  - Departures:
    - -139.7% while EBBR was closed with respect to before the attack
    - -5.5% after EBBR reopens with respect to before the attack
  - Arrivals:
    - -70.1% while EBBR was closed with respect to before the attack
    - -35.9% after EBBR reopens with respect to before the attack
- EBCI delays:
  - Departures:
    - +5.6% while EBBR was closed with respect to before the attack
    - -6.3% after EBBR reopens with respect to before the attack
  - Arrivals:
    - +38.9% while EBBR was closed with respect to before the attack
    - +69.6% after EBBR reopens with respect to before the attack
- EBLG delays:
  - Departures:
    - -26.6% while EBBR was closed with respect to before the attack
    - +2.6% after EBBR reopens with respect to before the attack
  - Arrivals:
    - -53.9% while EBBR was closed with respect to before the attack
    - -53.0% after EBBR reopens with respect to before the attack
- EBAW delays:
  - Departures:
    - -1.7% while EBBR was closed with respect to before the attack
    - -14.3% after EBBR reopens with respect to before the attack
  - Arrivals:
    - -85.6% while EBBR was closed with respect to before the attack
    - +73.1% after EBBR reopens with respect to before the attack
- EHEH delays:
  - Departures:
    - -31.6% while EBBR was closed with respect to before the attack
    - -6.2% after EBBR reopens with respect to before the attack
  - Arrivals:
    - -323.1% while EBBR was closed with respect to before the attack
    - +286.7% after EBBR reopens with respect to before the attack
- LFQQ delays:
  - Departures:
    - +113.2% while EBBR was closed with respect to before the attack
    - -20.4% after EBBR reopens with respect to before the attack
  - Arrivals:
    - +51.1% while EBBR was closed with respect to before the attack
    - -26.7% after EBBR reopens with respect to before the attack

In Figure 8, the average daily delays as a function of time are plotted. Then, box plots in Figures 9 and 10 prove that neither arrival nor departure delays change in any noticeable way during or after the incident with respect to before.

Airlines

From an economical point of view, it is interesting to look at the main airlines operating at Brussels Airport and analyze the evolution of their operations before, during and after the incident.
Overall, there is a moderate loss in flight density during the incident, mostly due to a generalized feeling of insecurity. Brussels Airlines, as one could expect, was the airline that was struck harder by the events, dropping to half its average traffic. After the incidents were over and the Brussels Airport reopened, airlines gained traffic and even surpassed that of before; this is probably due to other events happening, such as Easter, that motivated traveling.
Figure 11 depicts the air traffic evolution of the top five airlines most affected by the terrorist bombing:

- Brussels Airlines (ICAO: BEL), the flag carrier of Belgium (Star Alliance)
- Scandinavian Airlines (ICAO: SAS), the flag carrier of Sweden, Norway and Denmark (Star Alliance)
- Deutsche Lufthansa (ICAO: DLH), the largest German airline (Star Alliance)
- Widerøes Flyveselskap (ICAO: WIF), the largest regional airline operating in the Nordic countries
- Finnair (ICAO: FIN), the flag carrier of Finland (Oneworld)

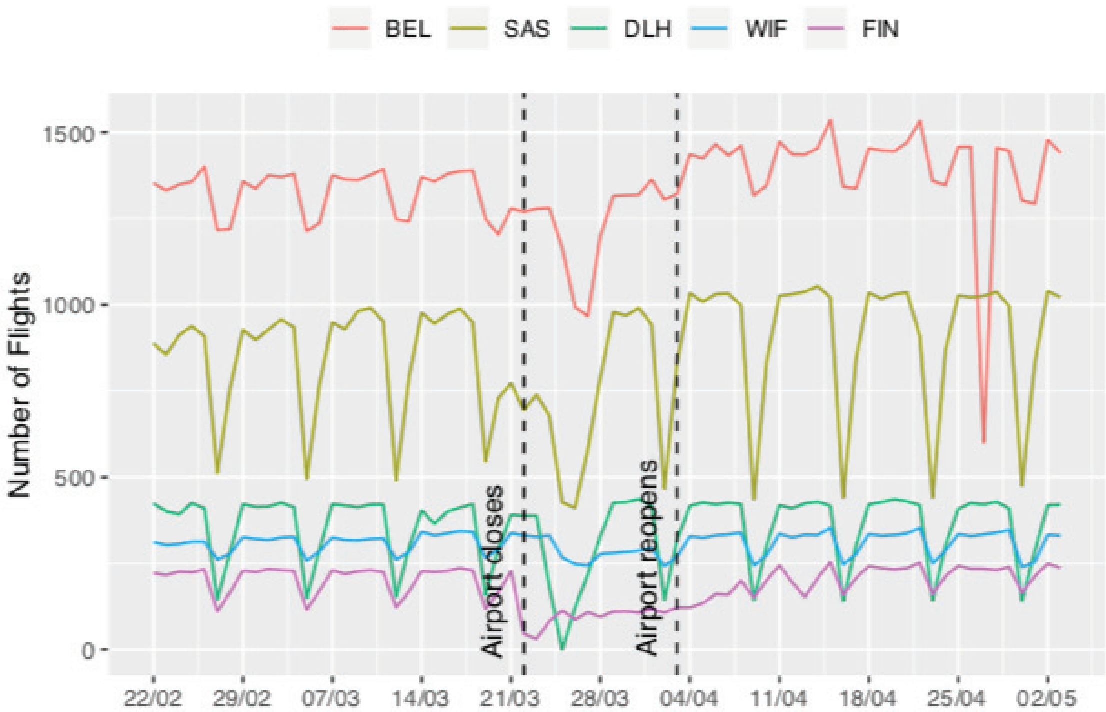

Figure 11: Most Affected Airlines

It is interesting to note that the sudden drop in flights on the 27th of April for Brussels Airlines is due to a strike which affected all Lufthansa Group pilots, which Brussels Airlines belongs to.

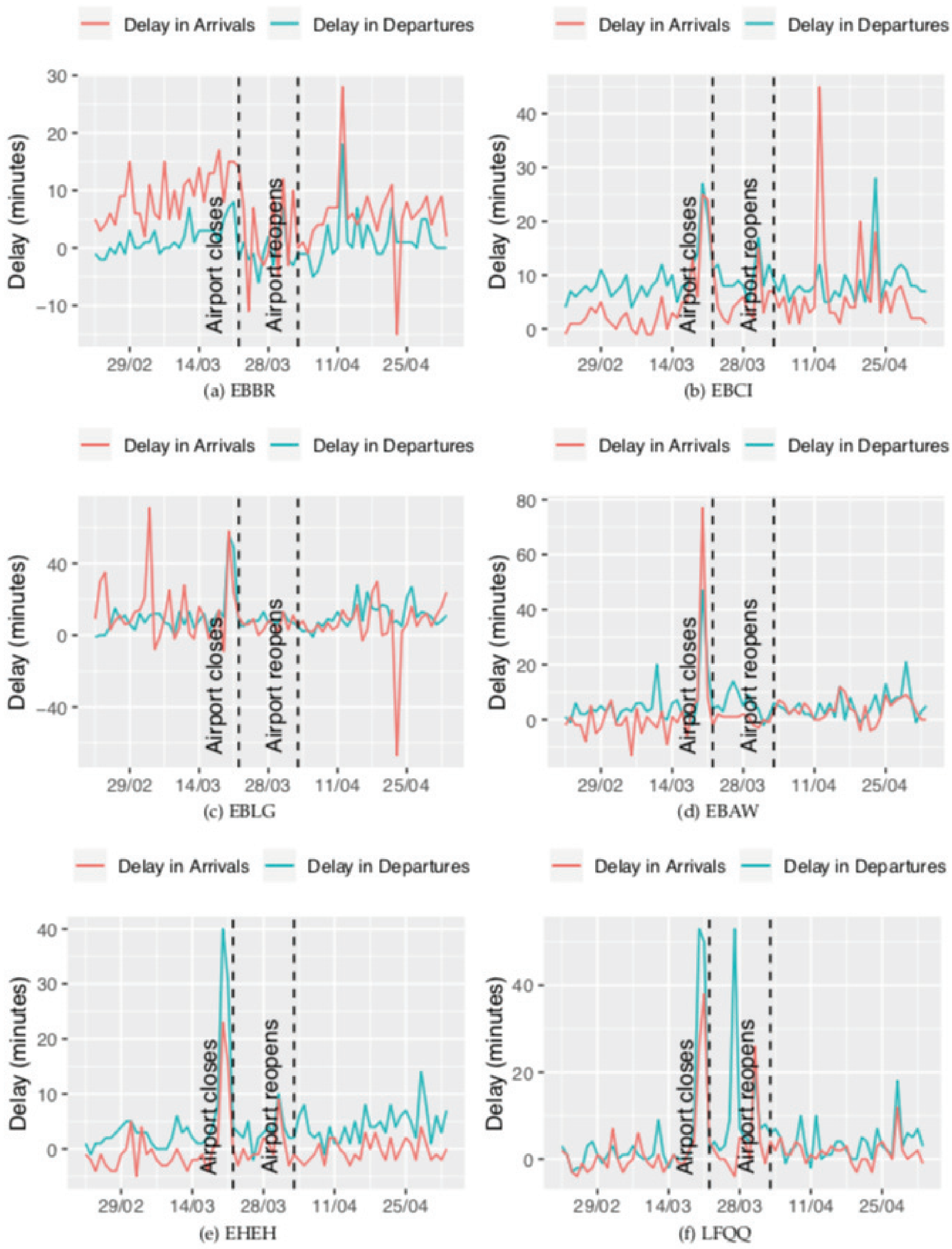

Figure 8: Average Daily Delays

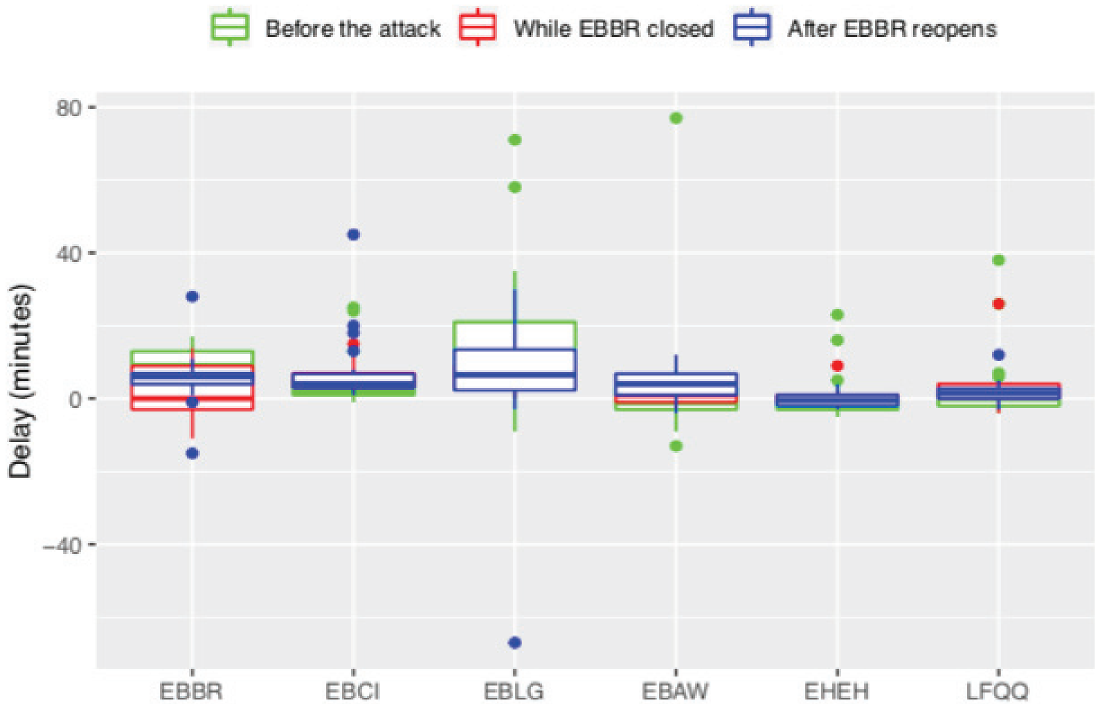

Figure 10: Average Daily Arrival Delays

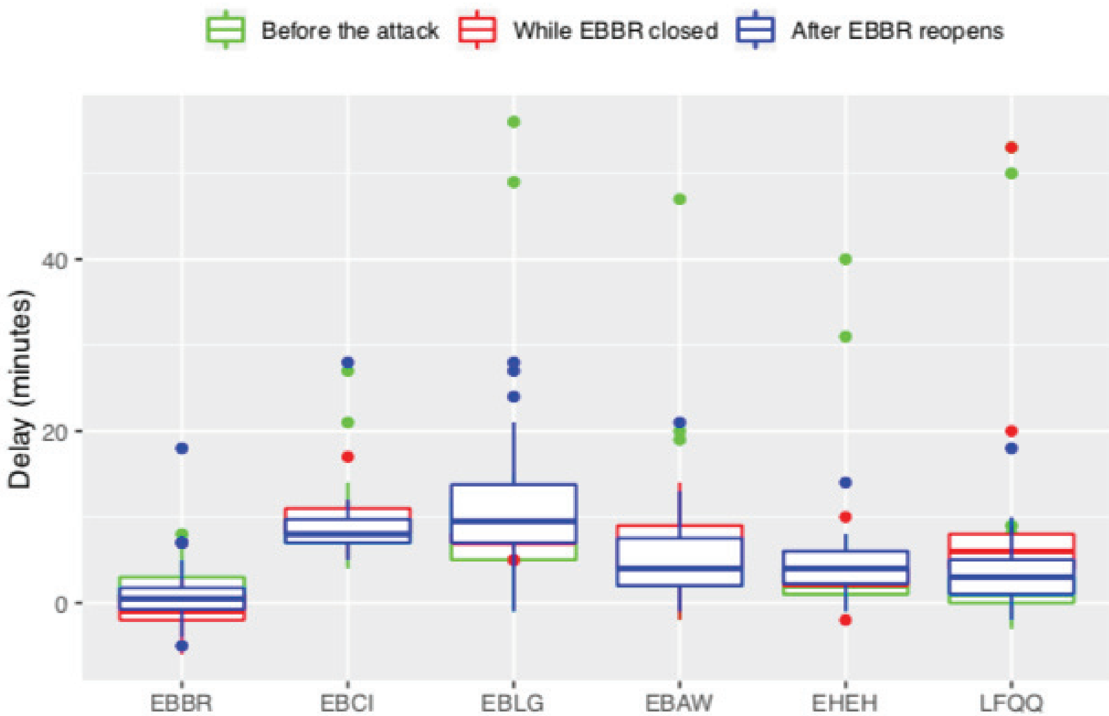

Figure 9: Average Daily Departure Delays

Conclusions

To summarize, there are two key aspects that had an impact in the European sky: the first, the shutdown and unavailability of Brussels main international airport caused a deficit in infrastructure capacity, leading to a considerable amount of flights diverted; the second, the fear induced by the terrorist attacks affected confidence in the security of airports, especially in the affected one, weakening its recovery after it was reopened again.
The former aspect is present mainly during the days following the attack. Secondary and nearby airports took the traffic load, and saw peaks in volume of traffic, increasing more than 600% in some cases (i.e., Liège).
The latter aspect is present after the airport was reopened. The recovery tendency was cut down by the lack of confidence and the temporary infrastructure put in place in Zaventem, which extended the time needed for a full recovery to more than a month after the bombings. Having said that, it is worth noting that the terror attack did not have a major impact at the European scale, but it is as well likely that many people cancelled their flights during a time of holidays due to the widespread fear.
Lastly, note that the effects presented an increased difficulty in their study as the event happened at a critical time: right after an ACT strike in France, and during Holy Week and Easter, which changed the tendency of flights and had to be taken into account.

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Air Transportation Sustainability Strategies: Technological, Operational, Economic, Social and Environmental.

Air Transport Operational Strategies

Optimizing Process of Airport Passengers Flow. The Case of Madeira International Airport Cristiano Ronaldo

Jose Dinarte Fernandes Goncalves - jd_goncalves@hotmail.com
University of Beira Interior
Jorge Silva - jmrs@ubi.pt
University of Beira Interior, Covilhã Portugal; CERIS, IST University of Lisbon, Lisbon Portugal
Maria E. Baltazar - mmila@ubi.pt
University of Beira Interior, Covilhã Portugal; CERIS, IST University of Lisbon, Lisbon Portugal

Abstract
The increased demand for air transportation has enlarged congestion problems in the areas of Passenger Terminals. This study proposes how to optimize the flows of passengers at the airport of Madeira to increase airport efficiency.
There are two specific approaches to achieve this study objective. Firstly, we analyse the flow of passengers at the airport terminal to detect where are the most critical congestion points. Secondly, using simulation software (MassMotion) we analyse different layouts of the airport terminal, including ramp area, considering passengers flows of different typologies, to find the most efficient layout configuration.
This study optimizes the flow of passengers in the terminal area of the International Airport of Madeira, making it more efficient in routing passengers and thus maintaining control over congestion levels. Thus, the proposed configurations for Check-in, Security, Border Control, Boarding Gates, Embark, Disembark, and Luggage Claim areas allow to considerably reduce (or even eliminate) passenger congestion at these critical points.
An airport is a complex transport infrastructure, and therefore any change in its physical structure must be made during its period of operation. Structural modifications must be simulated in software to be validated before being implemented; this was the option of Madeira International Airport, which thus seeks solutions to keep congestion levels under control, increase the efficiency of the terminal, and raise the level of passenger satisfaction.

Keywords
Airport Congestion; Optimizing Passengers Flow; Simulation; MassMotion

Passenger Flow Optimization at the Airport Terminal. The Case of Madeira International Airport Cristiano Ronaldo

Introduction

Air transport has grown in the last decades at a very fast pace, and the prediction according to a EUROCONTROL study [1] is that it continues to grow.

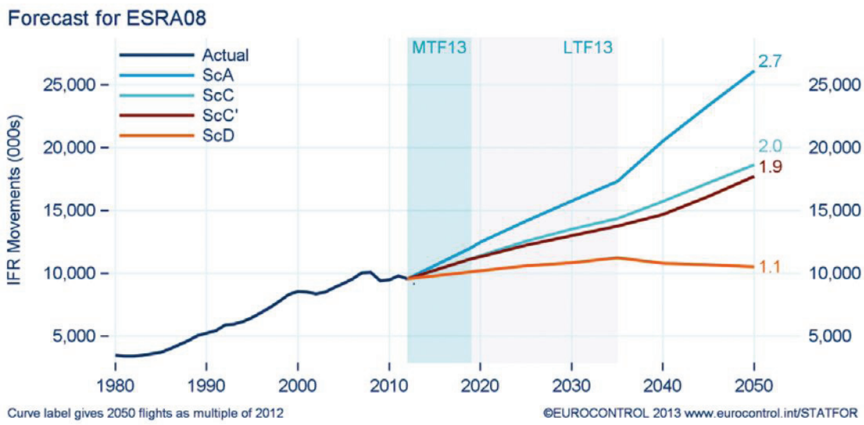

Figure 1 - Prediction of the number of aircraft movements until 2050 [1].

In Figure 1, we can see that according to the most probable scenario, in 2035 there will be approximately 50% more flights than those that currently exist, and the forecast for 2050 indicates that this number will double compared to the current one. Regarding the number of passengers flying, we can see that according to a forecast made by ICAO in 2016 [2], this number will also grow strongly in the coming years.

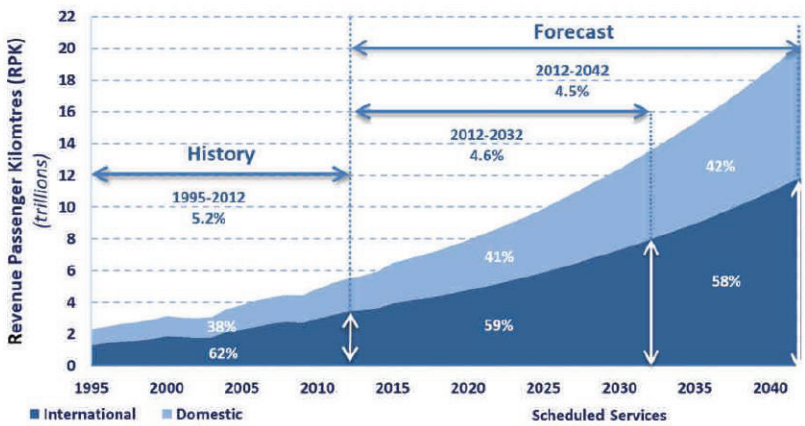

Figure 2 - Total passenger traffic: history and forecasts [2].

Figure 2 shows the expected annual growth rates over the next 20 and 30 years. We can see that in the period from 2012 to 2032 the forecast is that the number of passengers has a growth of 4.6% per year and in the period from 2012 to 2042 this growth is 4.5%.

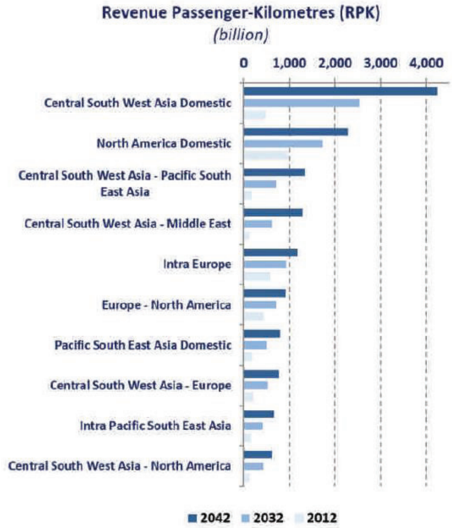

Figure 3 – World top 10 passenger traffic by route group: 2012 vs. 2032 and 2012 vs. 2042 [2].

Figure 3 shows the 10 main world routes and the growth projection for each one. The biggest growth will be in the Asian continent, more precisely in South Asia, where growth around 10% per year is expected. In Europe, the volume of passengers will also grow, but at a rate of 2.1% per year. However, this growth is not parallel to the increase of the airport capacity, which leads to congestion being a major issue. The EUROCONTROL study [1] estimates that by 2030, 1.9 million flights will not be able to be accommodated. By 2035, within the plans that the airports reported, it is estimated that 120 million passengers will not be able to travel. By 2035, more than 20 airports will be operating at 80% or more of their total capacity, in 2012 they were only 3. This entails delaying the airport which was about 1 minute per flight in 2012, to 5 to 6 minutes in 2035, making it switch from a minor or intermittent problem to a permanent problem in the delay of flights.
To respond to this growth, airports need to act, as more flights will bring more passengers to airports with airports where expansion is very limited; one of the solutions is to increase the efficiency of the airport.

Framework

At Madeira airport, growth follows the world trend, reaching a record of more than 3 million passengers in 2017 [3].

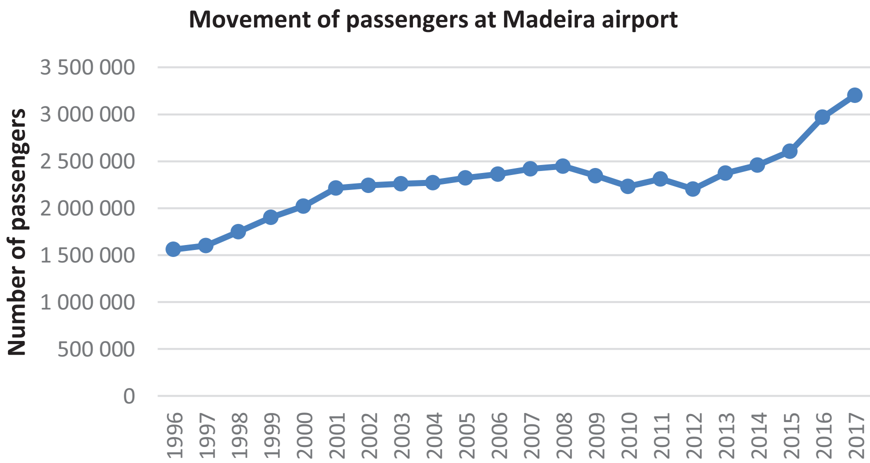

Figure 4 – Movement of passengers at the airport of Madeira between 1996 and 2017. Source: Own elaboration based on [4].

As we can see in Figure 4, growth in recent years was accentuated, with only a decline between 2008 and 2012, which can be explained by the global crisis that was felt during this period. The growth forecast for Europe by 2042 will be 2.1% each year, which will make the number of passengers by that time double compared to 2012. Figure 5 shows in more detail the growth of European routes by 2032 and 2042.

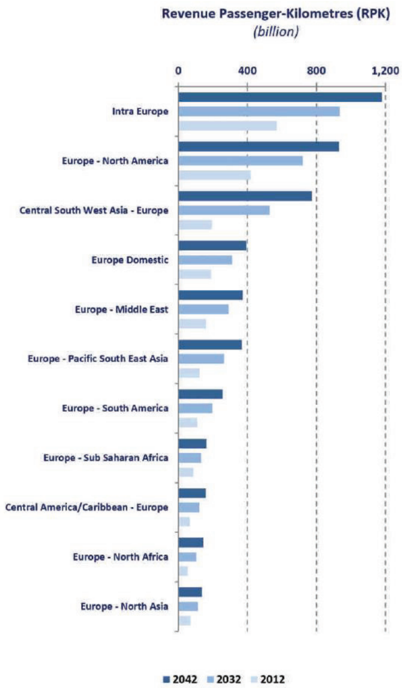

Figure 5 – Europe Passenger traffic forecast: 2012 vs. 2032 and 2012 vs. 2042 [2].

Case study

With the number of passengers increasing at the airport and considering that projections for the coming years will be continuously growing, it will be likely that there will be more congestion at the airport terminal. After observing the normal operation of the airport of Madeira, some points were observed in the terminal where the flow of passengers sometimes tends to congestion. Time measurements were taken where the passenger takes at all distinct phases of their route to the aircraft, as well as the observation of the procedures to which they are subject. In the context of this article, we will show only two of these phases, Check-in and Security, and we will compare the layout used in 2017 with a new layout, the latter with the aim of reducing or even eliminating the congestion observed in the layout of 2017.

Actual configuration

Check-in

Check-in at Madeira Airport is done on floor 1, where some points were found where the flow of passengers is not done smoothly. There are 40 check-in counters available, however, 38 are used to check-in, and two of the counters do not have a belt to dispatch a basement suitcase, so it is not very common to use them. To exemplify and analyse the current situation, we use the crowd simulation software: MassMotion is a very versatile program that shows us how crowds behave in certain spaces. For the cases that we will analyse in this article, we have the second busiest day at the airport in Madeira in the year 2017, which according to IATA should be considered the peak day [5]. A total of 53 flights corresponding to 7886 passengers were inserted into MassMotion, the times used for check-layouts analysed correspond to those used in 2017.

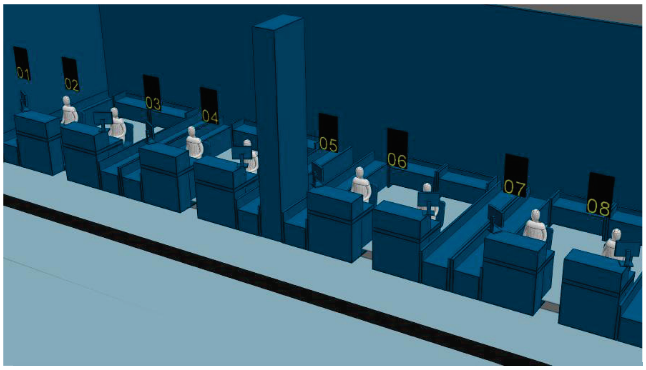

Figure 6 – Check-in counters. Source: Own elaboration.

Figure 7 – Entrance to access floor 3. Source: Own elaboration.

In Figure 6 we have an example of what the check-in counters are like. One of the problems with the passenger's arrangement at the check-in is that when more than 2 consecutive counters are used, passengers at the middle counter have some difficulty getting out of the counter toward the access door to floor 3 (Figure 7). This happens because the distance between the passenger who is at the check-in counter and the passenger immediately behind him is short and also the distance between queues are reduced, since the queues are individual at each counter, although it is the same flight, which means that the passenger has to try to arrange a passage between the passengers who are queuing for the check-in. In this configuration what happens is that the passenger immediately behind the passenger who has already checked-in, takes a few more seconds to reach the counter, this is because the passenger in queue is prevented by the passenger who has already checked-in and wants to go to the floor of the access door 3.This problem is represented in Figures 8 and 9, where passengers represented with the grey colour already have checked-in, and the coloured passengers are those who are queuing waiting for their turn to check-in. The different colours represent passengers on different flights.

Figure 8 - Arrangement of queues at check-in counters. Source: Own elaboration

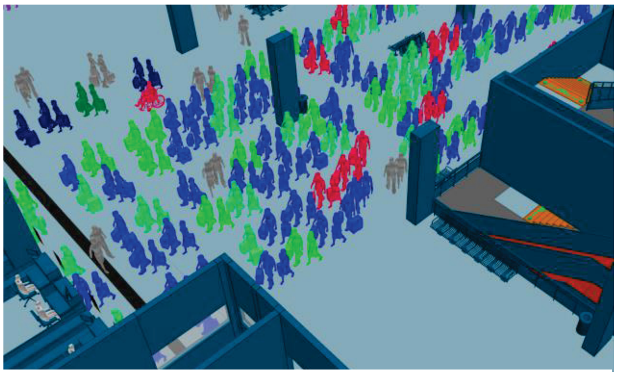

Figure 9 - Example of queue arrangement and exit of passengers from check-in counters. Source: Own elaboration

In order to analyse how these queues behave and how they are arranged in the terminal, we will use simulation software, MassMotion. With the experienced density map, which is shown in Figure 10, we can see where the passengers were in line until they were answered on the counter. This map is made considering the average density that was measured with the particularity of accenting the peaks of density. The colours shown on the maps represent the IATA level of service the passenger experienced. The scale of 0 to 1 represents the number of people per square meter at a given time.

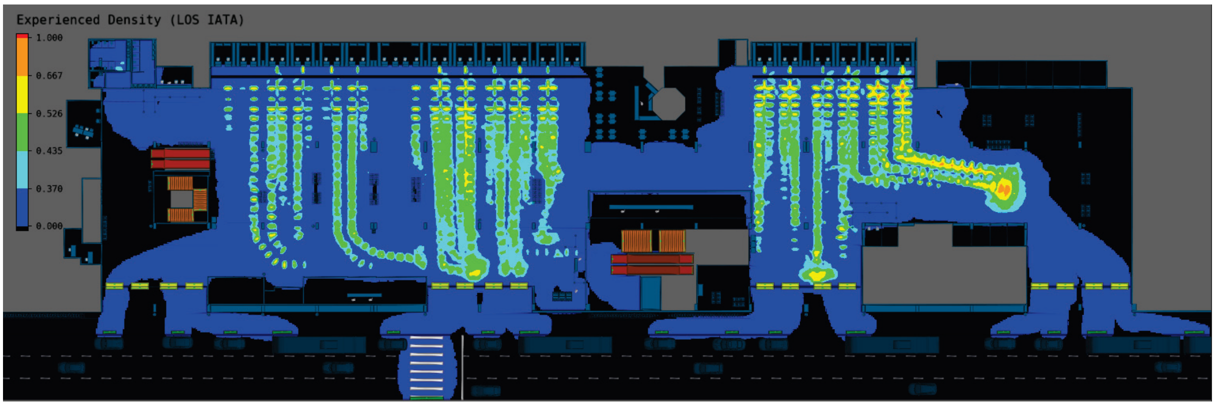

Figure 10 - Experienced density observed on the 1st floor on the busiest day of the high season. Source: Own elaboration.

In Figure 11 we have the map of maximum density from the arrival of the first passenger until the moment the last passenger climbs to the third floor.

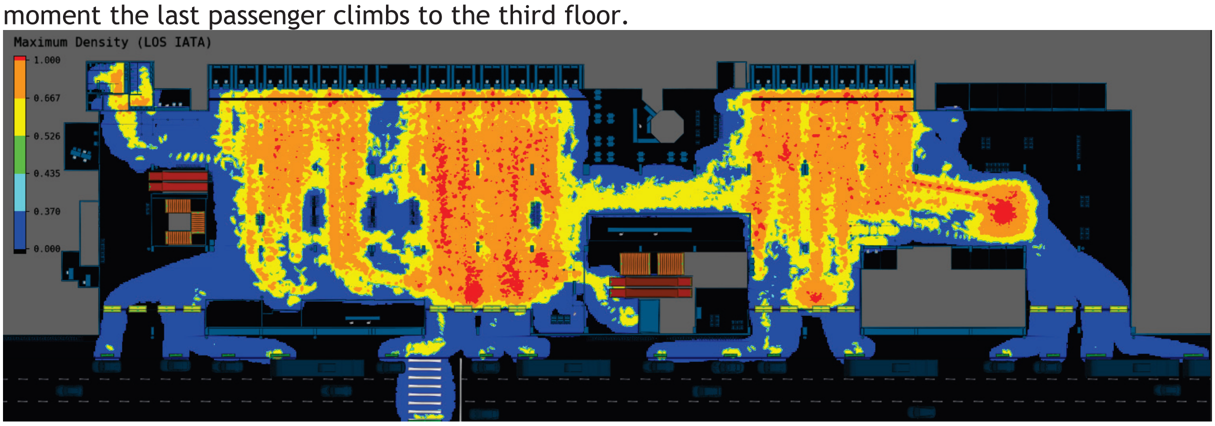

Figure 11 - Maximum density observed on the 1st floor on the busiest day of the high season. Source: Own elaboration.

When analysing the density maps we can see that there are areas where the flow of passengers is not fluid; considering the characteristics of the layout used and the area available for passengers to queue, we find some situations that lead to areas with some congestion. In Figures 12 and 13 we have two examples of congestion. Queues are organized in front of the counters and behave independently of each other; sometimes we have 2 queues of different sizes, depending on the speed of attendance of the employee at the check-in counter. As shown in Figure 12, passengers in purple are making it difficult for passengers to enter the terminal due to the length of the queue. In Figure 13 we have another example where we can see the passengers in line near the entrance doors and obstructing the passage that gives access to the floor 3, so the passengers who already checked-in have some difficulty in going through the access control and sometimes even in finding the access door. This makes the experience less pleasant for the passenger.

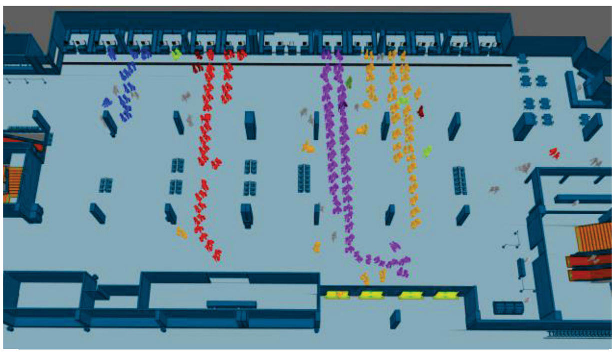

Figure 12 - Passenger queues in front of entry doors. Source: Own elaboration.

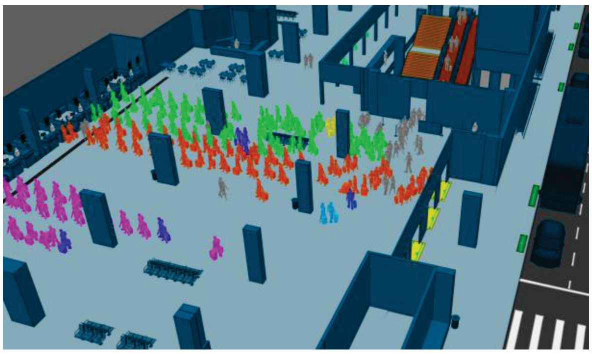

Figure 13 - Passenger queues in front of the access door to the 3rd floor. Source: Own elaboration.

Security

The security screening at Madeira Airport is located on floor 3 and is where all passengers with valid boarding ticket should be directed to move to the airside. As is a very sensitive topic, in this article we will approach this theme more loosely. We will essentially analyse the queues until we reach the trace line, where we found some points that can be improved. Tracking line 1 is where passengers with reduced mobility and fast track should go; as it is only a line for these two situations sometimes creates some conflict. We can see exemplified the situation in Figure 14, where we also see how it is waiting time for passengers with an economic ticket. Another case is in access control, in peak hours: this control is done by two agents, as we can see in Figure 15. In this case, two agents are not enough to give discharge to the number of people that are verified at the peak hour.

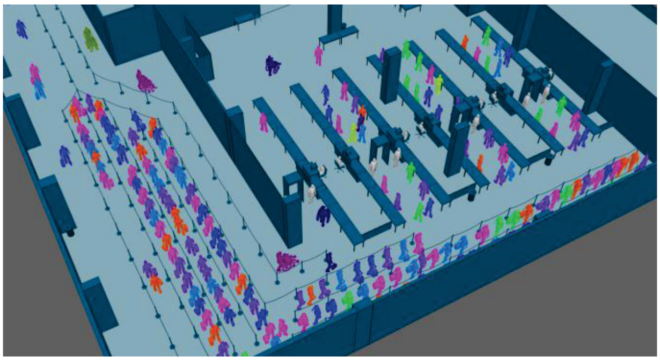

Figure 14 - Waiting queues for security. Source: Own elaboration.

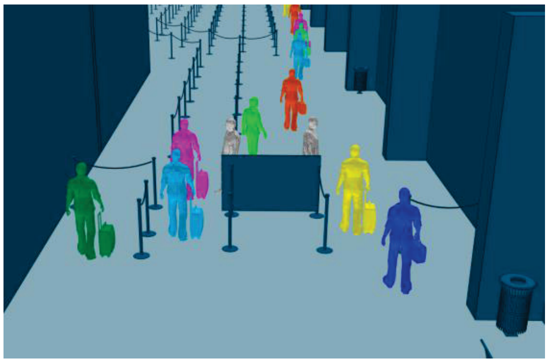

Figure 15 - Access control. Source: Own elaboration.

The current layout is shown in Figure 16. The marked areas represent the different queues, the area where the letter A is marked are for priority passengers, the areas with the letters B and C are for passengers with an economic ticket, zone C is only used when there is a large number of passengers. Row 1 is used only by passengers with reduced mobility, row 2 for passengers with an executive ticket or equivalent and for fast track, finally row 3 is for the remaining passengers.

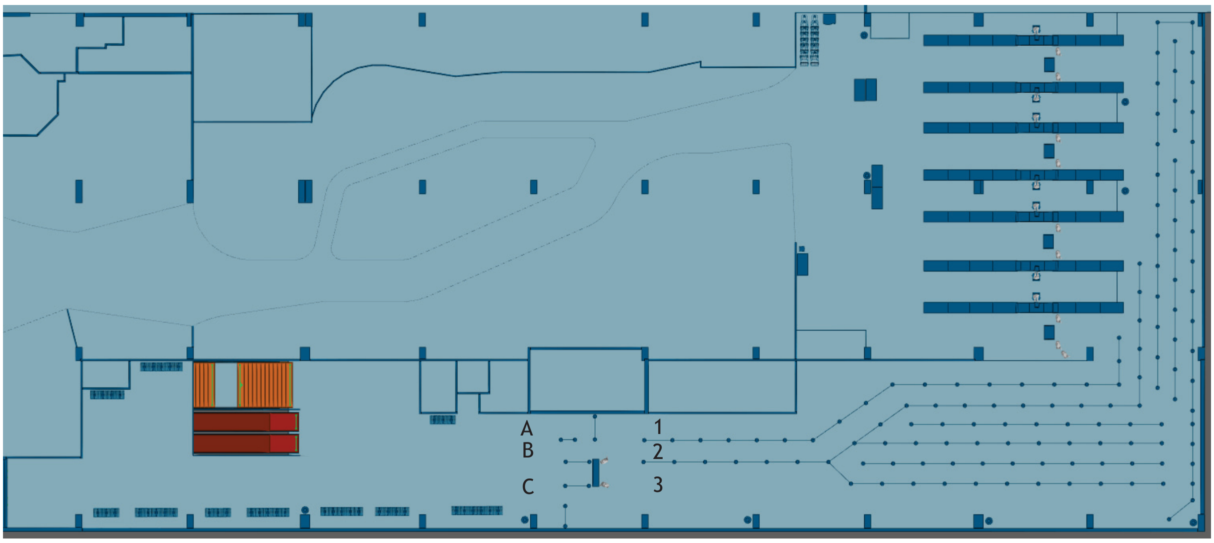

Figure 16 - Current layout of the security zone. Source: Own elaboration.

To better understand how the current layout behaves we will analyse the maximum density map.

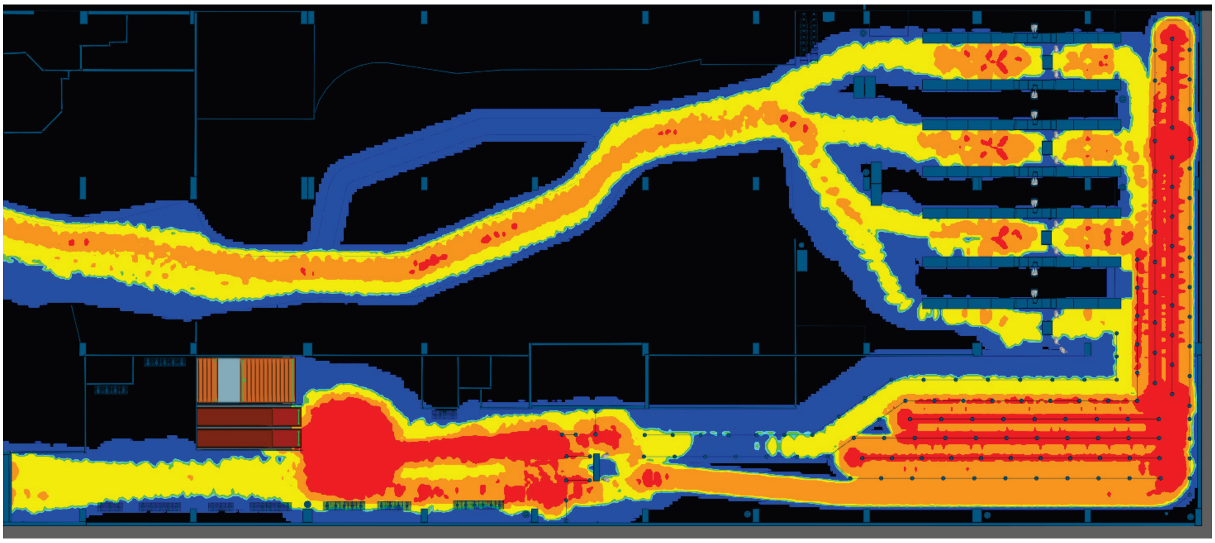

Figure 17 - Density map on floor 3. Source: Own elaboration.

As we can see in Figure 17, we have some congestion in the second access control: the first access control, as we saw at check-in, is done on floor 1, is essentially due to a peak. The layout for the queues is also oversized, according to the level of service recommended by IATA, which is 1 square meter per person [5], so space is not fully harnessed and optimized. In the tracing zone, we also find that it does not comply with the measures recommended by IATA, which is slightly lower than expected [6].

Optimized configuration

Check-in

Considering that the distance between the entrance doors and the check-in counters at the Madeira airport is reduced, some solutions have been found to try to solve this problem. The first change implemented was to retreat all check-in counters 1 meter, as exemplified in Figure 18, to create a check-in zone marked in green, between the pillars, and a movement corridor marked in red, as we can see in Figure 19.

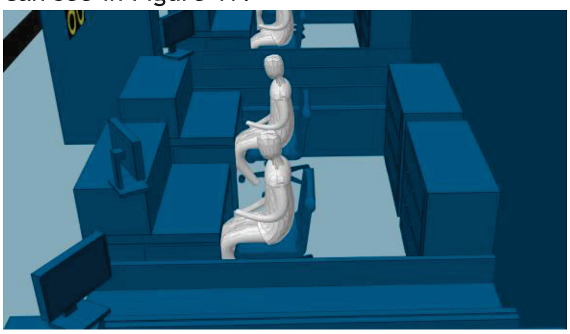

Figure 18 - Change of check-in counters. Source: Own elaboration.

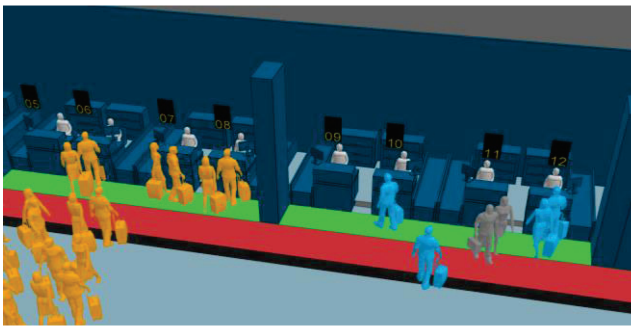

Figure 19 - Check-in area and corridor of movement. Source: Own elaboration.

The next change was in the construction of the layouts: the solution found was to distribute the passengers in parallel queues to the check-in counters, with zig-zag layouts, where they were preferably made within the area marked in green (zone A) in Figure 20. The yellow area (zone B) was only used on days of high affluence.

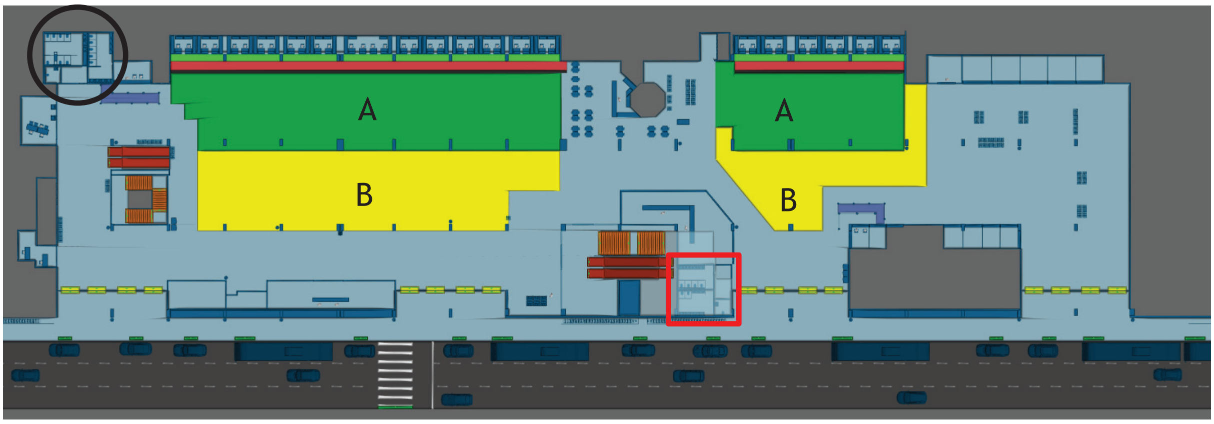

Figure 20 - Check-in areas. Source: Own elaboration.

The next change concerns the fact that there is only one bathroom on floor 1, which is marked with a black circle in Figure 20. A passenger checking-in on the opposite side of the terminal and having to move to the bathroom will have to go through the entire extension of the terminal and then go back to climb to the third floor. The solution found was to build another bathroom in the central area of the terminal; the location of this bathroom is marked in Figure 20 with a red square.

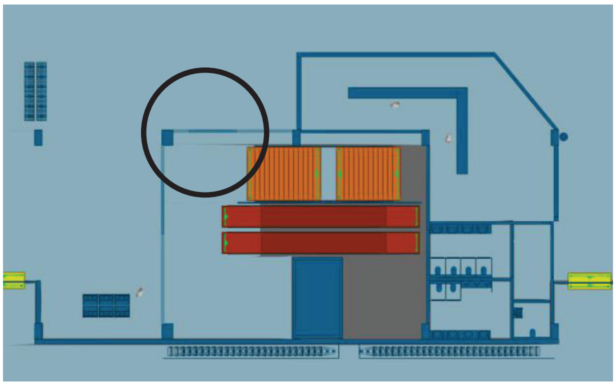

Figure 21 - Detail of the bathroom and access to the 3rd floor. Source: Own elaboration.

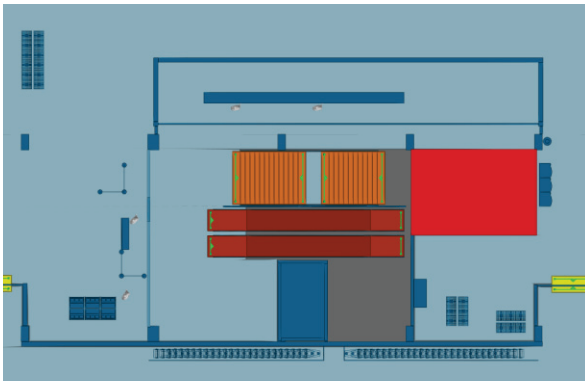

Figure 22 - Current layout of the zone to be changed. Source: Own elaboration.

In Figure 21 we see the bathroom in more detail and also a change in access to floor 3. Comparing with Figure 22 which is the current situation, we noticed that we have another door that is marked with a black circle in Figure 21; at this stage, there will be no preliminary access control for floor 3, since it will be done mainly on floor 3 itself, as it is currently done. For the store shown in Figure 22 to have the same area, it was necessary to close the floor in the area marked by a red filled rectangle in Figure 22, once the floor in that zone is opened.

Layout constructions were previously studied with the help of MassMotion software so that we could get the most efficient possible layout. These simulations considered the number of passengers on each flight so that we can comfortably accommodate all passengers throughout the length of the check-in zone. The counters to be assigned to each flight were also analysed in detail, to be able to assign the counters required by each company, but also to make the layout viable.

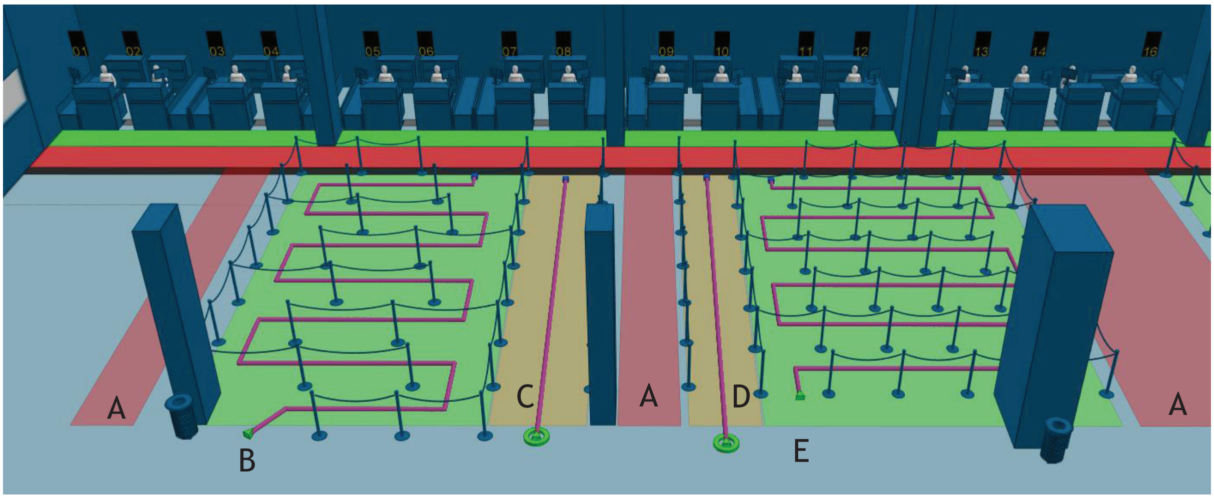

Figure 23 - New layout example. Source: Own elaboration.

In Figure 23 we also have four distinct single rows, the letters B and E are two single rows of economy class, which occupy the area marked in green, the letters C and D are single rows of business class, executive class and passengers with priority, occupying the area marked in yellow, the letters A represent exit corridors for passengers who have already checked-in and are marked in red. In Figure 24 we have the new layouts used for the same day analysed in the current situation.

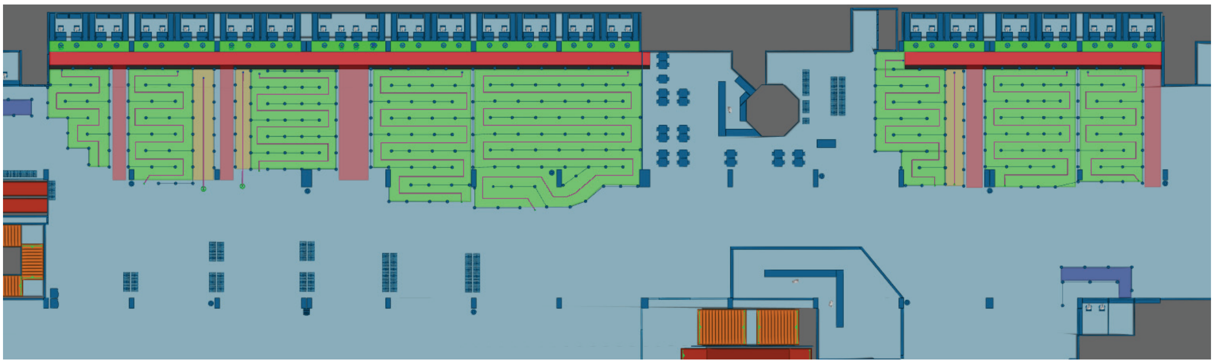

Figure 24 - New layouts for the 2nd busiest day. Source: Own elaboration.

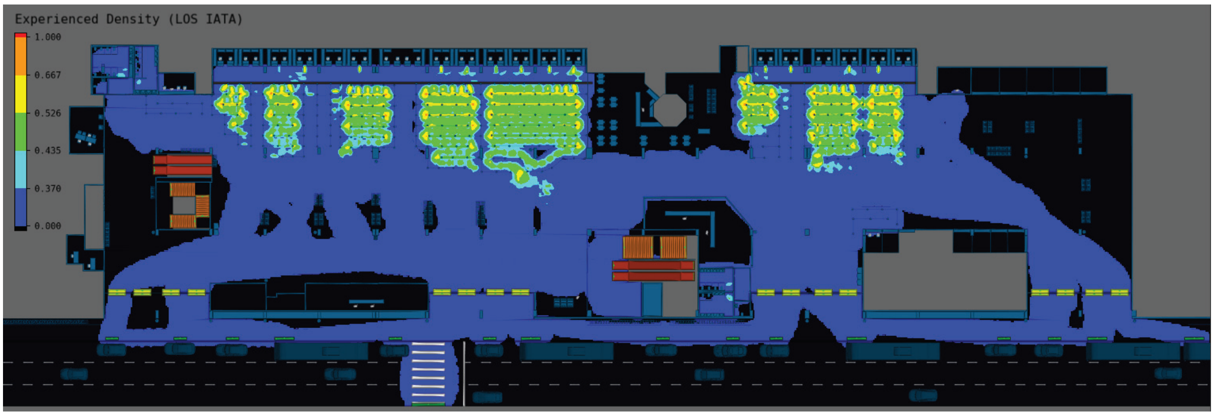

Figure 25 - Experienced density observed on the 1st floor on the busiest day of the high season. Source: Own elaboration.

In Figure 25 we have represented the experienced density map; with this map we were able to observe where the passengers are in queue, as expected: in all the flights it was possible to distribute the passengers so that they remained in the area closest to the counters, the green area (zone A) represented in Figure 20.

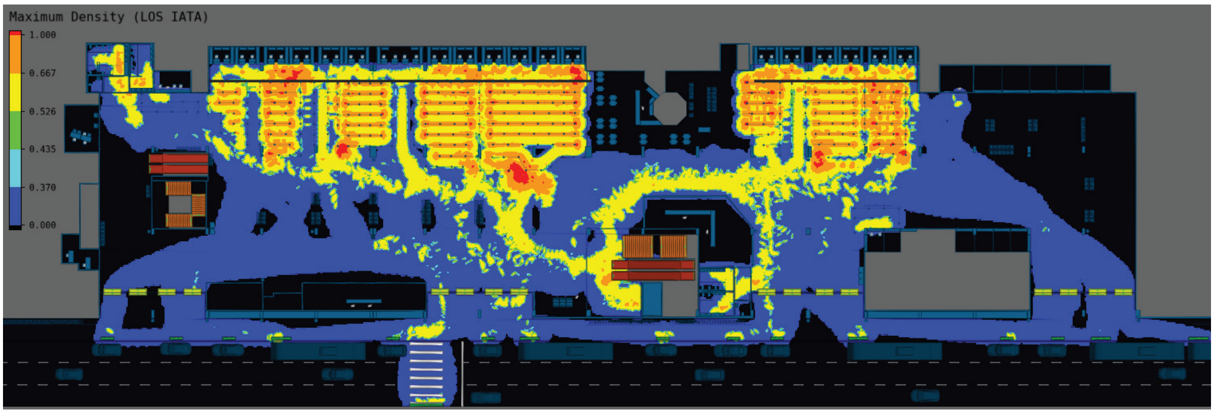

Figure 26 - Maximum density observed on the 1st floor on the busiest day of the high season. Source: Own elaboration.

In Figure 26 we have represented the maximum density map. As we can see, the areas where the density was the most critical was at the entrance to the layouts. In general, the level of service that the passenger experienced was better than the current layout. The entrance doors and also the access doors to the floor 3 are completely free of queues and also the passageway to the bathroom is completely unobstructed.

Security

On the third floor, the layout shown in Figure 27 was studied to comply with the measures recommended by IATA between the security lines and the level of service.

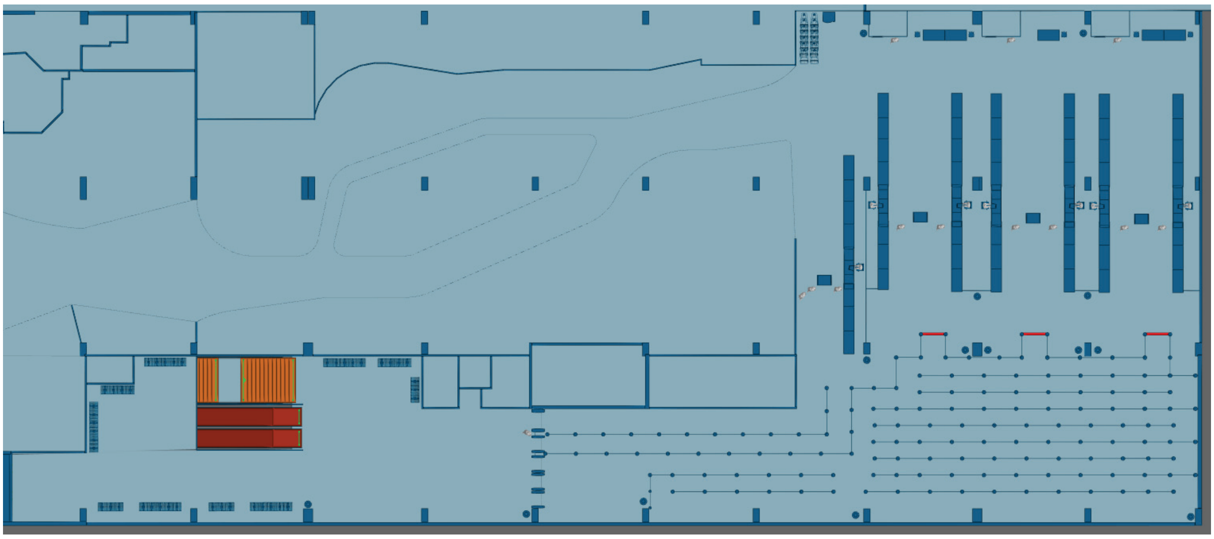

Figure 27 - New layout for security lines and queues. Source: Own elaboration.

In Figure 28 we can see that we have line 1 dedicated to passengers with reduced mobility. When there are no passengers with reduced mobility, passengers with fast track and an executive ticket can use this line; when it is not free, line 2 will be dedicated to these passengers. The remaining passengers use the remaining lines and when lines 1 and 2 are free, they can also use them. In access control, automatic access machines were implemented, 3 for the economy, 1 for fast track and executive, and 1 for passengers with reduced mobility, as we can see in Figure 29.

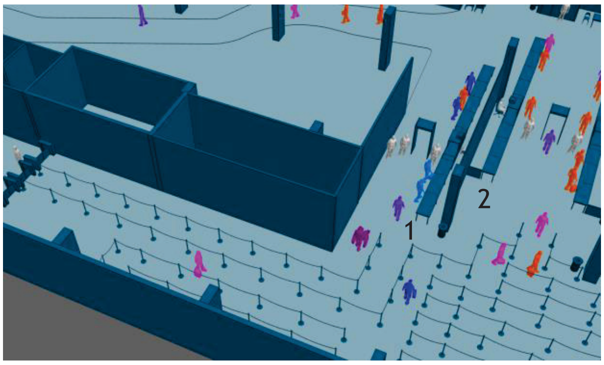

Figure 28 - Specific security lines. Source: Own elaboration.

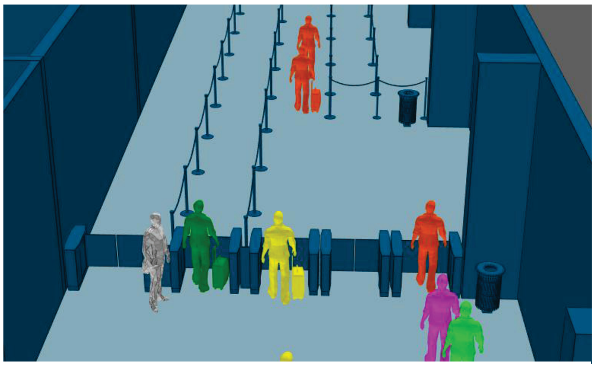

Figure 29 – Automated access machines. Source: Own elaboration.

In Figure 30 we have the maximum density map. We can see that there was a reducing in congestion in the queues for access control. In the queues for security, we have the level of service recommended by IATA, 1 square meter per person [5], which makes the area optimized to the maximum. Also the distance between the security lines has been increased, which has improved the level of service experienced by passengers in this area.

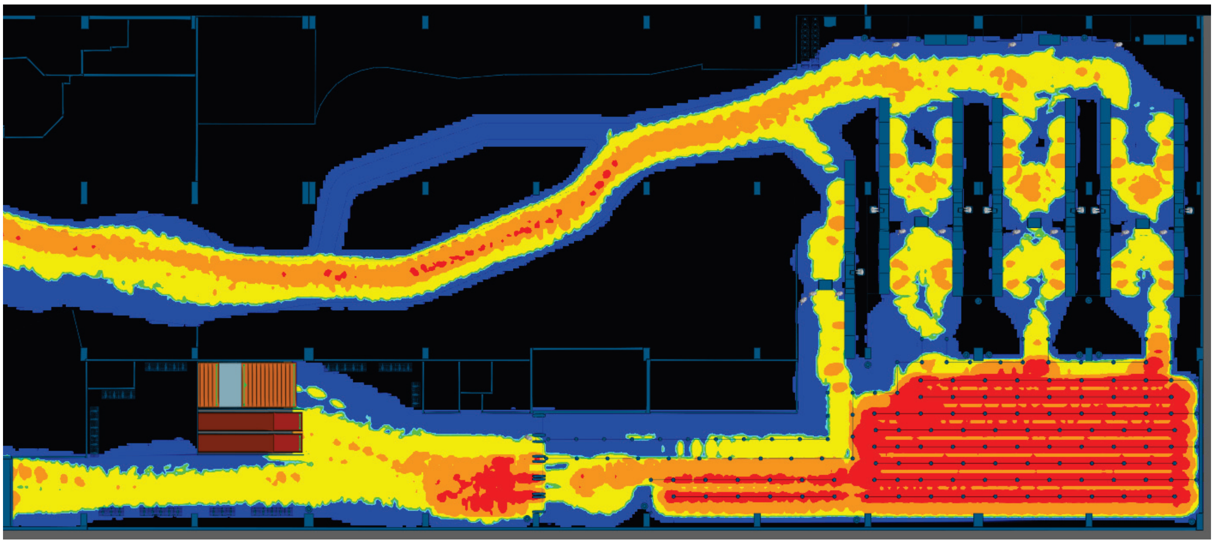

Figure 30 - Density map on floor 3. Source: Own elaboration.

Conclusions and Future Work

Air transport remains one of the most popular worldwide. Several sectors of air transport will continue to be pressured to accommodate more and more passengers and airports are one of them. In this regard, to solve the problem of airport congestion, it is necessary either to implement restrictive measures to accept passengers or to improve the layout of the premises. This paper analyses the problem of passenger congestion at Madeira Airport, and in two specific areas: Check-in and Security According to the obtained results, we realized that with more detailed planning for the check-in, we were able to make the area more comfortable for the passengers, and a little bit faster. We achieved a 62% reduction in waiting time in a row with the new layout, going from a maximum waiting time of about 49 minutes and 49 seconds to 18 minutes and 40 seconds. This reduction is mainly due to the implementation of a single queue. In the old layout, the queues for the same flight were independent of each other, if one passenger had a problem at check-in, that passenger made the whole queue stand still waiting until the problem was solved. With a single queue, the passengers immediately after that passenger whit the problem, can go to another available counter. Most of the proposed changes do not entail financial costs or imply relatively low costs for the airport, such as the organization of queues. Other changes already involve slightly higher costs, which would imply a cost-benefit analysis by the competent authorities. Regarding security we have a significant improvement, especially in the access queues, with the implementation of automatic machines, the average waiting time in this phase was reduced by 84%, going from 44 seconds in the current layout to only 7 seconds in the new layout and we could achieve a reduction in personnel costs. The improvements in the screening area were mainly in the distances between the lines, considering the measures recommended by IATA, making the passenger experience more comfortable. Regarding the time it takes from access control until the passenger reaches security screening lines, we went from 3 minutes and 29 seconds in the current layout to 2 minutes and 3 seconds in the new layout, which means a reduction of 41%. The proposed layout for the security lines would already involve some more significant changes and therefore would have to be analysed by the competent authorities. This work will extend to all areas at Madeira Airport and, we believe, to all major airports in the country.

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The concept of Aerotropolis applied to a medium-sized city and its airport. The case of Faro in the south of Portugal

João Jóia do Carmo - joia_prestige@hotmail.com
University of Beira Interior
Jorge Miguel dos Reis Silva - jmrs@ubi.pt
University of Beira Interior; CERIS/IST; Universidade de Lisboa
Maria Emília da Silva Baltazar - mmila@ubi.pt
University of Beira Interior; CERIS/IST; Universidade de Lisboa

Abstract
Movements in Faro airport have been on a constant rise even exceeding the airport capacity. Faro city has grown in the same proportion. Both occurred in a pattern that can be applied to compare with the development of an Aerotropolis.
At least three steps must be taken to develop an effective Aerotropolis plan. First, the catchment area is determined based on the existing transportation network and 60-minute travel time from the airport. Second, several socioeconomic indicators within the catchment area are evaluated through different periods using GIS software. Third, catchment area and socioeconomic indicators for the Faro region are compared with layouts obtained from several examples of Aerotropolises in Europe.
The Aerotropolis model created by John Kasarda has been used in several regions across Europe. One key aspect of this model is determining whether the region evolved along with the airport throughout the years. Faro, its airport and surrounding areas, are not an exception. Thus, it is possible to identify Faro development patterns of growth useful for several stakeholders: administrative authorities, airport authorities, and territory planners.
Faro airport movements have been on a constant rise. Faro city has grown, probably, in the same proportion. Both growths can be compared with an Aerotropolis development. Identifying development patterns of growth will be useful for: those responsible for the distribution of services in the territory; those who oversee the airport operation and expansion; those who are responsible for combining the interests of all for the regional development.

Keywords
Aerotropolis; GIS; Catchment Area; Faro Airport

The concept of Aerotropolis applied to a medium sized city and its airport. The case of Faro in the south of Portugal

I. Introduction

The continuous growth of air transport has been evident in recent decades, increasing at a fast pace and the forecast according to an EUROCONTROL study [1] is to continue to grow.

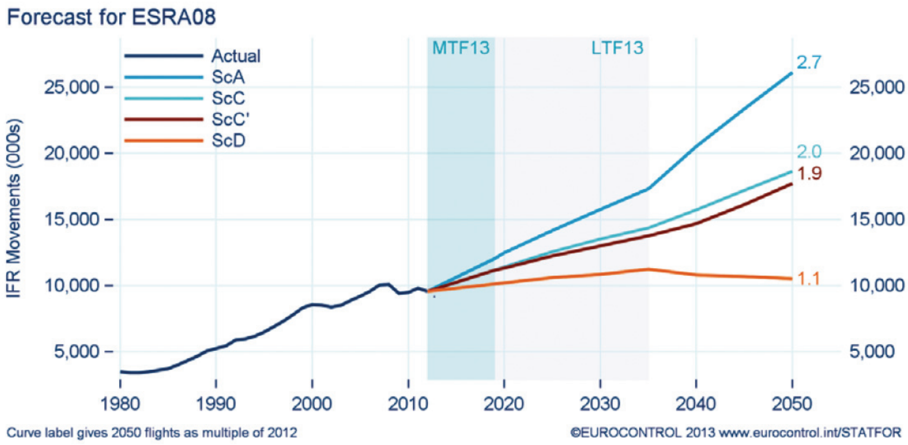

Figure 1 – Prediction of the number of aircraft movements until 2050
Source: [1]

Figure 1 sets the scenario for the future: in 2035 there will be approximately more 50% of flights than those currently exist, and the forecast for 2050 indicates that this number will double facing of current figures.
Air transport activity has a major impact over the global economy due to the number of jobs and revenue that directly or indirectly generates. In Portugal, air transport represents nearly €5.7 billion in GDP and 183 thousand jobs [2].
Airports have become essential to the global modern economy, as they represent high-speed access for freight, business and leisure travellers, but also contribute to social development and for better life quality [3].
In order to keep up with all this growth and evolution, a concept was developed by Dr. John Kasarda, called Aerotropolis. Over the years, the airport was made to serve the city, but as presented in Figure 1, the evolution of air transport has changed the scenario, which has boosted the idea of building cities around the airports. The main goal of an Aerotropolis is to facilitate activities related to air transportation, whether commercial or personal. This is why, in some cases, there is a need to create or adjust into an Aerotropolis.
This work is aimed at Faro International Airport, in the south of Portugal, where there is a pre-established Catchment Area, and from there, identify the counties inside the area, evaluate their socioeconomic indicators - using ArcGis software, assess how they influenced the region throughout chosen time periods, and try to implement an Aerotropolis planning to this airport following examples, such as Amsterdam or Paris Charles de Gaulle.

II. Methodology

The methodology that will be used in this work consists of studying in detail the State of the Art, specifically the literature mentioned in that chapter.
From there, a more practical approach is made with the use of software and analysis of the evolution that occurred in the airport Catchment Area.
Considering this basis and following the Aerotropolis concept, different layouts will be tested to assess the possibility of having one in this region.
In Figure 2, a flowchart details the methodology process, which is the foundation of this work.

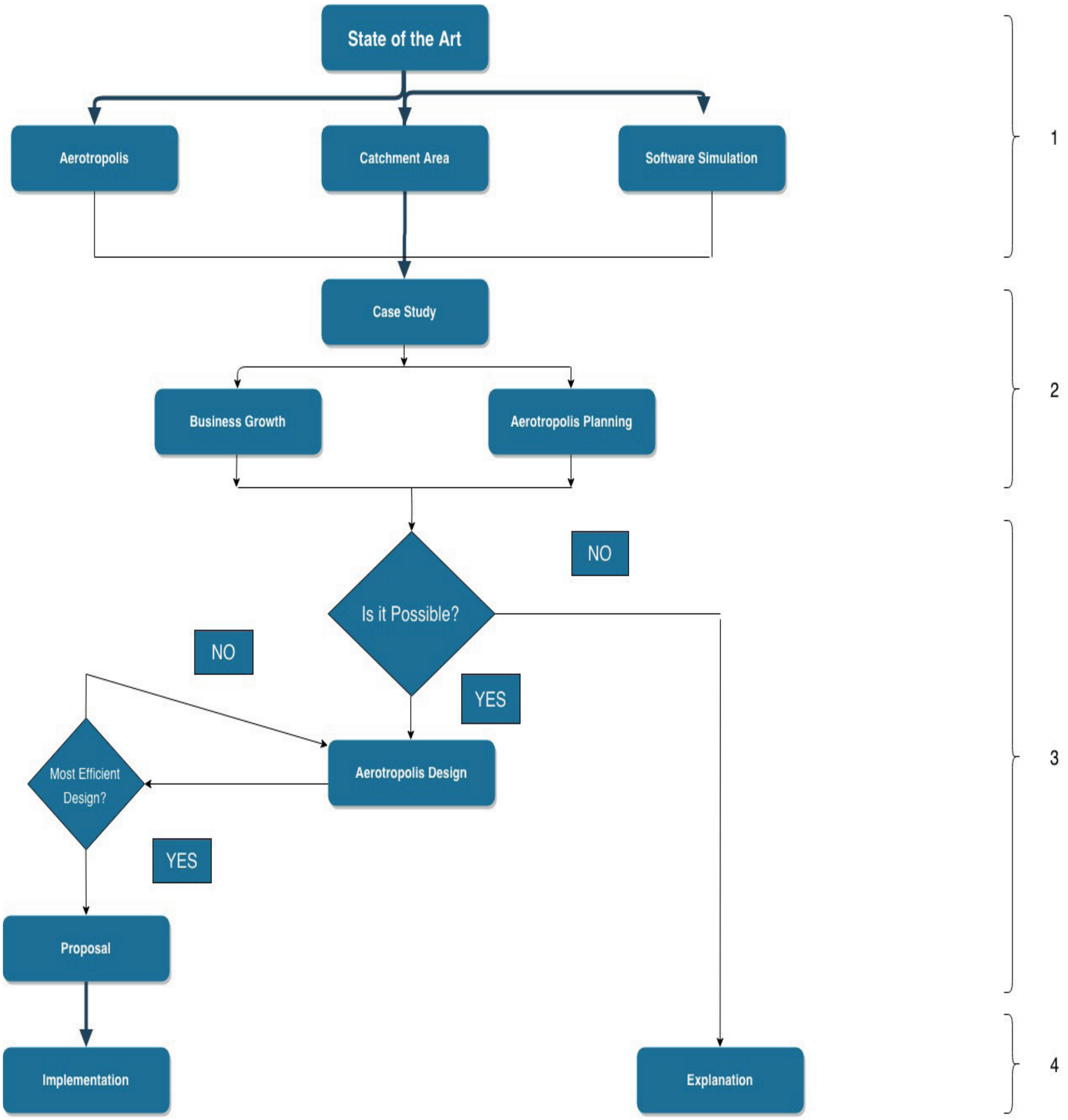

Figure 2 – Methodology Flowchart
Source: Own elaboration

As we can see from the flowchart, in Section 1, a further study of state of the art will be made to gather every information and understanding of the subject.

In Section 2 there is the case study, where the study of the business growth in the Catchment Area is conducted, and in parallel, the study of planning and development of such model, which is key to accomplish the main objective.
Section 3 is where the findings of the research will allow whether it is possible to transform the designated airport into an Aerotropolis. If that option turns out to be positive, then we design a possible model for the airport and improve it until it is the most efficient it can be.
Section 4 is about the proposal; creating one from the most efficient solution and after that, try to implement that proposal if possible with the local authorities.
However, if we have a negative outcome in Section 3, and therefore determine it is not possible to adapt to an Aerotropolis, an explanation about what will be the objective of the paper.

III. Aerotropolis and Airport City

Aerotropolis is a concept dated 1939 by Nicholas DeSantis, a commercial artist from New York. This plan took 5 years of studying and consists on a skyscraper 200-stories high capped by an airplane field eight city blocks long and three blocks wide [4].

Throughout the years, Aerotropolis was used in different ways, like as H. Mckinley Conley in the 1970s and later by Dr. John Kasarda. Traditionally airports have been located 15 to 30 kilometres away from their corresponding city, mainly for air transport purposes, and they lack high relevance to the economy in their neighborhood areas [5]. Facing these facts, a new urban form is emerging “The Aerotropolis” as more and more aviation-oriented are being drawn to airport areas. Transportation corridors are radiating from the Aerotropolis extending up to 30 kilometres outward from the major airports [6]. An Aerotropolis is considered a metropolitan subregion whose infrastructure, land use and economy are centered on airport.

The emergence of and evolution of airport cities in recent years is a response to four basic factors [8]:

1. Airports need to create new non-aeronautical revenues;
2. The commercial sector’s search for accessible land;
3. The increased passengers and cargo flow, generated by gateway airports;
4. Airports serving as a catalyst for landside business development.

The key value of Aerotropolis is that it offers businesses rapid connectivity on a massive scale. Inside the Aerotropolis study, there are various factors to consider like planning, layout and the industry.

Planning is vital into the Aerotropolis plan; it is the key to achieve its goals. An effective Aerotropolis master plan must also be both an economic plan and a strategic one, that articulates the drivers of and barriers to Aerotropolis development, as well as provide data-based assessments of commercial real estate demand for various functions and sites. Five planning requirements are focused upon [9]:

1. Local and regional market demand for air commerce;
2. Sufficiency and efficiency of air and ground connectivity;
3. Incorporating customers and stakeholders wants and needs;
4. The management of commercial real estate development;
5. Attracting investors and investment.

To validate this concept, Dr. John Kasarda created a layout schematic to represent a dynamic model, that although no Aerotropolis will look like this, most will adopt similar features. There are some key points to look for in an Aerotropolis model, which combined with Figure 3 representation of the model, help us picture the main goal [10]:

1. Dedicated airport expressway links (aero lanes) and airport express trains (aero trains) should efficiently connect airports to major regional business and residential concentrations;
2. Special truck-only lanes should be added to airport expressways, as should improve interchanges to reduce congestion;
3. Time-cost accessibility between key nodes should be the primary Aerotropolis planning metric rather than distance;
4. Businesses should be steered to locate in proximity to the airport based on their frequency of use, further reducing traffic while improving time-cost access;
5. Airport area goods-processing activities (manufacturing, warehousing, trucking) should be spatially segregated from white-collar service facilities and airport passenger flows;
6. Noise and emission-sensitive commercial and residential developments should be sited outside high-intensity flight paths;
7. Cluster rather than strip development should be encouraged along airport transportation corridors with sufficient green space between clusters;
8. Form-based codes should establish general design standards for airport area buildings, walkways, travel lanes, landscaping and public space;
9. Placemaking and way finding enhanced by thematic architectural features, public art and iconic structures should make Aerotroplis developments interpretable, navigable and welcoming;
10. Mixed-use residential/commercial communities housing airport area workers and frequent air travellers should be developed with easy commutes and designed to human scale providing local services, urban amenities and sense of neighborhood.

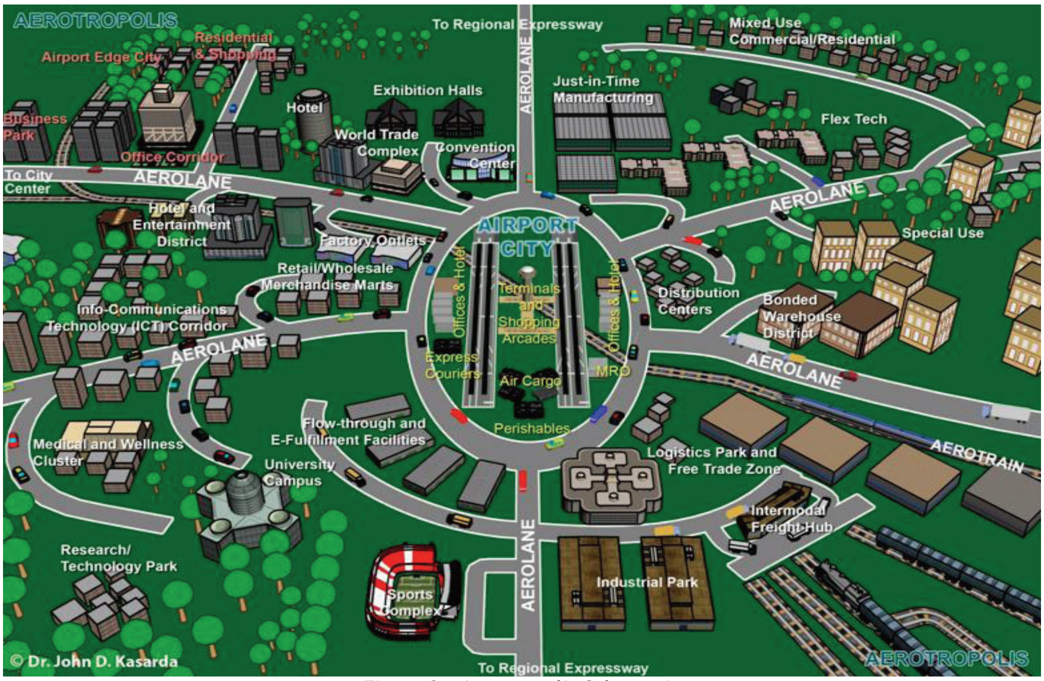

Figure 3 – Aerotropolis Schematic
Source: [10]

This industry has increased heavily, and it is safe to say that the employment scale and business mix of the Aerotropolis are far greater than many realize. A research conducted by Dr. Stephen Appold and Dr. John Kasarda on employment around the 25 busiest passenger airports within the U.S., found that: 3.1 million jobs as of 2009 were located within a 2.5-mile radius of these airports (2.8% of total U.S. employment); over 7.5 million jobs within a five-mile distance (6.8% of all U.S. employees); and 19 million jobs (17.2% of the U.S. total) within 10 miles [11]. In the European case, and looking more specifically for two examples: in the Paris Charles de Gaulle airport this adaptation led to the creation of 248 000 jobs, representing 6.1% of the salaried jobs in the Paris Region [12]; in Amsterdam the number of jobs created is 65 000 [13].

IV. Case Study

This work is aimed at the development of a proposal that can prove the viability and adaptability of an Aerotropolis in Faro. To reach such proposal, several steps must be taken to accomplish a credible conclusion. The first step is to take into consideration the Catchment Area, obtained in a previous work [14], to identify the counties that are within the area. The counties identified (20) are the following:

- Albufeira;
- Alcoutim;
- Aljezur;
- Aljustrel;
- Almodôvar;
- Castro Marim;
- Castro Verde;
- Faro;
- Lagos;
- Lagoa;
- Loulé;
- Mértola;
- Monchique;
- Olhão;
- Ourique;
- Portimão;
- São Brás de Alportel;
- Silves;
- Tavira;
- Vila Real de Santo António.

We set the temporal scenarios to evaluate the socioeconomic indicators presented in Table 1 of the twenty counties and analyze their evolution throughout the years.

Table 1 – Socioeconomic Indicators
Source: [14]

INDICATOR	DISCRIPTION
Population Density	Population density is expressed by the ratio between the population and the surface area. It is usually expressed in inhabitants per square kilometer
Education Level	It is a ratio between the inhabitants with higher education level by the total number of inhabitants
Household Income	Average income per capita by month (in euros)
Economically Active Population	It is the fraction of a population that is either employed or actively seeking employment. Is measured by the ratio between the economically active populations by the number of inhabitants
Employment Level	Is measured by the ratio between the numbers of employees by economically active population
Companies Density	It is the number of companies by square kilometer
Sectorial Structure of Employment	Is the number of employed people by the total of companies from the sectors (industrial, real estate and housing)
Business Volume	Is measured as a GDP (Gross Domestic Product) density
Health	It is the number of doctors by square kilometer
Tourist Attractions	Tourist Attractions are measured by the number of attractions by square kilometer. Includes museums, golf camps, zoos, botanic gardens…
Hotel Establishments	It is the number of hotels; apart hotel; guesthouses; motels; hostels; tourist villages
Accommodation Capacity	Is measured as the number of beds available in hotel establishments
Occupation Rate	Is measured as the ration between the number of beds occupied in hotel establishments, by the number of beds offered

One of the concerns is the accuracy of the study and with that in mind, six time periods were chosen: 2001, 2011, 2016, 2001-2011, 2001-2016, and 2011-2016. 2001 and 2011 were Census years, therefore all the data is available; while 2016 is the year where the data can be obtained directly or indirectly, with accurate results. The study has not an incidence previous to the year 2001 because the airport only began to be relevant to the region in the early 2000's, mainly because of the impact of increasing LCC movements (Figure 4).

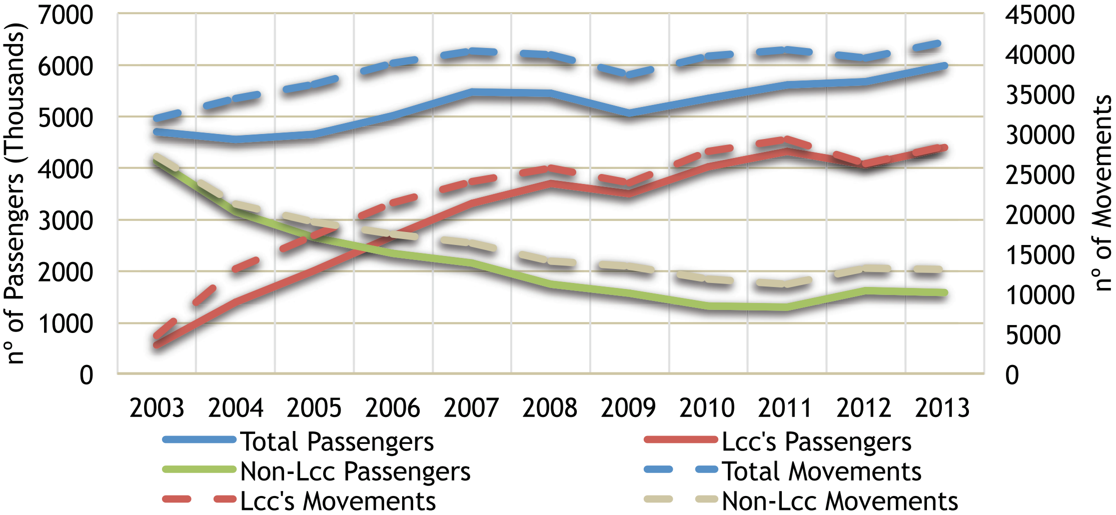

Figure 4 – Faro airport movements and passengers evolution distributed by type of airline. Source: [15]

The last step is to analyze the layout evolution throughout the years, observing if it adopted a more Aerotropolis-like model, along with the increasing number of movements and passengers. The LCC's growth transformed this airport, once seen only as a checkpoint to reach Portugal, into nowadays one of critical importance to serve whole its Catchment Area. One important observation to do is if the airport does serve the region adequately and has the main characteristics that make it an Aerotropolis, or if it at least can adapt into one is the objective.

V. Results

At this stage, the Catchment Area evaluation must be made in order to determine the counties that have benefitted the most from the closeness to the airport. Using the socioeconomic indicators to evaluate the six different time periods (2001, 2011, 2016, 2001-2011, 2001-2016, and 2011-2016), and while it is impossible to present all the data here, Figure 5 shows the Population Density in the year 2001 to illustrate the study, the following conclusions can be drawn:

- In the year 2001, Mértola ranked bottom three in all but one indicator and did not make the top three in any indicator. Alcoutim ranked bottom three in 10 of the 13 indicators. Faro and Albufeira ranked top three in 7 of the 13 indicators. In this year, one can say that Faro and Albufeira benefitted from their relatively close location to the airport, while Mértola and Alcoutim, being close to the end of the Catchment Area, felt the least advantages of being within this Area;
- The results for the year 2011 shows that Alcoutim ranked bottom three in 10 of the 13 indicators and top three in one of them, while Ourique ranks bottom three in 9 of the 13 indicators and none in the top three. Ourique belongs to a Competition Zone between Faro and Lisbon, therefore is located at the end of both Catchment Areas, while Alcoutim is within only one Catchment Area, but also at the end of it. Faro and Portimão, however, rank top three in 9 of the 13 indicators. Faro is closer to the airport, and that is whit it ranks so high, while Portimão is easily accessible by highways, shows good values for Health, Companies Density and Accommodation Capacity, making it one of the counties affected positively by the development of the airport;
- In the year 2016, Ourique had the lowest numbers in 9 of the 13 indicators, while Albufeira ranked top three in 11 of the 13 indicators. Albufeira took advantage of the rise in the movements in the airport in the latest years to reach these values;
- The evolution between 2001 and 2011 happened somewhat evenly. Ourique ranked bottom

three in 6 indicators, which is less than half, while Portimão ranked top three in 7. Thus, this occurred due to the development of the accessibility to each county and the growth of the airport in these years;

- In the fifteen years interval between 2001-2016, one county came on top in terms of evolution, Albufeira. It ranked top three in 9 indicators, and it is a visible indication that Albufeira followed the airport's improvement in this period, taking advantage of the easy accessibility. On the other hand, São Brás de Alportel ranked bottom three in 6 of the 13 indicators and zero in the top three. Being a small county and not very reachable, the ageing population contributed to the low scores in this period;
- Finally, in the evolution from 2011 to 2016 does not exist a big disparity between the county's evolution, as almost every single one ranked bottom and top three in the 13 indicators. Albufeira ranked top three in 6 indicators, the most by any county, therefore maintaining the status as one of the most influenced by the airport evolution.

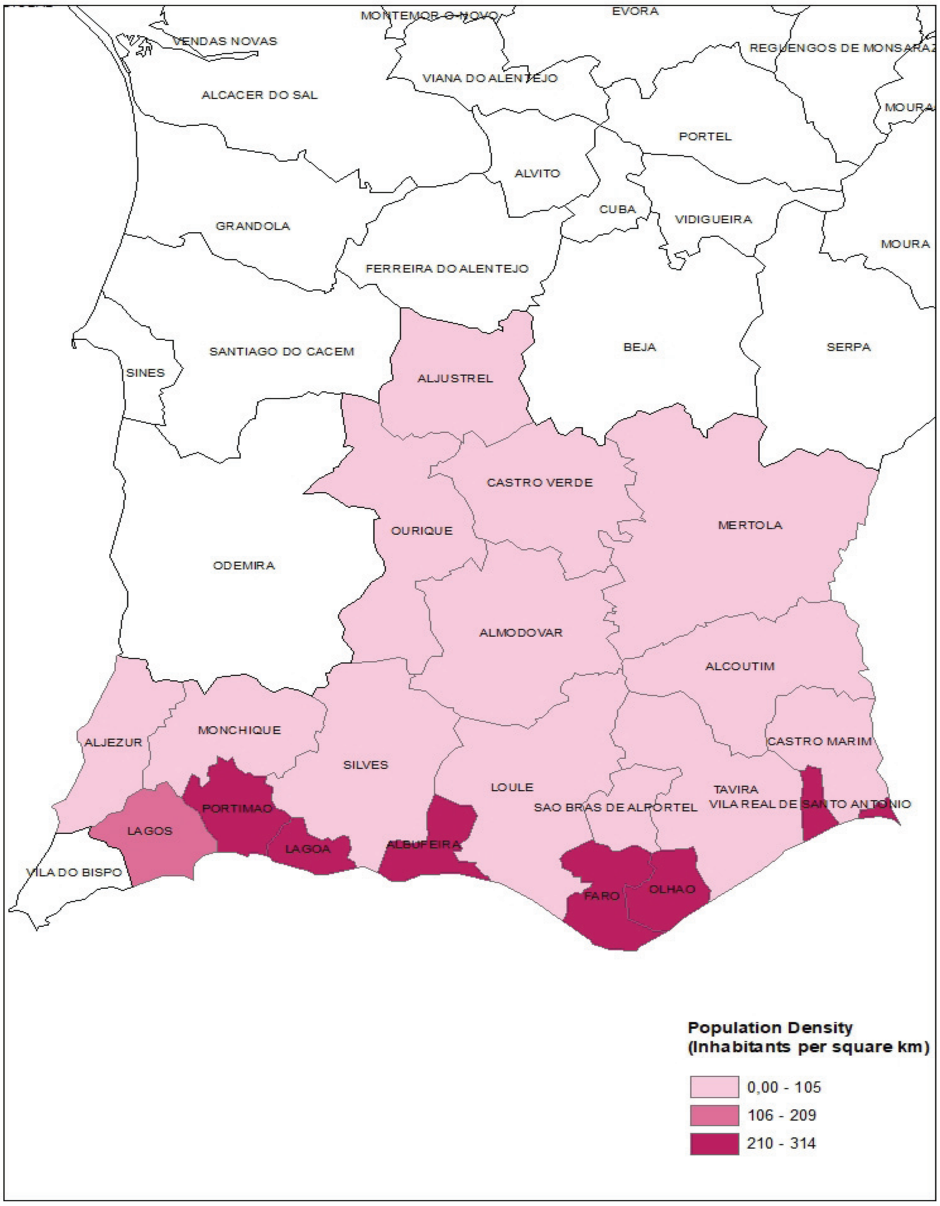

Figure 5 – Population Density (2001)

Source: Own elaboration

The layout of Faro International Airport remained very similar over the years; Figure 6 presents an overlap of the layout in 2016 over the 2011. Comparing with Amsterdam or Paris Charles-de-Gaulle, the current layout lacks housing in the proximity, multimodal connections and a clearer district to where the idea must grow and develop.

Figure 6 – Faro Airport 2016 over 2011
Source: Adapted from Google Earth

In Table 2, a better illustration of the assessment of the urban form of Aerotropolis currently in place is presented.

Table 2 – Assessing the urban form of Aerotropolis
Source: Adapted from [16]

Building Block	Centres	Districts	Preserves	Corridors	Assessment
Zuidas, Aalsmeer, Amsterdam (Schiphol)	Town Centres with mixed land-use, offices, retail, hotels	Amsterdam Airport Area (AAA) Zuidas (business district), Aalsmeer ("global floral hub") airport city district	Built on a drained lake; agriculture/ Greenbelt; World's "green floral hub".	Multimodal, roads, trains, rail, Aalsmeer shuttle, Zuidas	District with regional centers; housing in proximity; district is in a regional city with multimodal mobility
Charles de Gaulle, Roissy, Paris	Mixed land-use with offices, hotels, sporting cultures	Roissy-en-France, Charles de Gaulle	Built around an area with floor space ranging from several thousands of km^2	Multimodal, roads, rail, rivers, boat, maritime	High density, potential housing in proximity; a regional city with multimodal mobility
Faro	Mixed land-use with hotels, offices	Faro, Algarve and Baixo Alentejo	Partially covered by the sea; cannot be expanded	Roads, buses connecting to the Algarve region, Lisbon and Seville	Regional city, lacking housing in proximity, a business district with some multimodal mobility

Analyzing the Table 2, it stands out how well thought out Paris and Amsterdam are, while Faro lacks some infrastructures. Faro has two restraints: it cannot be expanded, and it is only a medium-sized city. However, Faro needs improvement on its infrastructure to support movements as the airport, currently exceeds its capacity, surpassing the six million passengers a year. It is crucial to establish a business district strong enough to attract important stakeholders and create housing in the proximity to become an efficient Aerotropolis, within the Catchment Area.
According to the results of the socioeconomic indicators, there are counties, that could operate as a business hub: Faro, Albufeira and Portimão ranked high in indicators such as Companies Density, Business Volume and Population Density. Faro city is closest to the airport and seems to be the most viable option, while Loulé being close and recording good results on most indicators could be an alternative too.
The next in creating an Aerotropolis plan is to ensure there are accessibilities that efficiently serve the area. Right now, Faro airport only offers roads and buses routes to the city Centre, Seville, Lisbon and some parts along the Algarve region. Geographically covered by the sea and close to Africa, the creation of a port infrastructure would contribute to an ideal Aerotropolis planning in this city, because it would create new ways of cargo and passenger routes to Northern Africa, something that would boost the economy in this area. Faro airport also lacks a train connection, something that most Aerotropolis offer; however, there is a train station within seven kilometres that connect Faro to everywhere within the Catchment Area and most important cities in the country. Figure 9 presents a possible planning schematic to adapt Faro into an Aerotropolis.

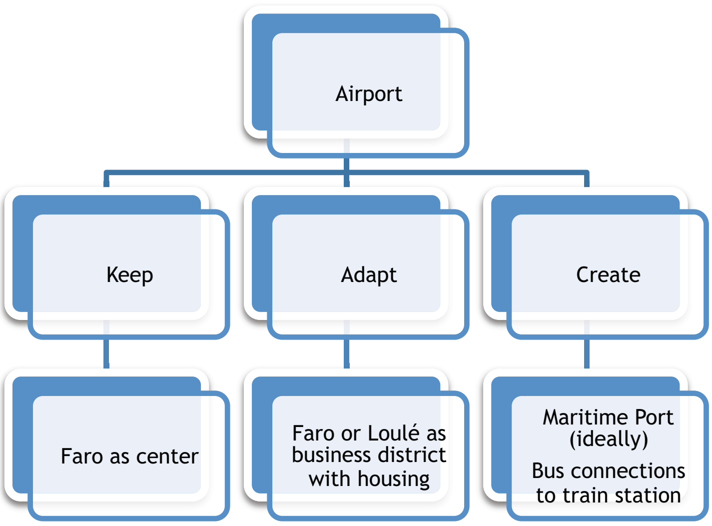

Figure 7 - Faro Aerotropolis Schematic
Source: Own elaboration

The assessment concludes that Faro can be adapted into a medium-sized Aerotropolis, like (unless the scale, of course) the mega-Aerotropolis of Paris and Amsterdam. The airport and region show much potential to be an attractive site, not just for tourism, but also for companies.

VI. Conclusions

The main object of this work is to determine the possibility and consequent viability of an adaptation of Faro airport into an Aerotropolis-like model, using a GIS conventional approach and evaluation of the Catchment Area.

This work has three specific objectives: use the socioeconomic indicators to evaluate the Catchment Area based on data from public and other sources, compare the results of the indicators in three temporal scenarios (2001, 2011 and 2016); with layout examples of operational Aerotropolis

combined with the gathered data, reach a general assessment on the possibility and viability of the Aerotropolis adaptation in this region.
These goals were achieved; however, more time would allow a broader and extensive discussion of the results; also, it could be included older data of the Catchment Area to make a deeper analysis to the area and create more correlations between the more temporal scenarios and the evolution of different businesses. In terms of evaluation of the Catchment Area, the limitations to get actual data were determinant for choosing the temporal scenarios.
Gathering the socioeconomic indicators data was very time consuming, especially in 2016, because there was no census in that year and they had to be achieved in alternative sources. Some of the indicators also had to be calculated using secondary indicators to provide more accurate results.
Despite some difficulties and missteps, this work was rewarding in how it brings a new perspective, a modern one, to an ever-evolving region.
Future developments in this area must be focused on the following items:

- To research a new model to integrate all the information about airport performance with the Catchment Area component;
- To research the best indicators that can describe the characterisation of the region;
- To geo-refer all the data with GIS software;
- To extend the transportation network to other modes of transport, as water and rail transport;
- To study the possibility and viability of an Aerotropolis both in Lisbon and Oporto, considering that both cities are of a higher dimension and importance to the country;
- To perform a study regarding the impact of using Beja as a commercial airport, helping Lisbon and Faro to relief the override of the movements limit.
- Perform an environmental and health impact study concerning this work, to find out the risks for people living close to the airport.

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Centrality evaluation of the Brazilian air transport system

Deivison Da Silveira Pereira - dspereira@id.uff.br
Universidade Federal Fluminense
Joao Carlos Correia Baptista Soares de Mello - joaocsmello@gmail.com
Universidade Federal Fluminense

Abstract

The Brazilian air transport system includes more than two thousand airports and landing areas, however only 128 of them are commercially used. This work seeks to analyze the centrality of the Brazilian airport commercial system and including operational consequences.

The work analyzes the Brazilian airport system comparing the results of layer centrality (Brand?o et al, 2015) and h-type centrality (Pereira et al, 2015). These methodologies of centrality, unlike other traditional methods in graphs, try to evaluate the comprehensiveness of each vertex (in the case of the airport) and the influence on the others in the network.

Considering that only 3 Brazilian airports are on the list of the top 100 airports in the world, the centrality assessment provides a deep verification of the agents for targeting the improvement resources such as infrastructure. These central airports require accurate planning in several operational fields (maintenance, traffic control, mobility, etc.) to raise the quality of the system, especially if we consider current Brazilian economic challenges.

Keywords

air transport; h-centrality; layer centrality

Centrality evaluation of the Brazilian air transport system

Introduction

The air transport industry performs one third, in value, of global cargo trade. On the other hand, in Brazil, this sector responsible for only 1.4% of the country´s GDP [1]. In this industry, airports play a strategic role to both government and private companies [2], [3].

Indeed, the availability of Brazilian airports and the coverage of domestic air network are adequate, with a distribution that mirrors population concentration, according to [4]. There are approximately 2,498 airports (including landing areas) in Brazil, i.e., the second largest number of airports in the world, only behind the United States.

However, only 128 of them are commercially explored, and 34 airports are used for international connections. Moreover, only three, of all commercial airports, are rated among the top 100 in the world [1] In fact, the quality of airport infrastructure in Brazil is ranked by executives in 19th place, out of 23 countries from Latin America and Caribbean, and 112th globally [1]. From [5] we highlight air transport used as mode of freight has less time of travel and greater security, but at a high cost which is suitable to high added value products.

In terms of historical data, Figure 1 shows the sector´s growth over the past few years, regarding the number of flights, as well as the proportion of the domestic and the international market, based on data from the National Civil Aviation Agency – ANAC (in Portuguese, Agência Nacional de Aviação Civil [6]). We could observe that the number of flights increased 31.6%, from 2007 to 2016, although its peak occurred in 2012. We highlight this is a sector with great importance for Brazilian economics [7]. Moreover, the proportion of international flights grew considerably.

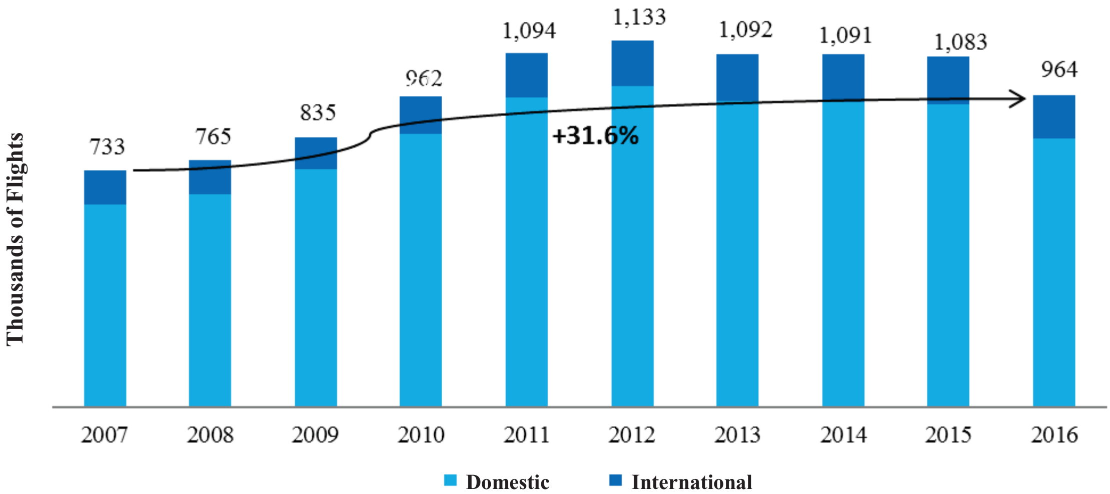

Figure 1 – Evolution of the number of flights in Brazil
Source: [6]

The aim of the paper is to evaluate the Brazilian air network comparing the results from measure of h-centrality [8] and layer centrality [9] graphs proposed by, where the h-index concepts and graph theory were adapted to form the proposed measure.

From h-centrality core list we could afford main airports in the air network considering the characteristics from relevance and availability. When we consider the whole air network, the h-centrality core list provides the main hubs without any prior definition from decision maker. The layer centrality provides the airports ranking considering the relevance, however to define the top main airports the decision maker shall outline the cut-off list previously.

Centrality Measures

The definition of the central points of a network involves the identification of its most impacting points, which can be calculated based on centrality measures [10]. Studies on centrality have a variety of application such as academic evaluation [11] or even a general industry assessment [12].

In general, centrality evaluates the relative importance of a vertex in a network [13], and can be measured in several different ways, with different meanings and interpretations. Some centrality measures are related to the h-centrality and layer centrality: the centrality of degree that measures the amount of edges connected to the vertex; the centrality of layers that measures the influence of the neighbors, but by exclusion of the lower degree vertices, and the eigenvector centrality that measures the influence of the neighbours by linear combination.

Air network centralities

Centralities studies on airport network involve definitions of hub center points and air routes. The concepts of hubs are explored from the need for models to define routes in those location with high connectivity and demand, according to. We verified that [15] indicate the airport hubs influence the cargo sector as well where the greater frequency of flights easy the deliveries. [12] evaluate the network from a Brazilian airline company comparing classical centralities measures and providing the main airports through multicriteria method.

So [16] verifies the choice of a hub and spoke network model by a company involves decisions looking for gains in scale for its operations as well as competition judgment where diverse players seek to maximize their profit.

Nevertheless, competition from large companies with low cost airlines weakens the margins at these big airports to large ones, as seen by [17], in an analysis of the European network. This also influences the efficiency of companies according to [18].
Then [19] find that low-cost airlines tend to take on greater gains with point-to-point routes where they work practically in monopoly, and large companies tend to focus passengers on hubs to better utilize the air network.

Though, as seen by [19], large companies are making alliances, such as Delta acquiring GOL shares in 2011, or creating low-cost subsidiaries such as Lufthansa on creation of Germanwings in 2012. Indeed, some aspects aid in the implementation of low-cost routes, as seen by [20] in the analysis of these factors in Taiwan, as the price government, the operational supporting efficiency and the airport authority with the policies. As indicated by [21] the high prices in the hubs pressure the fee of airline tickets and end up impacting the profitability of large companies.

H-centrality

The centrality based on the h-index [8] provides e central vertices by adjusting the bibliometric concepts of the h-index. This method is similar to degree centrality, which measures the number of adjacent vertices for each vertex analyzed, so-called neighbors. From a graph $G = (V, E)$, where V is the set of n vertices $v_i$and E is the set of m edges (v_i, v_j), which each edge is formed by a pair of vertices of V, in this case $v_i, v_j \in V$. We have h- centrality for v_i, defined by $C_H\ (v_i)$, is obtained in the ordering of the j vertices v_j decreasing by the number of connections (edges), so $\sum v_i v_j$ in module.

The h-centrality will be the number $j \leq \sum v_i\, v_j$. In Figure 2 is presented illustratively contrast of the h-index with h- centrality. In the original h-index proposed by [22], v_i is the researcher, v_j is article, $\sum v_i\, v_j$ is the quantity of citations of article v_j and j is the order given decreasing by the number of citations.

The j neighbors vertices of v_i which have $\sum v_i\, v_j$ at least the number h form the core list of vertices v_i [23]. The h-centrality differs from the other methods in literature since it has the prioritization by the quantity h of the adjacent vertices. This method presents the impact of the vertex analyzed, distinct from measure of degree or the measure of closeness which consider only the adjacent connections without to carry out the ordering.

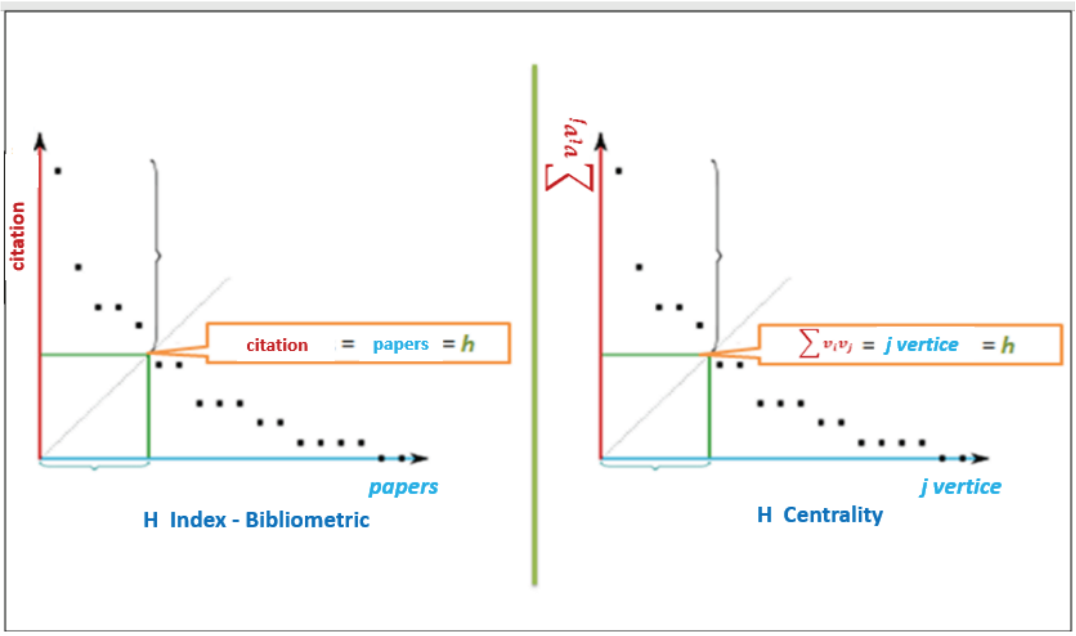

Figure 2 – H-index versus H-centrality comparative
Source: Authors

We verified some studies which analyze the structure of the network of air routes through centrality measures, as [24] in an evaluation of Australia. They also verify and determine the important hubs in the country, as well as the influence on the network of the airlines and also analyze the routes detailing competitions among companies.

In another approach, [25] verify China's air network considering the measures of centrality for central cities directly linked to cities with greater economic activity. Therefore, the analysis of the companies' strategies of action depends on a greater management of the network of action.

Layer centrality

As [9] proposed a centrality measure based on concepts on Data Envelopment Analysis method of layer [26] which consists in evaluation of units considering its influence into the production frontier. In graphs view, the analysis reflects the influence of a vertex among the adjacent neighbours.

The first step of layer centrality is to identify from an adjacency matrix the element with the smallest sum of the coordinates on the line, and order it in the last place, thus considering it as the vertex of lesser centrality. The line and column of that element are then excluded in the matrix. This eliminates the vertex of the matrix, so it could not be ordered again, but it also eliminates the connections of the other vertices with that element.

All this process must be repeated, ordering the vertices in ascending order of centrality and excluding the respective rows and columns, until the last vertex of the matrix. If more than one element has the same summed coordinates in its lines, both must be ordered in the same position and have their rows and columns excluded from the matrix simultaneously. That is, these vertices are in the same layer. Figure 3 shows an example of a graph ordering by layers excluding the vertex following the methodology, in this case we have 4 layers to be consider.

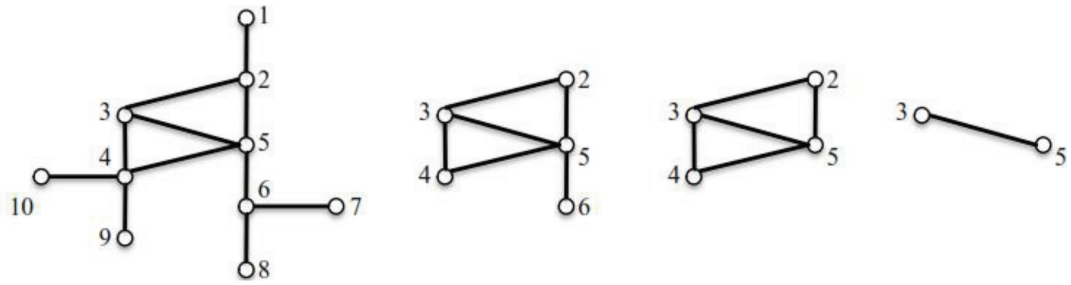

Figure 3 – Layer centrality excluding vertex process
Source: [9]

In terms of graphs, this methodology consists to identify the lowest degree vertex (s) and order it last. Next, a subgraph is created, in which all vertices except the one (or more) with the lowest degree are present. In the following iteration, the new degrees are calculated for the subgraph formed, again identifying the minor degree vertex (s), and removing it to form a new induced subgraph. This process is thus repeated until there are no more vertices to be removed.

The layer centrality shows a ranking of the vertexes by each relevance according the layer step considered, nevertheless the methodology does not provide any number of the measure for each vertex only the layer it came from.

STUDY OF BRAZILIAN AIR NETWORK

The data used in this study are based on the HOTRAN table, where the national civil aviation regulator ANAC (National Civil Aviation Agency) defines all regular commercial flights (domestic and international) for transporting of passengers including cargo. The table data was extracted from August 2015, where the direct routes for all the airports were listed.

In this paper a flight will be defined only as direct connection two airports, according to the method used by [27]. They verify a model for calculation of aerial accessibility of airports from the direct connections offered. Illustrating this concept of flight, consider the flight JJ3307 operated by Latam Airline with following itinerary: GIG - Galeão Airport, Rio de Janeiro / RJ x FOR - Fortaleza Airport / CE x Natal - RN x GRU Airport - Airport of Guarulhos / SP. In this case, 1 flight will be counted for each direct flight origin, i.e.: 1 flight to the GIG, referring to the GIG x FOR flight, 1 flight to the FOR, referring to the FOR x NAT and 1 flight to the NAT, section NAT x GRU.

The code used in this study is following the IATA (International Air Transport Association), which are better known for being the same used for ticket reservation. For example, for Santos Dumont Airport, which airport is in Rio de Janeiro-RJ, the code is SDU.

Some steps are followed before the determination of the Brazilian central network, according to the h-centrality measure. We start with data processing, where arbitrarily defined commercial flights of passengers with departures on Mondays, excluding from the HOTRAN table the freight flights and the postal network. Mondays present the largest number of destinations served and therefore the we can analyze the wide-ranging case of the network.

A matrix of adjacency with the core h-index of each airport is formed from the connections between the airports. However, the central network is defined by the square matrix, where you need to exclude the secondary airports, which are those that are not present in the airports core list.

In this, we define a starting point and preferably starts at one of the largest airports in terms of the number of flights on the network. This method shall probably cover the final central network. Table 1 presents the core list ordered by the h-centrality measure of the 6 main airports that form the central network of the Brazilian air network.

Table 1 – Brazilian airports H Centrality
Source: Authors

H position	H Centrality	Code	Airport
1	11	GRU	Guarulhos – SP Airport
2	9	CGH	Congonhas Airport - São Paulo - SP
3	8	BSB	Brasília – DF Airport
3	8	GIG	Galeão Airport - Rio de Janeiro - RJ
4	7	CNF	Confins – MG Airport
4	7	VCP	Viracopos Airport - Campinas - SP

The importance of this central network is given by the representativeness of more than 50% of the approved flights within the Brazilian network considering these six main Brazilian.

For the layer centrality, an adjacency matrix of airports is formed with all flights from data set, then the airports with the smallest connection number are excluded their line and column in the matrix. In this case, these airports could not be ordered again, and also eliminate another vertices connection forming a new adjacency matrix

Table 2 show the layer centrality Brazilian airports ranking. However, we shall define a cut-off layer to show the top airports. Herein, we show some airport from the list up to 29th layer.

Table 2 – Brazilian airports Layer Centrality Network
Source: Authors

Layer Centrality	Code	Airport
1	SDU VCP	Santos Dumont Airport-Rio de Janeiro-RJ Viracopos Airport - Campinas - SP
2	CNF	Confins – MG Airport
3	BSB	Brasília – DF Airport
4	GRU	Guarulhos – SP Airport
5	CGH	Congonhas Airport - São Paulo - SP
6	POA	Porto Alegre – RS Airport
...	...	...
16	NVT RAO	Navegantes - SC Airport Riberão Preto - SP Airport
17	CGB	Cuiabá - MT Airport
18	NAT	Natal - RN Airport
...	...	...
28	LDB	Londrina - PR Airport
29	CGR MCZ	Campo Grande - MS Airport Maceió - AL Airport

The Table 2 shows tied airports for some layers, and this is a limitation from layer centrality methodology where we could not define the difference among them. And also, as discussed before the layer centrality does not provide a measure number for the centrality.

As already verified by [10] the central points of a network are verified by the most impacting points, and both the h- centrality and layer centrality analysis provide this identification, however the h-centrality provides the core list without any prior definition.

We highlight for the Southeast region as the largest number of airports in the network according to h-centrality core list, 5 airports from 6 are from Southeast as we could verify in Figure 4.

Figure 4 – Brazilian air network system
Source: ANAC

With the h- centrality measure, this study presented the core list with 6 airports from whole Brazilian network (Table 1). The layer centrality showed by Table 2 the top important airports. These analysis in common demonstrate the peculiar characteristics of the Brazilian aviation market, such as the distribution and concentration of operations.

CONCLUSION

The original h-index reflects a history of the articles published by each author, but in the case of airports the market dynamics changes the behaviour of the network. As mentioned by [8], h-centrality measure presents the situation at the moment when the data were analysed, which we could verify the same characteristic to layer centrality.

Additionally, further studies could be carried out to verify the interconnectivity of the global network, including Brazilian airports. Finally, another proposal for a future study could be to increase the data to consider the size of each airport as well as the types of aircraft that operate, to avoid discrepancies among the network.

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Air traffic forecast and its impact on runway capacity. A System Dynamics approach

Diana Tascón Hoyos - dianatascon@ustadistancia.edu.co
Universidad Santo Tomás, Colombia
Oscar Díaz Olariaga - oscardiazolariaga@usantotomas.edu.co
Universidad Santo Tomás, Colombia

Abstract
To evaluate the impact of future demand on the runway capacity of the Dorado International Airport (BOG), in Bogotá, the capital of Colombia.
Due to the complexity of the air transport forecast, the use of System Dynamics (SD), is considered to be appropriate as an analysis approach (Angarita-Zapata et al., 2016; Suryani et al., 2012, 2010). To develop the relations and equations involved in SD real data from the official aeronautical it is been used. SD is based on feedback control theory and it is equipped with mathematical computer simulation models, which uses linear and non-linear differential equations (Ogata, 2014; Sterman, 2000).
The uninterrupted growth of air traffic in Colombia has been reinforced since the 1990s by a public policy of liberalization of airspace, and by redirecting public and private investment towards the modernization and updating of airport infrastructures (Díaz Olariaga, 2017), giving in concession the busiest airports in the country. In the last two and a half decades, passenger transport in Colombia grew by 863%. This growth rate has been driven and led by the country's main airport. The contribution of this research has two aspects: a) from the methodological point of view, the use of System Dynamics to make demand projections and generate scenarios, and thereby evaluate the behavior of the runway capacity of a large hub airport; and b) from the geographical perspective, the great gap existing in the literature in the treatment of this topic is covered both at regional level (Latin America) and at local level (Colombia).

Keywords
Airport; Runway capacity; Operacions; Air transport demand

Air traffic forecast and its impact on runway capacity. A System Dynamics approach

Introduction

The uninterrupted growth of air traffic in Colombia has been reinforced since the 1990s by a public policy of liberalization of airspace, and by redirecting public and private investment towards the modernization of airport infrastructures [1] [2]. The public policies of the air sector led to the fact that in the last two and a half decades passenger transport in Colombia grew by 863% [3]. This important growth rate has been driven and led by the country's main airport, the Bogota-El Dorado Airport (hereinafter BOG). But some technical reports estimate that the airport will reach its maximum capacity in the short term mainly because of its inability to expand its flight field (currently two runways) [4]. Due to this circumstance, the aeronautical public authority of Colombia gave direction to the planning, design and construction of a new airport (complementary) to the outskirts of the city of Bogotá, which is estimated to enter into operations in 2025/2026 [5].

Then, it is considered opportune, and of great interest, the development of a traffic forecast for BOG in the short term and to evaluate the impact of future demand on the runway capacity of the airport. Due to the complexity of the forecast of air transport, the use of the System Dynamics (hereinafter SD) approach is founded appropriate for the present investigation, since with SD it is possible to develop a model to forecast the demand of operations on runway and evaluate its impact over the capacity of the BOG runway. Basically, once a set of variables of level, flow and parameters that must be included in the model are defined, the limits of the model, the subsystems, the causality structures and the level flows will be stablished, and then we proceed to quantify the model and run the simulation referred to the airport object of the case study. So that, in accordance with the principles of SD, a better understanding of the behavior of the system is achieved. The data for the investigation are obtained from the aeronautical public authority of Colombia (hereinafter Aerocivil).

Methodology

Approach and methodological references

This article seeks to evaluate the impact of demand forecasts on the management of runway capacity, taking El Dorado International Airport in Bogotá, Colombia as a case study. The situation described was faced with the use of simulation under the SD approach.

There is a proposed SD model [6], which was taken as a reference for the described purpose, in it the authors forecast and analyze the demand of air passengers with the aim of evaluating the future requirements of runway capacity as well as passenger terminal for Taiwan Taoyuan International Airport (TTIA). The use of SD allowed them to evaluate some scenarios of track capacity expansion.

SD incorporates a set of tools that allow the understanding of complex environments; tools such as causality diagrams, that encourage systemic thinking among managers of processes, capture the dynamic complexity of a given system and provide the considerable advantage of simulating the model to evaluate the interaction results and thus anticipate the effects long-term collateral policies before its implementation [7].

The use of Systems Dynamics, in the modeling and simulation of complex systems, implies the execution of a set of tasks that are synthesized in Table 1.

Table 1-Activities, methods, products
Source: [8]

Activity	Method	Product
Definition and structuring of the dynamic behavior of the system	It focuses on the definition and elaboration of a system mapping that involves the following elements: -Limits of the model -Subsystems -Causality structures -Flows and levels	Conceptual mapping
Quantification of the model	The quantification implies: -Definition of decision rules that govern the system. -Estimation of parameters, correlations and initial conditions. -Execution of consistency tests	Quantified model
Simulation	Simulation and analysis of the behavior of response variables	Results of the simulation and its analysis

In general, the use of the runway depends on the demand of flights that are affected by external and internal factors. The demand for air transport tends to evolve based on changes in prices and economic conditions. There are several factors that affect the demand for air travel, which are basically socio-economic and demographic [9].

Definition and structuring of the dynamic behavior of the system

In the model developed, the analysis will focus on the impact of demand forecasts on the management of the runway capacity of the terminal area, so it was decided to work the forecast directly in terms of demand for landings and take-offs (flights), for which data and statistics were taken from the Aerocivil [10], the socio-economic data was obtained from the Bank of the Republic of Colombia [11] and DANE [12].

Initially, we started with a set of variables (both response and input), which are considered to be typically relevant for air traffic forecast, thus, a preliminary analysis consisted in determining the correlation between these variables, obtaining the results shown in Table 2.

Table 2-Correlation indexes between preliminary variables
Source: Authors

	Flights	Year	Month	GDP	GDP per capita	population	IPI	Total exports	Total imports	CPI	Exchange rate
Flights	1,00										
Year	0,93	1,00									
Month	0,09	0,00	1,00								
GDP	0,91	0,99	0,00	1,00							
GDP per capita	0,91	0,99	0,00	1,00	1,00						
population	0,92	1,00	0,00	0,99	0,99	1,00					
Industrial Production Index (IPI)	0,85	0,93	0,00	0,91	0,92	0,94	1,00				
Total exports	0,82	0,76	0,00	0,70	0,72	0,76	0,78	1,00			
Total imports	0,91	0,88	0,00	0,84	0,85	0,88	0,86	0,96	1,00		
Consumer price index (CPI)	0,90	1,00	0,00	0,99	1,00	1,00	0,94	0,73	0,84	1,00	
Exchange rate (USD to COP)	0,06	0,17	0,00	0,25	0,22	0,17	-0,01	-0,41	-0,17	0,20	1,00

Concentrating on the variable to predict in the model, which means the demand for runway operations (flights), only the variables with the highest incidence were included. Also in order to simplify the model and avoid redundancies, those variables that are highly explained by others were in some cases excluded. As a conclusion of this analysis the socioeconomic indicators listed in Table 3 were incorporated.

Table 3-Socio-economic indicators to be included in the model
Source: Authors

Indicators
GDP per capita
population
Total exports
Total imports
Consumer price index (CPI)
Exchange rate (USD to COP)

Even when a low correlation is observed between the number of flights and the Exchange Rate, it will remain in modeling since it is conceptually relevant for the case studied. The variables and parameters contemplated in the modeling are specified the Table 4, along with their type (according to SD), some observations and the source (if applicable).

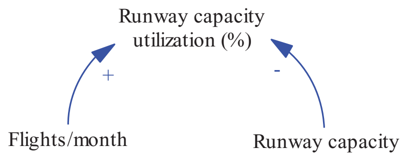
Table 4-Variables and parameters of the model
Source: Authors

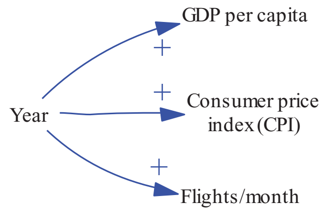
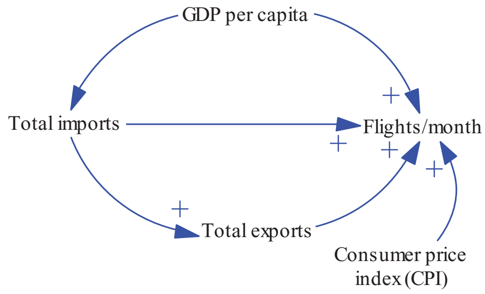
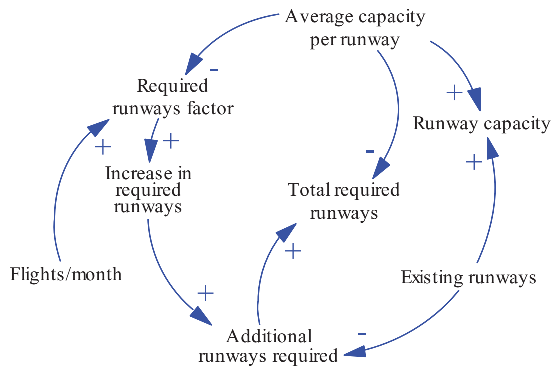
Variable / Parameter	Type	Observations / source
Runway capacity	Parameter	Historical data
Year	Auxiliary	Counts the years of operation that are being simulated
Flights/month	Auxiliary	Equation of the model, built from historical data
Runway capacity utilization (%)	Auxiliary	Equation of the model
GDP per capita	Auxiliary	Equation of the model, built from historical data
Total exports	Auxiliary	Equation of the model, built from historical data
Total imports	Auxiliary	Equation of the model, built from historical data
Consumer price index (CPI)	Auxiliary	Equation of the model, built from historical data
Exchange rate (USD to COP)	Auxiliary	Equation of the model, built from historical data
Average capacity per runway	Parameter	Historical data
Existing runways	Parameter	Historical data
Required runways factor	Auxiliary	Equation of the model
Increase in required runways	Flow	Equation of the model
Additional runways required	Level	Equation of the model
Total required runways	Auxiliary	Equation of the model

Conceptual mapping of the model

Using SD causality diagrams, we proceed to propose the relationships that exist between the variables included within the scope of the model. In this sense, Table 5 contains the description of some of the causality relationships considered.

Table 5-Representation of some relationships and model feedback cycles
Source: Authors

Type of relationship	Graphic representation
This fraction of the model indicates that as the number of flights increases, the runway utilization increase. And an increase in runway capacity would means a decrease in runway utilization.	

Type of relationship	Graphic representation
Here the influence of the passage of time (year), on variables such as the CPI, GDP per capita and the demand for operations is represented; which is incremental for all these cases	
This fraction of the conceptual map emphasizes on the variables that impact the flights per month. It is shown that an increase in any of the related variables would lead to an increase in the number of flights	
Finally are shown causality relationships such as: If current the existing runways increases, the amount of additional runways required will decrease. If the average capacity per runway increases, the required runways factor will decrease. Other relations can be observed in the graphic.	

Quantification of the model

The data taken as the main input to quantify the model are between the first of January of 2000, which in the simulation corresponds to period 1; and December 31th of 2017, which in the simulation corresponds to period 216. The flights, both departures and arrivals, that involved the El Dorado Airport in Bogotá, were contemplated, as well as parameters like the capacity of its runways.

The runway capacity data comes from Aerocivil [13], and corresponds to the operating capacity averages given in annual terms and taken for convenience of the model to their monthly equivalences. In order to forecast the behavior of the demand for operations, monthly data is available from January 2000 to December 2017. The behavior of the total execution of monthly operations for the referenced year is reflected in Figure 1.

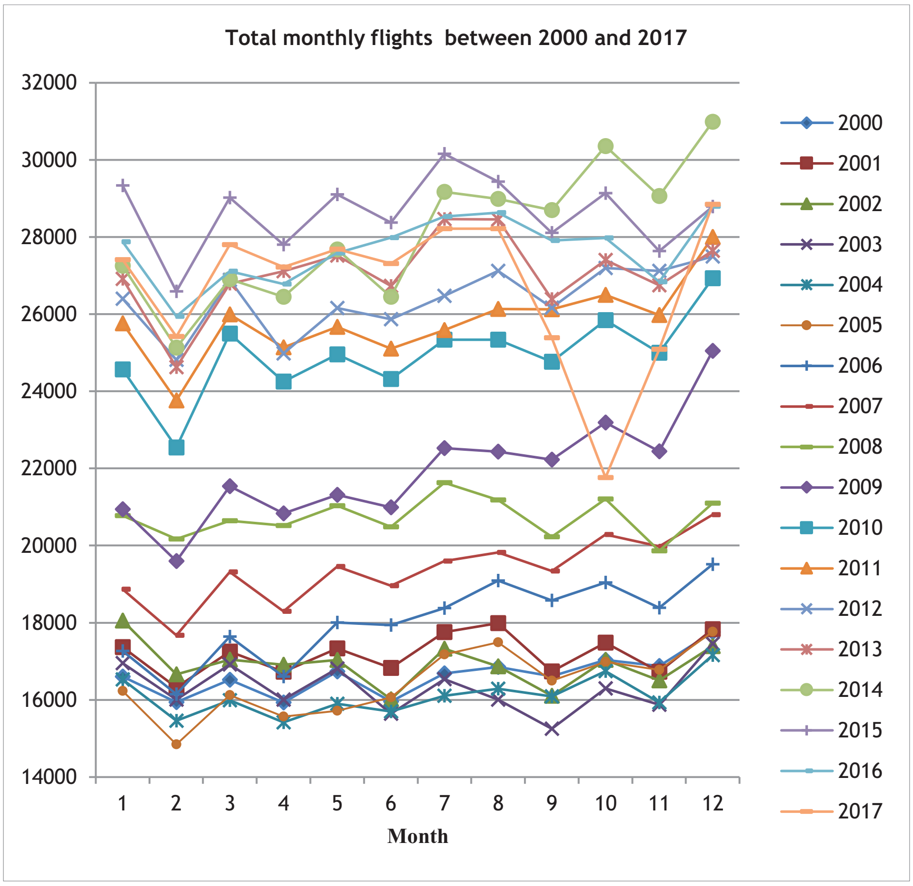


Figure 1 - Total monthly flights between 2000 and 2017
Source: [10]

Figure 2 shows the annual behavior of this variable, this allows us to identify an annual trend of the presented data.

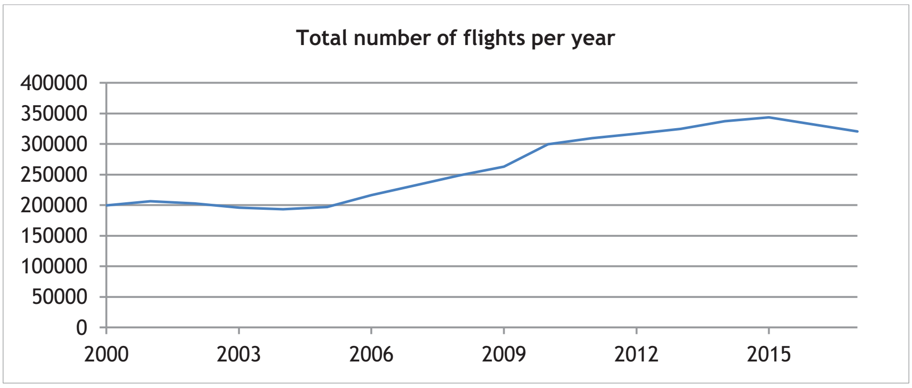


Figure 2 - Total number of flights per year
Source: Authors

By using data analysis and in several cases linear regressions, the relationships between variables and the equations that described them were established. The quantified model was simulated by using Vensim®, software for SD. The flows and levels diagram related with the quantified model is shown in Figure 3. The obtained results are presented in the next section.

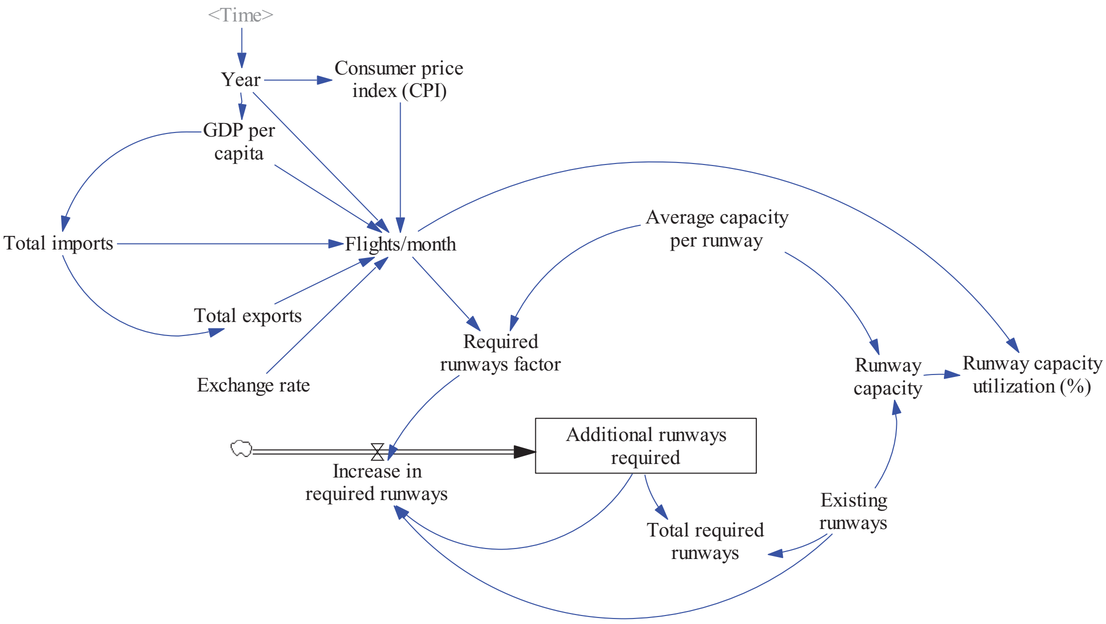


Figure 3 - Flows and levels diagram
Source: Authors

Results

To evaluate the performance of the model with respect to the historical data behavior, a simulation, for the period between January 2000 and December 2017, was run. Figure 4 illustrates the average of monthly flights per year for both, the historical available data and the simulation.

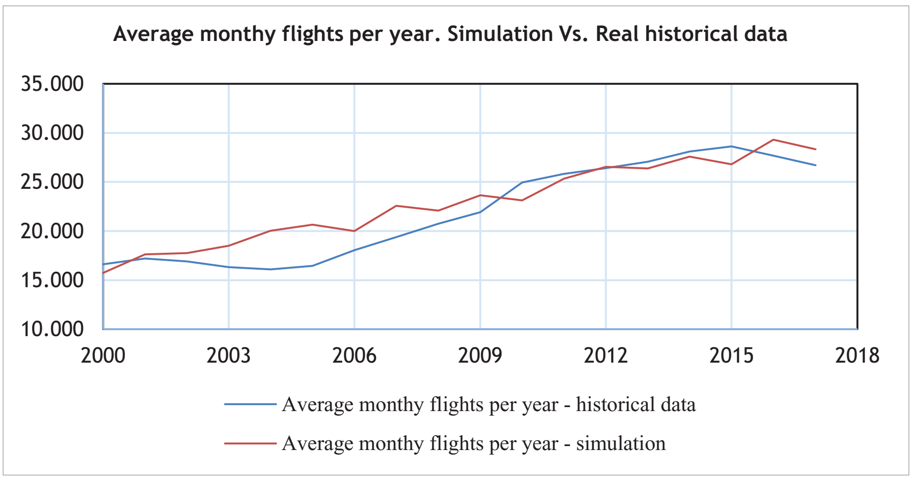


Figure 4 - Average monthly flights per year. Simulations Vs. Real historical data
Source: Authors

In order to forecast the required runway capacity, the model was simulated considering both, a past period (between 2000 and 2017), and a projection of five years, between January 2018 and December 2023 (periods 217 to 312 in the simulation).

In the next figures the results for the variables of greatest interest are presented. Those are, flights/month (figure 5), use of runway capacity (figure 6), and total runways required (figure 7).

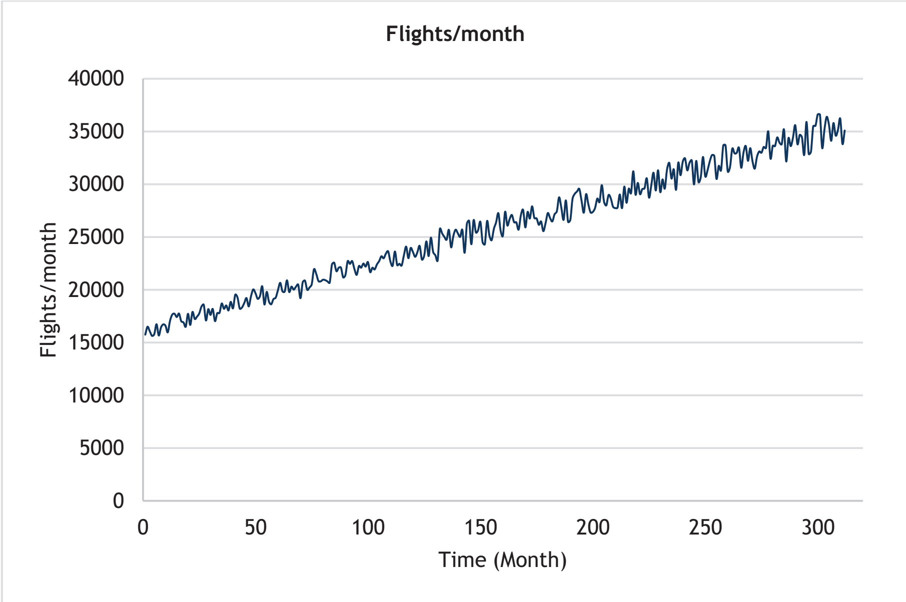


Figure 5 - Number of flights per month. Simulation between 2000 and 2023
Source: Authors

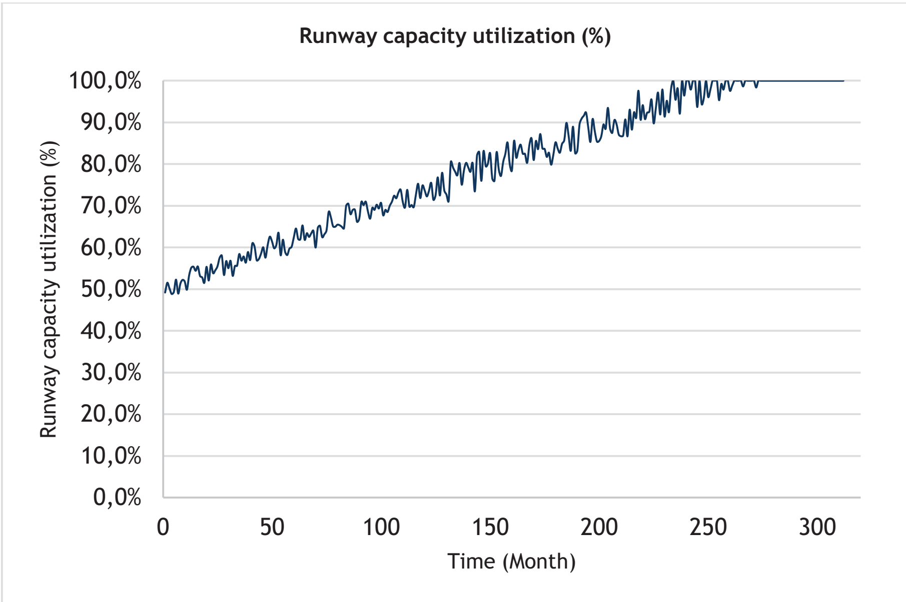


Figure 6 - Runway utilization (%). Simulation between 2000 and 2023
Source: Authors

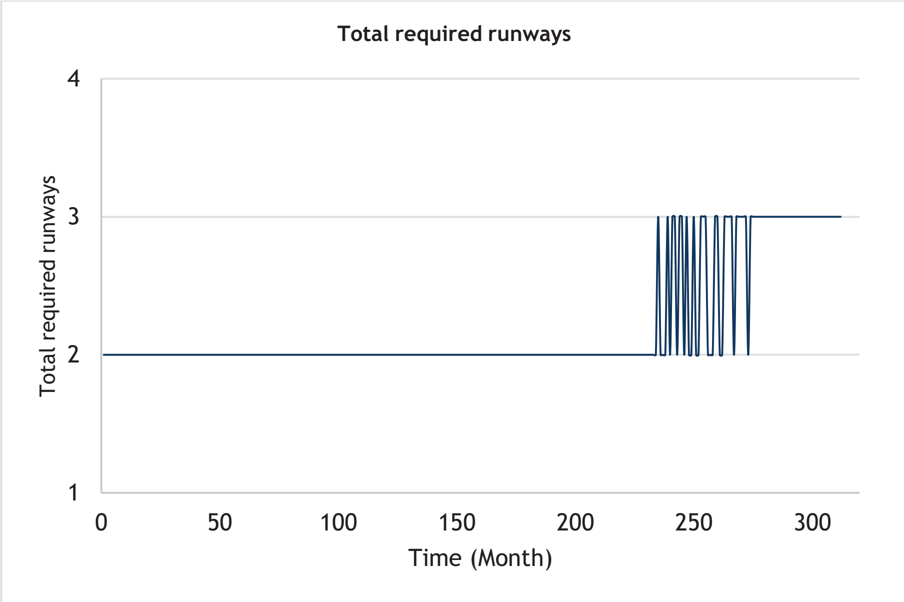


Figure 7 - Required runways
Source: Authors

Conclusions

Through the use of a Systems Dynamics model it has been possible to analyze the behavior of the demand for runway operations (flights), associated with air transport in a high growth liberalized market.

The simulation gives evidence of a need to expand the airport case study after mid-2019, where the current capacity utilization factor is around 100% and two to three runways will be required for the normal operation; after October 2022, the numer runways requiered is set to three until the last period simulated, wich corresponds to Decembre 2023.

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Estudio de las horas pico de aeronaves en aeropuertos del Sistema Nacional de Aeropuertos

Rogelio Faut - rogelio.faut@ing.unlp.edu.ar
Universidad Nacional de La Plata/ Grupo Transporte Aéreo – UIDET GTA-GIAI, Departamento de Aeronáutica, Facultad de Ingeniería
Joaquin Piechocki - joaquin.piechocki@ing.unlp.edu.ar
Universidad Nacional de La Plata/ Grupo Transporte Aéreo – UIDET GTA-GIAI, Departamento de Aeronáutica, Facultad de Ingeniería
Gabriel Ramirez Díaz - ramirezdiaz.gabriel@gmail.com
Universidad Nacional de La Plata/ Grupo Transporte Aéreo – UIDET GTA-GIAI, Departamento de Aeronáutica, Facultad de Ingeniería
Ezequiel Burela - ezequielburela@gmail.com
Universidad Nacional de La Plata/ Grupo Transporte Aéreo – UIDET GTA-GIAI, Departamento de Aeronáutica, Facultad de Ingeniería
Alejandro Di Bernardi - cadibern@ing.unlp.edu.ar
Universidad Nacional de La Plata/ Grupo Transporte Aéreo – UIDET GTA-GIAI, Departamento de Aeronáutica, Facultad de Ingeniería

Abstract

Caracterizar el tráfico aéreo de aeronaves comerciales que se desarrolla en aeropuertos del Sistema Nacional de Aeropuertos en términos de las horas pico máximas/medias, la concentración de tráfico y el nivel de ocupación de la capacidad de sus infraestructuras.

A partir del registro de operaciones del 2017, se cuentan la cantidad de operaciones aéreas en intervalos de una hora, cada cinco minutos. Se determina las horas pico máximas/medias. Además, se determinan los movimientos de aeronaves del día promedio del mes pico (ADPM). También se cuantifica la capacidad de las infraestructuras de la parte aeronáutica. Así se obtiene un factor de concentración de tráfico y un factor de ocupación.

Estimar el nivel de saturación de las infraestructuras de la parte aeronáutica en aeropuertos del SNA, y resaltar la utilidad de estos estudios como herramienta en instancias de planificación de las infraestructuras e instalaciones de los aeródromos a nivel sistémico. Los resultados se presentan en mapas georreferenciados que facilitan la interpretación de los resultados y la complementación con otros estudios.

Resaltar la necesidad de contar con un sistema de gestión de la información referida al tráfico aéreo, que asegure la fiabilidad de los datos, y permita el desarrollo de estudios tendientes a caracterizar una red aeroportuaria, buscando una herramienta útil para la toma de decisiones en etapas de planificación.

Keywords

Planificación; Hora Pico; Capacidad; Factor de concentración

Estudio de las horas pico de aeronaves en aeropuertos del Sistema Nacional de Aeropuertos

INTRODUCCIÓN

El sistema de transporte que se configura en determinado país, incluyendo todos sus modos, juega un rol fundamental en el desarrollo de su territorio, en función del impacto que tiene en la dimensión territorial de un Estado impactando directamente en los aspectos económicos, sociales, política y cultural.

Los países centrales de orden mundial, se caracterizan por buscar la configuración de sistemas de transporte multimodales balanceados, donde el tratamiento que reciben los productos de sus industrias se enmarcan en una cadena logística de origen-destino, que pretende optimizar los procesos según las demandas involucradas, en busca de un equilibrio entre los tiempos de traslado y los costos de los productos finales [1].

La planificación de estos sistemas debe entenderse como un proceso multivariable y dinámico. Multivariable porque depende de numerosos factores que deberán ser relevados y ponderados para la toma de decisiones, esta condición evidencia la incompatibilidad de esta tarea con metodologías rígidas y estructuradas. Además, el proceso es dinámico, referido a la necesidad de revisiones periódicas en búsqueda de actualizar las informaciones relevadas, y detectar modificaciones en el marco conceptual en el que se desarrolla el proceso de planificación. Estas modificaciones del contexto se pueden originar por factores internos del sistema, como pueden ser modificaciones en el marco regulatorio de la actividad, o cambios en las estrategias políticas de gestión estatal. También pueden originarse por factores externos, como pueden ser cambios en las tecnologías aplicadas en algún modo de transporte o las variaciones en los costos operativos.

En este marco, es posible definir la planificación del sistema de transporte como el estudio de las demandas de movilidad, actuales y futuras, de personas y mercancías, con el objetivo de intervenir en su desarrollo, en la búsqueda de la optimización de indicadores específicos, asociados a determinado criterio de planificación, como suele ser la eficiencia de los procesos o su impacto ambiental.

Este estudio presenta un análisis del tráfico aéreo desarrollado durante el año 2017 en aeropuertos del Sistema Nacional de Aeropuertos (SNA) de la República Argentina, pertenecientes al Grupo A.

El análisis aborda la determinación de la cantidad de movimientos de aeronaves por hora (interhorario), obtenidas en intervalos cada cinco minutos, a partir de los registros de operativos. Esta información permite la identificación del mes pico en cuanto a este parámetro, y la determinación del día promedio correspondiente (Average Day Peak Month, ADPM), siguiendo lineamientos de la *Federal Aviation Administration* [2]. También permite la determinación de la hora pico máxima de cada aeropuerto, así como establecer un ranking de horas pico, que resulta de gran utilidad para el estudio de la demanda aérea en instancias de planificación y diseño. Además, posibilitan la construcción de indicadores de caracterización del perfil operativo de los aeropuertos, como la concentración del tráfico aéreo diario y del nivel de ocupación de las infraestructuras de la parte aeronáutca.

Este análisis admite la clasificación de los aeródromos según su densidad de tránsito de aeródromo, acorde a lo descrito en la 8ª edición del Anexo 14 al Convenio de Chicago, de la Organización Internacional de Aviación Civil (OACI).

La unidad introducida, movimientos por hora, también es utilizado para caracterizar la capacidad de servicio con el que cuenta el sistema aeroportuario del lado aire del aeródromo. Indica, en este caso, una cantidad general de operaciones, que están ligadas intrínsecamente a la generación de demoras. Esta valoración de la capacidad surge de lo descrito en los documentos Planes Maestros de cada aeropuerto considerado. Relacionando la hora pico máxima del aeródromo con la capacidad asignada al lado aire, se obtiene un indicador del factor de ocupación de la parte aeronáutica del aeropuerto.

Buscando facilitar su interpretación y su complementación con otros estudios, los resultados obtenidos se presentan en formato de tablas y mapas georreferenciados.

METODOLOGÍA

Día promedio y horas pico

La determinación de la cantidad de operaciones aéreas, aterrizajes o despegues, en intervalos de una hora se lleva adelante considerando información proveniente de las bases TAMS para el registro del tráfico aéreo en los aeropuertos estudiados. Se dispone de información referida a aeropuertos pertenecientes al grupo A de aeródromos del SNA. Los datos disponibles contemplan todo el año 2017.

Las planillas que concentraron la información de base cuentan con información referida a cada operación que se realiza en el aeródromo, incluyendo tipo de movimiento (aterrizaje o despegue), así como fecha y hora estimada y real de cada operación, entre otros. Se consideran únicamente operaciones comerciales, ya sean regulares o no regulares.

La determinación del día promedio de movimientos de aeronaves se obtuvo siguiendo los lineamientos de la FAA [2], que propone le identificación del mes pico y la determinación del día promedio de dicho mes (ADPM), para cada aeropuerto analizado.

Utilizando un software que permitió el procesamiento de los datos, se cuentan la cantidad de operaciones aéreas registradas en intervalos de una hora. Este cálculo se realizó para intervalos horarios cada cinco minutos (de 7:50 a 8:50, 7:55 a 8:55, 8:00 a 9:00, etc). Se obtuvo un total de 101.105 horas calculadas en 2017 para cada aeródromo bajo estudio.

Los resultados obtenidos permitieron determinar la hora pico máxima para el movimiento de aeronaves de cada aeropuerto durante el año 2017, así como establecer un ranking de horas pico, que permitió una caracterización de la demanda de tráfico aéreo de aeronaves de cada aeropuerto.

Con estos resultados se desarrolló un indicador (C), que relaciona la cantidad de movimientos de aeronaves durante la hora pico máxima y la cantidad de movimientos de aeronaves durante día promedio.

$$C = \frac{Movimiento\ de\ Aeronaves\ en\ Hora\ pico}{Movimiento\ de\ Aeronaves\ en\ Día\ Promedio}$$

Este indicador permitió inferir el nivel de concentración de tráfico que representa la hora pico máxima en el perfil operativo diario. Cuando el indicador toma valores cercanos a la unidad, evidencia perfiles diarios de baja operatividad y gran concentración, donde la hora pico calculada representa casi la totalidad del movimiento de aeronaves diario. Valores del indicador cercanos al valor nulo, evidencian perfiles de tráfico diario de mayor intensidad en horarios que no coinciden con la hora pico determinada, es decir, una menor concentración del tráfico aéreo diario.

Es necesario aclarar que, debido a las metodologías empleadas para la determinación del día promedio de movimiento de aeronaves y la hora pico máxima, este indicador puede tomar valores mayores a la unidad, representando casos de aeropuertos de muy baja intensidad de tráfico, sin participación de vuelos regulares.
El Anexo 14 al Convenio de Chicago de la OACI, establece en su 8ª edición una clasificación de los aeródromos según su *densidad de tránsito*:

Densidad de tránsito de aeródromo

a) Reducida. Cuando el número de movimientos durante la hora punta media no es superior a 15 por pisto, o típicamente inferior a un total de 20 movimientos en el aeródromo.
b) Media. Cuando el número de movimientos durante la hora punta media es del orden de 16 a 25 por pista, o típicamente entre 20 a 35 movimientos en el aeródromo.
c) Intensa. Cuando el número de movimientos durante la hora punta media es del orden de 26 o más por pista, o típicamente superior a un total de 35 movimientos en el aeródromo.

Nota 1.- El número de movimientos durante la hora punta media es la media aritmética del año del número de movimientos durante la hora punta diaria.
Nota 2.- Tanto los despegues como los aterrizajes constituyen un movimiento.

Fig. 1 Clasificación según Densidad de tránsito de aeródromo, OACI

Fuente: OACI

Como se observa en la figura, la clasificación depende de la *hora punta media* del aeródromo, definida como la media aritmética del año del número de movimientos durante la hora punta diaria.

La metodología propuesta permite la determinación de la *hora punta media* para cada aeródromo analizado, pudiendo de esta manera clasificarlos según densidad de tránsito *reducida*, *media* o *intensa*.

Capacidad del lado aire

La determinación del valor de capacidad asignada a la parte aeronáutica de los aeropuertos en estudio, ponderada en movimientos de aeronaves por hora, se realiza mediante una metodología analítica utilizada en los documentos Plan Maestro de los aeropuertos considerados.

La metodología analítica supone analizar la capacidad y las demoras asociadas al servicio de las operaciones en cada uno de los componentes de la denominada parte aeronáutica. La asociación de las diferentes operaciones y componentes de infraestructura se encuentra dominada por los fenómenos de colas de espera, y por las interferencias entre las servidumbres de cada operación.

Una categorización básica de componentes los agrupa según:

- ✓ Pista y sistema de rodaje
- ✓ Plataforma y puestos de estacionamiento

A partir del análisis de cada componente, en determinadas condiciones de utilización, resulta en un valor de capacidad general alcanzable de servicio por hora, y volumen anual teórico. Si sobre esta base se establece un nivel de demora tolerable y un patrón de demanda específica, es posible obtener como resultado la capacidad del componente, que denominamos capacidad práctica y que tiene una demora por operación esperada. La capacidad del sistema queda establecida por el componente de menor capacidad.

Como criterio general, los datos de entrada para los cálculos de capacidad son todos aquellos procedimientos y condicionamientos en la operación de la aeronave en el contexto físico, operacional, climático y legal. De este modo los principales condicionantes impuestos por el método son las dimensiones de la infraestructura, las distancias recorridas por las aeronaves, las velocidades de operación y las separaciones entre aeronave impuestas por condiciones climáticas y legales. Dichos condicionantes se traducen en tiempo operativo entre el evento i y el evento j (T_{ij}).

La metodología para la evaluación de demora y capacidad se basa en la llamada teoría de colas, la cual permite el estudio de líneas de espera permitiendo el análisis de varios procesos relacionados.

La evaluación de capacidades y demora en el caso de puestos de estacionamiento presenta particularidades por su carácter dinámico, al estar referida a los flujos que es capaz de acumular, albergar y brindar servicio. Por lo tanto, si bien fue analizado con el mismo criterio que en el resto de los casos, las variables que incidirán en los cálculos estarán asociadas principalmente a la disponibilidad, al tipo y performance de servicios disponibles, al carácter asignado del puesto de estacionamiento, a la política de asignación de puestos de aterrizaje, y al agrupamiento de aeronaves de acuerdo a esta política.

Para el análisis del sistema completo es necesario analizar la red de colas de espera determinada por los procesos de los componentes del sistema, sus puntos de contacto, y transferencias.

La aplicación de la teoría de colas a la situación operativa de la parte aeronáutica del aeropuerto supone dividir al sistema en componentes más simples de modelar, en función de su tipología operacional, y analizar su eficiencia funcional.

La presente metodología se basa en el siguiente proceso:

Tabla 1 Proceso para la determinación de la capacidad del Sistema

DETERMINACIÓN DE CAPACIDAD	
Índices	Comentarios
Capacidad por componente	La expresión universal que se usa, corresponde a la ecuación de Little, para determinar las capacidades horarias es: Ch=60 min/(ΣP_{ij}*T_{ij}) Donde P_{ij}, en el componente Pista, es la probabilidad que una aeronave con determinada capacidad de generación de estela esté precedida por otra de determinadas características en un suceso tipo y, T_{ij} es el tiempo en minutos entre el evento i y el j. Para determinar la capacidad de cada componente es necesario generar escenarios considerando los siguientes parámetros constitutivos: patrón de servicio y capacidad de atención, disciplina de espera y canales de servicio El resultado de esta evaluación es la determinación de capacidades teóricas por componente para cada uno de los escenarios adoptados, el cual posteriormente es afectado por las características de la demanda y la demora dando lugar a la capacidad práctica.
Demanda por componente	Es necesario generar modelos para la caracterización de la demanda a la que será sometido cada componente del sistema para la evaluación posterior de sus demoras. Para la caracterización de la demanda es necesario establecer escenarios considerando los siguientes parámetros constitutivos para cada una de las componentes del sistema: patrón de llegada y disciplina de espera. De esta manera, se consideran tiempos entre arribos en aterrizaje con distribución exponencial con media 1/λ, y tiempos de servicio con media 1/μi, para cada componente "i" del sistema. Se supone, por otro lado, que el orden de atención reproduce el orden de llegada en la cola, queda definido así los patrones de servicio y las disciplinas de espera. El objetivo de esta evaluación es la determinación de la demanda de diseño para cada componente.
Demora por componente	Las demoras en las operaciones están ocasionadas por el efecto de simultaneidad de la demanda sobre una capacidad de servicio del componente del sistema. Los escenarios sobre los cuales se analiza el efecto de demora deberán contemplar un espacio temporal, el cual tendrá una demanda de diseño asociada y una capacidad de servicio determinada. El objetivo de esta evaluación es la determinación de la demora media por aeronave, sobre la base de escenarios de diseño y un espacio temporal determinado. De este modo, si se considera 4 minutos promedio de demora por operación, existirá, en virtud de la distribución estadística asignada (exponencial) a la demanda aeronáutica y al servicio por parte de la infraestructura, un nivel de confianza de que las aeronaves no superen un nivel dado de demora por operación. Para el caso de las capacidades prácticas, el nivel de confianza en que el tiempo de espera no sea mayor a 4 minutos es superior al 95%.

DETERMINACIÓN DE CAPACIDAD	
Índices	Comentarios
Capacidad del sistema	La capacidad total del sistema corresponde al volumen de servicios que es capaz de brindar el conjunto de componentes que lo constituyen de manera acoplada bajo determinado escenario operativo. En particular, la capacidad total valora los efectos de saturación de los componentes asociados en serie o paralelo, sobre el volumen total de servicios que es capaz de generar.
Demora del sistema	La demora del sistema sobre la operación de una aeronave dada depende del escenario adoptado de demanda de entrada, del acoplamiento, en serie o paralelo, de los componentes del sistema y las capacidades de cada componente.

El resultado final de este proceso determina un valor de capacidad práctica, ponderado en operaciones de aeronaves atendidas en una hora, para el sistema de pistas y calles de rodaje, y un valor para el sistema de plataformas comerciales. De estos dos valores obtenidos, se asigna el menor de ellos como la capacidad de la parte aeronáutica del aeropuerto analizado.

Una vez asignados los valores de capacidad es posible construir un factor de ocupación (*F*), que relacione la cantidad de aeronaves durante la hora pico máxima, y el valor de capacidad correspondiente.

$$F = \frac{Movimiento\ de\ Aeronaves\ en\ Hora\ pico}{Capacidad\ práctica\ de\ la\ parte\ aeronáutica}$$

Dado que la capacidad de servicio depende de la especificidad de su utilización y una de ellas es la relación entre operaciones de aterrizaje y despegue, se asume un factor de demanda de aterrizajes y despegues del 50%.

RESULTADOS

Los resultados obtenidos se presentan en formatos de tablas y mapas georreferenciados que facilitan la interpretación y la complementación con otras fuentes de información.

La tabla 1 presenta los resultados referidos a la cantidad de movimientos (arribos o partidas) durante el día promedio, *Día Prom.*, la hora pico máxima, *HP máx*, y la hora pico media, *HP med*. Se presenta además los valores obtenidos para el indicador de concentración de tráfico, *C*, y la clasificación OACI del aeropuerto según su densidad de tráfico.

Tabla 2 Día promedio, hora pico máxima, hora pico media, concentración y densidad de tráfico por aeropuerto

Aeropuertos	Id IATA	Día Prom.	HP máx	Concentración (*C*)	HP med	OACI Dens. tráfico
Aeroparque	AEP	351	32	0,09	26	Intensa
Bariloche	BRC	45	11	0,24	5	Reducida
Catamarca	CTC	3	2	0,67	2	Reducida
C. Rivadavia	CRD	22	7	0,32	3	Reducida
Córdoba	COR	72	11	0,15	7	Reducida
Esquel	EQS	2	2	1,00	2	Reducida
Ezeiza	EZE	187	21	0,11	16	Media
Formosa	FMA	3	2	0,67	2	Reducida
Iguazú	IGR	26	7	0,27	4	Reducida
Jujuy	JUJ	10	4	0,40	2	Reducida
La Rioja	IRJ	4	3	0,75	2	Reducida
Malargüe	LGS	1	2	2,00	2	Reducida
Mar del Plata	MDQ	16	6	0,38	3	Reducida
Mendoza	MDZ	49	9	0,18	6	Reducida
Paraná	PRA	5	3	0,60	2	Reducida
Posadas	PSS	6	3	0,50	2	Reducida
Puerto Madryn	PMY	7	4	0,57	1	Reducida
Reconquista	RCQ	1	3	3,00	1	Reducida
Resistencia	RES	9	4	0,44	2	Reducida
Río Cuarto	RCU	3	3	1,00	2	Reducida

Aeropuertos	Id IATA	Día Prom.	HP máx	Concentración (C)	HP med	OACI Dens. tráfico
Río Gallegos	RGL	8	6	0,75	2	Reducida
Río Grande	RGA	5	4	0,80	2	Reducida
Salta	SLA	31	7	0,23	4	Reducida
San Juan	UAQ	7	4	0,57	2	Reducida
San Luís	LUQ	4	2	0,50	2	Reducida
San Rafael	AFA	3	2	0,67	2	Reducida
Santa Rosa	RSA	2	2	1,00	1	Reducida
Santiago del Estero	SDE	4	3	0,75	2	Reducida
Tucumán	TUC	21	6	0,29	3	Reducida
Viedma	VDM	2	2	1,00	2	Reducida

La tabla 2 presenta los resultados referidos a los movimientos de aeronaves en la hora pico determinada, *HP*, la capacidad asignada a la parte aeronáutica de cada aeropuerto estudiado, *CP*, y el factor de ocupación, *F*, que relaciona estos valores.

Tabla 3 Aeronaves en hora pico, capacidad asignada y factor de ocupación por aeropuerto

Aeropuertos	Id IATA	HP	CP	Ocupación (F)
Aeroparque	AEP	32	38	0,84
Bariloche	BRC	11	8	1,38
Catamarca	CTC	2	2	1,00
C. Rivadavia	CRD	7	7	1,00
Córdoba	COR	11	11	1,00
Esquel	EQS	2	4	0,50
Ezeiza	EZE	21	30	0,70
Formosa	FMA	2	7	0,29
Iguazú	IGR	7	5	1,40
Jujuy	JUJ	4	8	0,50
La Rioja	IRJ	3	7	0,43
Malargüe	LGS	2	5	0,40
Mar del Plata	MDQ	6	20	0,30
Mendoza	MDZ	9	12	0,75
Paraná	PRA	3	9	0,33
Posadas	PSS	3	7	0,43
Puerto Madryn	PMY	4	4	1,00
Reconquista	RCQ	3	13	0,23
Resistencia	RES	4	8	0,50
Río Cuarto	RCU	3	4	0,75
Río Gallegos	RGL	6	7	0,86
Río Grande	RGA	4	7	0,57
Salta	SLA	7	7	1,00
San Juan	UAQ	4	8	0,50
San Luís	LUQ	2	10	0,20
San Rafael	AFA	2	3	0,67
Santa Rosa	RSA	2	5	0,40
Santiago del Estero	SDE	3	2	1,50
Tucumán	TUC	6	9	0,67
Viedma	VDM	2	11	0,18

Los resultados en formato de mapas georreferenciados se presentan en la siguiente figura.

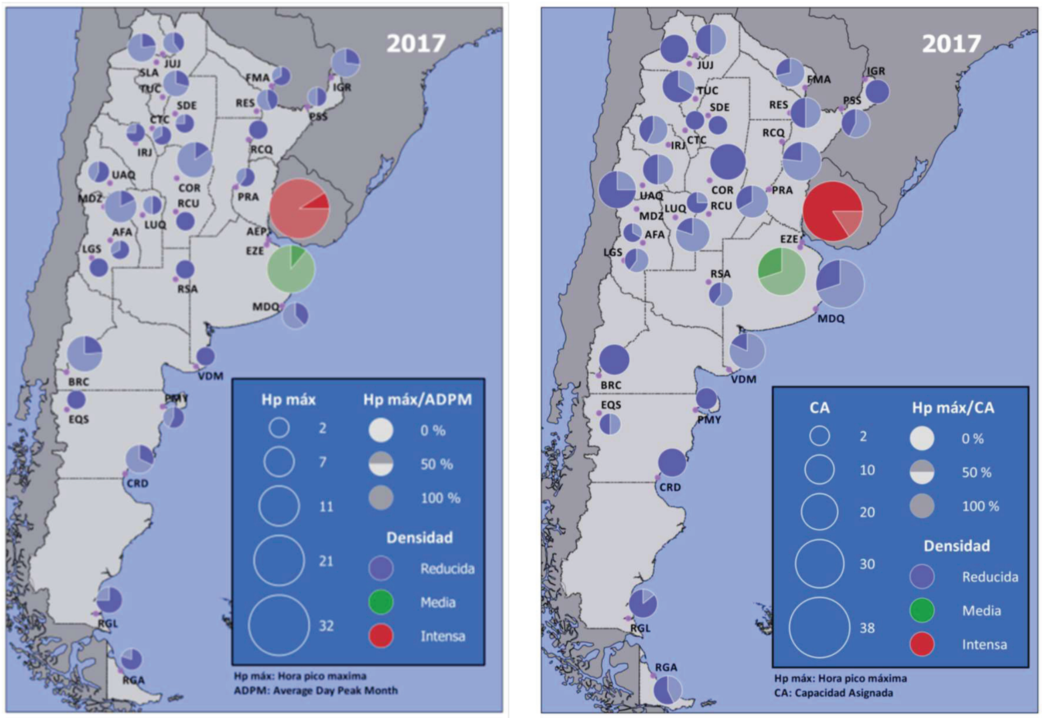

Fig. 2 Resultados obtenidos en formato mapas georreferenciados

Fuente: elaboración propia

CONCLUSIONES

Se presentó una metodología sintética en donde se realizó un procesamiento de datos de tráfico aéreo referido al movimiento de aeronaves en el año 2017 en los aeropuertos pertenecientes al grupo A del Sistema Nacional de Aeropuertos. Además, se dispuso de información referida a la capacidad de la parte aeronáutica de esos aeródromos, proveniente de los documentos Plan Maestro. Del procesamiento de esta información se presentaron parámetros e indicadores que permitieron caracterizar el perfil operativo de los aeródromos pertenecientes a la red, resultando de gran utilidad para la toma de decisiones durante las instancias de planificación y diseño de nuevas instalaciones y nuevas infraestructuras.

En referencia a la hora pico máxima, se observa que Aeroparque y Ezeiza presentan valores muy por encima de los demás aeródromos del sistema, y presentan una densidad de tráfico *Intensa* y *Media* respectivamente. El resto de los aeródromos presenta una densidad de tráfico *Reducida*. En un segundo grupo se ubican los aeropuertos de Córdoba, Bariloche, Mendoza, Iguazú, Comodoro Rivadavia, Salta, Mar del Plata, y Río Gallegos. El resto de los aeródromos, presentan valores por debajo de 4 movimientos de aeronaves en hora pico. Se destaca que los aeropuertos de Malargüe y Reconquista, no presentan vuelos comerciales regulares.

Observando los resultados del factor de concentración, se observa que aquellos aeródromos que presentan valores altos de movimiento de aeronaves en hora pico, primer y segundo grupo, presentan valores bajos del factor de concentración *C* (con la excepción del aeropuerto de Río Gallegos, cuyo factor resulta de 0,75). Los aeropuertos de Posadas, San Luís, Puerto Madryn, San Juan, Paraná, Catamarca, Formosa, San Rafael, presentan factores de concentración entre 0,5 y 0,7, representando niveles medios de concentración. El resto de los aeropuertos presenta valores por encima de 0,75, indicando que los movimientos de aeronaves comerciales en la hora pico, representan casi la totalidad

del movimiento diario promedio. Los valores obtenidos en los casos Malargüe y Reconquista refieren a la ausencia de tráfico aéreo comercial regular en dichos emplazamientos.

Respecto a los resultados del factor de ocupación *F* se observa que, según los criterios establecidos en este trabajo, los aeropuertos de Catamarca, Comodoro Rivadavia, Córdoba, Puerto Madryn, y Salta, han alcanzado la saturación de su parte aeronáutica al menos una hora en el 2017. Los aeropuertos de Río Gallegos, Aeroparque, Mendoza, Río Cuarto, Ezeiza, San Rafael, Tucumán, y Río Grande, presentan valores entre el 0,85 y 0,60. El resto de los aeropuertos presentan valores por debajo de 0,5.

Los resultados del factor de ocupación F mayores a la unidad, obtenidos en los aeropuertos de Bariloche, Iguazú y Santiago del Estero, permiten inferir diferentes causalidades. Entre ellas se consideran:

- Modificaciones en las infraestructuras de la parte aeronáutica, o en su configuración, que resulten en mayores capacidades horarias a aquellas consideradas en los Planes Maestros tomados de referencia,
- El perfil de demanda asociado a la hora pico máxima puede diferir de aquella adoptada como característica, resultando en procesos con menores tiempos entre eventos que aquellos considerados en el cálculo de la determinación de la capacidad práctica del sistema. En este mismo sentido puede existir un procedimiento operativo especial ante un evento no esperado, como el arribo de una aeronave que no ingresa a plataforma comercial,
- Puede existir una acumulación de demoras que se manifiesta en las horas posteriores a la considerada,
- En el caso de Santiago del Estero, donde la diferencia es un único movimiento, puede considerarse un error de carga en la base de datos de referencia.

Como trabajos futuros que complementen la caracterización operativa de los aeródromos pertenecientes al SNA, es posible complementar este estudio con información referida a los aeropuertos del sistema que no fueron considerados aquí, así como la capacidad de otros componentes del sistema aeroportuario, como la estructura del espacio aéreo, o los servicios de asistencia a la aeronave.

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Indicador ambiental: emisiones de CO_2 en los aeropuertos SABE, SACO, SASA, SAZB, SAZS, SAVC, SANC, SAVE de Argentina

Matias J. Coppa - matias.coppa@gmail.com
Universidad Nacional de La Plata/ Grupo Transporte Aéreo – UIDET GTA-GIAI, Departamento de Aeronáutica, Facultad de Ingeniería
Alejandro Di Bernardi1 - aledibernardi@hotmail.com
Universidad Nacional de La Plata/ Grupo Transporte Aéreo – UIDET GTA-GIAI, Departamento de Aeronáutica, Facultad de Ingeniería
Carlos Trujillo - carlostrujilloguerrero@gmail.com
Universidad Nacional de La Plata/ Grupo Transporte Aéreo – UIDET GTA-GIAI, Departamento de Aeronáutica, Facultad de Ingeniería
Lucas Sznajderman - sznajdermanlucas@gmail.com
Universidad Nacional de La Plata/ Grupo Transporte Aéreo – UIDET GTA-GIAI, Departamento de Aeronáutica, Facultad de Ingeniería

Abstract
El presente estudio busca cuantificar y comparar el aporte contaminante de CO2 , producido por las principales fuentes en los aeropuertos: vehículos de acceso al aeropuerto, edificio terminal y consumo eléctrico asociado, operaciones de aeronaves comerciales, y vehículos de asistencia al avión e mediante la aplicación de metodologías específicas desarrolladas por distintos organismos (1) (2) (3) para cada una de las fuentes mencionadas, se realiza un inventario de las emisiones de CO2 de los siguientes aeropuertos: SABE, SACO, SASA, SAZB, SAZS, SAVC, SANC, SAVE.
Mediante el desarrollo de distintos indicadores, se analizan las emisiones de CO2 relacionados a los pasajeros transportados y operaciones de aeronaves civiles y comerciales. A partir de este análisis comparativo, es posible a su vez caracterizar el peso relativo de cada fuente aeroportuaria en el total de las emisiones, como punto de partida para la aplicación de medidas de mitigación.
Un inventario de emisiones gaseosas (HC, CO, NOx, y CO2, entre otros contaminantes) proporciona los valores totales de los gases liberados al ambiente, y constituye la base para la aplicación de medidas de mitigación. La OACI reconoce que las fuentes de emisiones relacionadas con los aeropuertos tienen la capacidad de generar emisiones que pueden contribuir al deterioro de la calidad del aire tanto en las comunidades circundantes como en el calentamiento global.

Keywords
Emisiones GEI; Fuentes Aeroportuarias; Aeropuertos

Indicador ambiental: emisiones de CO2 en los aeropuertos SABE, SACO, SASA, SAZB, SAZS, SAVC, SANC, SAVE de Argentina

Introducción

Las infraestructuras aeroportuarias, a la vez de ser centros fundamentales de actividad, impulsores de la economía, del desarrollo social y cultural, así como vertebradores e integradores de regiones y estados, son también elementos que interaccionan con el medio ambiente sobre el que se asientan. La necesidad de hacer compatible el desarrollo del transporte aéreo con la conservación de los valores naturales y de la calidad de vida en el entorno aeroportuario precisa un modelo de actuación basado en el equilibrio entre los factores económicos, sociales y ambientales, que permita el acercamiento a un modelo sostenible de desarrollo.

La OACI reconoce la contaminación acústica como uno de los principales aspectos ambientales generados a causa de la actividad aérea y específicamente la aeroportuaria [1]. De ahí que la reducción al mínimo de los niveles acústicos y la protección de la calidad de vida de las poblaciones del entorno aeroportuario se haya convertido en una de las prioridades para dicha organización. Respecto a las emisiones gaseosas contaminantes, el foco está puesto en la reducción en la fuente de generación, es decir, los motores que equipan a las aeronaves. Los mismos deben cumplir con los estándares establecidos en el Anexo 16 - Protección del medio ambiente, Volumen II: Emisiones de los motores de las aeronaves para su certificación [2] y el Volumen III: Emisión de CO2 de los aviones.

Uno de los objetivos de la OACI respecto al medio ambiente es el de limitar o reducir las repercusiones de las emisiones de la aviación en la calidad del aire local. Los contaminantes de las aeronaves que causan preocupación respecto a este son las emisiones gaseosas que actualmente se controlan para la certificación de motores de aeronave en el marco del Anexo 16, Volumen II, incluidos los óxidos de nitrógeno (NO_x), el monóxido de carbono (CO) y los hidrocarburos sin quemar (HC). También se reconoce que las emisiones de contaminantes secundarios (VOC_s) y el material particulado (PM) de las aeronaves pueden tener efectos locales adversos [3].

Se considera que el aire limpio es un requisito básico del bienestar. Sin embargo, su contaminación sigue representando una amenaza importante para la salud en todo el mundo. Según una evaluación de la OMS de la carga de enfermedad debida a la contaminación del aire, son más de dos millones las muertes prematuras que se pueden atribuir cada año a los efectos de la contaminación del aire en espacios abiertos urbanos y en espacios cerrados (producida por la quema de combustibles sólidos) [4]. De acuerdo a distintos estudios, las emisiones gaseosas producto del transporte aéreo (año 2006), produjeron 9.970 muertes prematuras en todo el mundo de las cuales el 20% de ellas son atribuidas a la actividad aeroportuaria [5].

De acuerdo con el primer informe técnico de la IPCC destinado específicamente al sector del transporte aéreo la cuota parte de las emisiones totales de CO_2 antropogénicas es del 2%. Teniendo en cuenta la totalidad de los gases emitidos, su interacción con la atmosfera y su respectivo impacto en el cambio climático el valor alcanzado es de un 3,5% en el forzamiento radiativo mundial antropogénico. [6]. De acuerdo con distintas proyecciones de tráfico de la OACI se estima que las emisiones de CO_2 producto del transporte aéreo internacional aumentarán entre 111 y 144 por ciento entre 2005 y 2025 (es decir, de 416 Mt a entre 876 y 1013 Mt). [7]

La cuantificación de emisiones de dióxido de carbono, tanto en niveles crucero como en las operaciones aeroportuarias, posee un método de cálculo demostrado y aceptado [8] [9]. Se han publicado distintos estudios, presentando inventarios específicos a nivel nacional [10], como a nivel internacional en base a estimaciones de trafico de OACI [11] [12] [13].

Marco Teórico

El volumen del tráfico aéreo mundial se ha ido duplicando una vez cada 15 años desde 1977, y se espera que este este crecimiento continúe a pesar de ciclos de recesión cada vez mayores. Se pronostica que el tráfico regular de pasajeros, medido en términos de Revenue Passenger Kilometres (RPK), crezca de cinco mil millones a más de 13 mil millones en el período: 2010-2030, con un promedio anual de tasa de crecimiento de 4,9% [14]. Respecto al tráfico internacional de pasajeros, se estima un aumento del 5,1% anual, mientras que el tráfico doméstico crecería a un ritmo más lento del 4,4% (período 2010-2030). Cabe mencionar, que en este último sector se espera un crecimiento con un promedio anual de 5.2% de 2010 a 2030, incrementado de 200 billones de Revenue Passenger Kilometres (RTK) en 2010, a 562 billones en 2030 [15] .

La consecuencia directa del crecimiento del tráfico aéreo es un mayor consumo de combustible y una mayor contaminación gaseosa que afecta la calidad del aire, de vida, la fauna y zonas protegidas en las áreas vecinas a un aeropuerto. Considerando además que la tendencia temporal del crecimiento urbano lleva a la ciudad hacia las inmediaciones del predio aeroportuario, la anticipada identificación de áreas sensibles permite una menor afectación tanto en el desarrollo urbano como aeroportuario bajo la premisa de competitividad territorial.

Específicamente, las emisiones de los motores de los aviones incluyen el dióxido de carbono (CO_2), vapor de agua (H_2O), óxidos de nitrógeno (NO_x), monóxido de carbono (CO), óxidos de azufre (SOX), hidrocarburos no quemados (HC), material particulado (PM), compuestos orgánicos volátiles (VOCs), y otros compuestos [16]. Aproximadamente, un 70% de dichas emisiones son CO_2 y un 30 % de H_2O, donde el resto de los compuestos representan menos del 1%. Las cantidades totales de gases emanados dependerán de ciertos factores tales como el tipo de combustible utilizado, la riqueza de la mezcla, el mantenimiento de la cámara de combustión o del motor en general, las condiciones atmosféricas de operación, la etapa de vuelo analizada, entre otros.

Las normas OACI sobre emisiones de los motores, se aplican mediante procesos de certificación nacionales y multinacionales de los motores de turborreacción y turbofan con empuje superior a 26,7 kilonewtons (kN), no así a los motores turbohélice, alternativos y grupos auxiliares de energía (APU) [2]. Dicha normativa se basan en la performance de los motores en el ciclo de aterrizaje y despegue (LTO) idealizado como se muestra a continuación [3], Figura 1:

Fase de operación	Tiempo en el modo (minutos)	
Aproximación	4,0	
Rodaje y marcha lenta en tierra	26	7,0 (entrada) 19,0 (salida)
Despegue	0,7	
Ascenso	2,2	

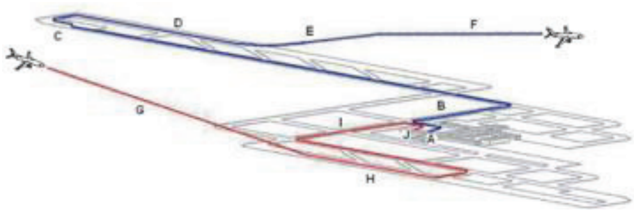

Figura 1 - Tiempos en el Ciclo LTO
Fuente: [3].

Para la determinación del impacto ambiental en el entorno aeroportuario, se define dicho ciclo como aquel que comprende las siguientes fases [3] :

- Landing - (Aproximación): son todas aquellas operaciones que se realizan desde los 1.000 metros de altura sobre la cota del aeropuerto hasta que alcanza la superficie de la pista.

- Taxi - (Rodaje): son las maniobras que realiza el avión hasta llegar a su puesto de estacionamiento en plataforma en condición de Block-On (calzos colocados) y las maniobras que realiza el avión desde el Block-Off (calzos afuera) hasta llegar a la cabecera de pista.
- Take off - (Despegue): son las operaciones que realiza el avión en la pista para lograr el despegue.
- Climb out - (Ascenso): son las operaciones que realiza el avión hasta alcanzar los 1.000 metros de altura sobre la cota del aeropuerto.

Los reglajes de empuje y tiempo en cada etapa dependen, en gran medida, de condiciones específicas como el peso de la aeronave, temperatura exterior, viento, altitud del aeropuerto, condiciones de las pistas y procedimientos de la línea aérea. En distintos estudios se ha demostrado la notable diferencia en la concentración adoptando un ciclo con valores estándares y reales en un aeropuerto [17]–[20]. Mas allá de dicha situación, a nivel global podemos afirmar que aproximadamente el 10% de las emisiones gaseosas totales de la actividad aeronáutica se emiten en dicho ciclo y el restante 90%, se emite a altitudes por encima de los 1000 m [21].

De acuerdo con [3], los aeropuertos deben mantener un inventario de emisiones gaseosas con el objetivo de:

- Colectar información y monitorear las tendencias para evaluar escenarios futuros;
- Evaluar comparativamente en acuerdo a requerimientos legales;
- Crear datos de entrada para modelos de dispersión en un esfuerzo para determinar la concentración de contaminantes; y
- Establecer bases para programas de mitigación.

Si bien las emisiones producto de los movimientos de aeronaves representan el mayor porcentaje del total, en la actualidad, debido a la complejidad y profundidad del tema no se han publicado estudios específicos que caractericen, cuantifiquen y discreticen el porcentaje de los distintos gases contaminantes respecto a la totalidad de las posibles fuentes en un aeropuerto. A partir del análisis de distintos estudios [22] [23] [24], se observa la variación de los porcentajes relativos de las emisiones en cada una de las fuentes y por ende la necesidad de realizar un inventario y análisis integral que contemple la totalidad de las mismas.

De acuerdo con las distintas metodologías desarrolladas [24] para el análisis de las emisiones producto de los vehículos de acceso a los aeropuertos, se discrimina la flota vehicular en 3 tipos: vehículo de pasajeros, vehículos de transporte livianos (taxis, remises, VANs, entre otros) y vehículos de transporte pesados (buses, trenes, subterráneos, transfer, entre otros). Este a su vez se subdivide según tres tipos de combustible gasolina, diésel y gas natural comprimido (GNC).

En cuanto al servicio o asistencia en tierra a las aeronaves (denominados Ground Support Equipment-GSE) se engloban entre sus operaciones el transporte de pasajeros desde las terminales a las aeronaves y viceversa, los procesos de carga y descarga de mercancías y equipajes, el suministro de energía y combustible a la aeronave, transporte de tripulaciones, así como todas las maniobras que deben realizarse para situar al avión en posición para efectuar el despegue o el inicio del rodaje según el caso. Estos incluyen todos los equipos de servicio en tierra y los vehículos asociados con los movimientos de la aeronave en la plataforma. Cada uno de estos vehículos poseen distintos tiempos de operación que, debido a su función, no todos los procesos pueden realizarse simultáneamente [25]. Según el modelo realizado por [26], el cálculo puede ajustarse con la discretización de los tiempos según espera, conexión, servicio y desconexión con sus respectivos factores de carga. Se presenta a continuación una imagen ilustrativa de las fuentes analizadas (Figura 2):

Figura 2 – Izq: Vehículos de apoyo a las aeronaves (GSE). Der: Vehículos de acceso al aeropuerto (GAV).
Fuente: Imágenes obtenidas de la web.

En cuanto a las fuentes estacionarias en un aeropuerto podemos encontrar aquellos generadores, motores, cocinas, calderas, y todo elemento que consuma, energía eléctrica, gas y/o combustible. Los valores de consumos de cada una de dichas fuentes energéticas suelen ser por lo general valores reservados entre los operadores aeroportuarios y muchas veces, sin una previa caracterización energética de todas las instalaciones e infraestructura aeroportuaria, se dificulta la incorporación en un inventario de emisiones. Sin embargo, el aporte de dichos sistemas poseen su cuota respectiva de emisiones que no pueden ser omitidas en un análisis de mayor profundidad [27].

Metodología

A continuación, se detalla el proceso para el cálculo de las emisiones de CO_2 producto de las operaciones de las aeronaves, de los respectivos GSE, los GAV y la energía eléctrica consumida para ocho aeropuertos nacionales.

- Caracterización del Aeropuerto: mezcla de tráfico, planta poder, distribución de perfiles, diarios, mensuales y anuales de operaciones. Elección del día punta del aeropuerto por el método Average day peak month (ADPM)
- Análisis de herramientas de cálculo a utilizar: determinación de cada método a aplicar en cada fuente según información disponible.
- Determinación de flota operativa, planta poder y tiempos en el ciclo LTO.
- Determinación de perfiles de servicio típico según aeronave. Análisis de todos los vehículos handling soporte de cada avión (tiempos de servicio, potencia de motores, factores de carga, etc.)
- Cuantificación de las emisiones de CO_2 de cada fuente analizada para todos los aeropuertos bajo estudio. Obtención de resultados comparativos y relativos a parámetros de operaciones y pasajeros transportados.

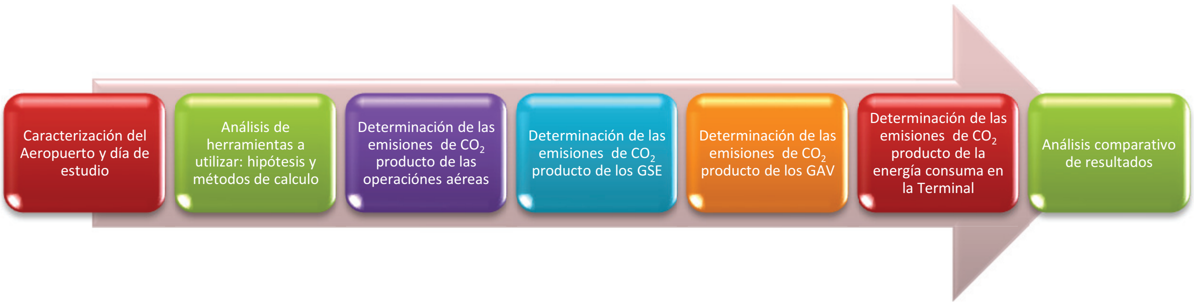

Figura 3 - Proceso lógico de trabajo para determinar la contaminación gaseosa.

Caracterización de los Aeropuertos

A partir de la información obtenida por la UIDET: GTA-GIAI del Departamento de Aeronáutica de la Facultad de Ingeniería de la UNLP, respecto a mezcla de tráfico, consumos, entre otros se procedió a la selección de ocho aeropuertos del Sistema Nacional Aeroportuario (SNA), cabe destacar que como el objetivo del presente es la obtención de índices de CO_2 se buscó un amplio rango los parámetros de Pasajeros y Operaciones por año. Se presenta a continuación los aeropuertos seleccionados (Tabla 1):

Tabla 1- Aeropuertos bajo estudio, pasajeros/año y operaciones/año.
Fuente: desarrollado por el Autor a partir de [28]

Aeropuerto	Ciudad, Provincia	Código ICAO	Pasajeros/año	Operaciones/año
Aeropuerto Internacional Jorge Newbery	Ciudad de Bs. As., Buenos Aires	SABE	13.461.580	126.612
Aeropuerto Ing. Aeronáutico Ambrosio Taravella	Córdoba, Córdoba	SACO	3.392.802	33.553
Aeropuerto Internacional San Carlos de Bariloche teniente Luis Candelaria	Bariloche, Neuquén	SAZS	1.578.312	14.062
Aeropuerto Internacional Martín Miguel de Güemes	Salta, Salta	SASA	1.124.812	12.100
Aeropuerto Internacional General Enrique Mosconi	Comodoro Rivadavia, Chubut	SAVC	679.958	10.197
Aeropuerto Comandante Espora	Bahía Blanca, Buenos Aires	SAZB	457.273	6.047
Aeropuerto coronel Felipe Varela	San Fernando del Valle de Catamarca, Catamarca	SANC	66.905	2.196
Aeropuerto Brigadier General Antonio Parodi	Esquel, Chubut	SAVE	51.603	997

Como se observa en la siguiente figura, existe una variedad en el tráfico de cada uno de ellos lo cual permitirá la obtención de índices de acuerdo a las Operaciones y Pasajeros trasportados (Figura 4).

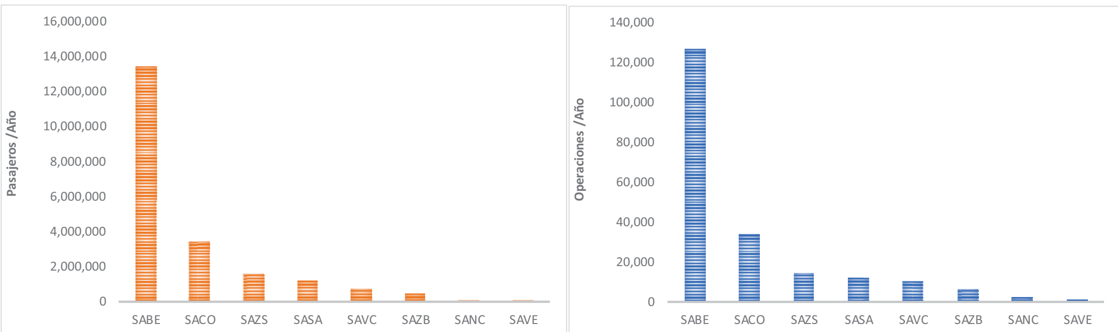

Figura 4 – Aeropuertos bajo estudio. Izq: Pasajeros/año. Der: Operaciones/año.
Fuente: desarrollado por el Autor

Figura 5 - Caracterización de las fuentes. Ejemplo: Aeropuerto Jorge Newbery (SABE).
Fuente: desarrollado por el Autor

Figura 6 - Vista aérea de los Aeropuertos de Izq. Córdoba, Der. Salta.
Fuente: Google Earth.

Emisiones de CO_2 producto de la operación de aeronaves

Las emisiones de dióxido de carbono producto de las operaciones de aterrizaje y despegue dependen principalmente de Time in Mode - TIM (segundos), los Índices de emisión del motor principal – EI, por sus siglas en inglés *Emission index* (kg de CO_2/ kg de combustible), y flujo de combustible del motor principal - FF (kg), por sus siglas en ingles Fuel Flow.

- ***Time in Mode (TIM)***: es el periodo de tiempo real donde los motores de las aeronaves operan a un reglaje de potencia identificado, normalmente correspondiente a uno de los modos de operación del LTO del ciclo de vuelo operacional.

- **Índice de emisión (EI) y flujo de combustible**: El índice de emisión se define como la masa de contaminante emitida por unidad de masa de combustible consumido para un determinado motor. El Banco de datos sobre emisiones de motores (EEDB) [29] de OACI proporciona el EI para más de 500 motores certificados, así como el flujo de combustible específico del modo en unidades de kilogramo por segundo (kg/s), para los cuatro reglajes de potencia del plan de certificación de emisiones de motores. Para el caso específico del CO_2 el **EI** es 3,157 [9].

La siguiente formula representa la base para el cálculo de las emisiones de CO_2 para una única combinación de aeronave y motor, (Ecuación 1) (2):

$$Ei_j = \sum (TIM_{jk} * 60) * (FF_{jk}) * (Ei_{ijk}) * (Ne_j)$$

Dónde:

- $Ei_j =$ emisiones totales de contaminantes i (CO_2 en este caso), en gramos, producidas por el tipo de aeronave j para un ciclo LTO;
- $Ei_{ijk} =$ índice de emisión para el contaminante i (CO_2 en este caso), en gramos por contaminante por kilogramo de combustible (g/kg de combustible), en el modo k (p. ej., despegue, ascenso, marcha lenta y aproximación) para cada motor empleado en el tipo de aeronave j;
- FF_{jk} = flujo de combustible para el modo k (p. ej., despegue, ascenso, marcha lenta y aproximación), en kilogramos por segundo (kg/s), para cada motor empleado en el tipo de aeronave j;
- TIM_{jk} = tiempo en el modo para el modo k (p. ej., marcha lenta, aproximación, ascenso y despegue), en minutos, para el tipo de aeronave j;
- $Ne_j =$ número de motores empleados en el tipo de aeronave j.

En el método de cálculo, los tiempos de cada una de las etapas del ciclo tiene asociado un valor en el consumo de combustible y por consecuencia un impacto en la concentración de los gases contaminantes. Como se mencionó anteriormente, debido a la diferencia existente entre los tiempos del ciclo LTO de referencia y el real en un aeropuerto bajo estudio, en el presente informe, analizando las velocidades de carreteo, aproximación, distancias y tiempos de taxeo, se adaptaron las condiciones operativas de cada aeropuerto a fin de cuantificar con mayor precisión las emisiones.

Emisiones de CO_2 producto de los GSE

Para la cuantificación de las emisiones producto de los GSE, se utiliza la metodología simplificada utilizando el número de llegadas, salidas o ambas de las aeronaves según tipo de fuselaje. Es un enfoque en donde no se realiza un análisis de las operaciones de los vehículos de asistencia y utiliza los factores de emisión proporcionados por el Aeropuerto de Zúrich, Suiza [30], cuyos valores varían según el tipo de fuselaje de cada aeronave (Tabla 2).

Tabla 2 - Ejemplo de los factores de emisión del CO_2 para los GSE en el Aeropuerto de Zúrich.
Fuente: [30]

Contaminante	Unidad	Tecnología 1990-2005		Tecnología 2000-2015	
		Fuselaje angosto	Fuselaje ancho	Fuselaje angosto	Fuselaje ancho
CO_2	Kg/ciclo	18	58	20	48

Las emisiones se calculan entonces multiplicando el número de movimientos según la caracterización de las aeronaves (tipo de fuselaje) con el factor de emisión del CO_2 correspondiente (Ecuación 2):

$$Emisiones\ (kg) = M * fe$$

Dónde:

- *fe: factor de emisión según tipo de fuselaje (kg de* CO_2*/ciclo)*
- *M: cantidad de movimientos de las aeronaves*

Emisiones de CO_2 producto de los GAVs (Ground Access Vehicles)

Para el análisis del aporte contaminante producido por la operación de los vehículos de acceso terrestre denominados en su conjunto como GAV (*Ground Access Vehicles*), es necesario establecer distintos parámetros que definirán los casos de estudio. El proceso de cálculo requiere de:

- Determinación de distancias de los segmentos de rutas de acceso.
- Determinación de porcentajes de circulación vehicular por mezcla de flota y por tipo de combustible.
- Determinación de la cantidad de kilómetros transitados de la mezcla de flota vehicular.
- Factores de emisión de cada contaminante en unidades de masa por kilómetro transitado.

Como se mencionó previamente, se discrimina la flota vehicular en 3 tipos: vehículo de pasajeros, vehículos de transporte livianos (taxis, remises, VANs, entre otros) y vehículos de transporte pesados (buses, trenes, subterráneos, transfer, entre otros). Este a su vez se subdivide según tres tipos de combustible gasolina, diésel y gas natural comprimido (GNC).

La cantidad de kilómetros transitados por la mezcla vehicular (VKT: *Vehicles Kilometers Traveled*) es estimada a partir de datos del año 2017 otorgados por Organismo Regulador del Sistema Nacional de Aeropuertos [31], en el cual se presenta la cantidad de pasajeros anual y porcentajes de modos de acceso. Se presenta a continuación los cálculos a realizar a de acuerdo a la metodología planteada (Ecuación 3):

$$E_{total} = (RL_1\ x\ NV_1\ x\ EF_1) + (RL_2\ x\ NV_2\ x\ EF_2) + \ldots (RL_n\ x\ NV_n\ x\ EF_n\ )$$

Dónde:
E_{total}: total de emisiones de CO_2 en cada segmento de ruta de acceso
RL_n: longitud de ruta de acceso *n*
NV_n: cantidad de vehículos que transitan en la ruta de acceso *n*
EF_n: factor de emisión del CO_2 considerando tipo de flota vehicular, según base de datos "emission factor for green house inventories" en la ruta de acceso *n*

Tabla 3 - Porcentaje de modos de acceso a los aeropuertos bajo estudio.
Fuente: [31]

Aeropuerto	Ciudad, Provincia	Taxi	Automóvil particular	Transfer	Transporte público (bus)
Aeropuerto Internacional Jorge Newbery	Ciudad de Bs. As., Buenos Aires	61	23	10	6
Aeropuerto Ing. Aeronáutico Ambrosio Taravella	Córdoba, Córdoba	43	53	2	2
Aeropuerto Internacional San Carlos de Bariloche teniente Luis Candelaria	Bariloche, Neuquén	38	38	4	20
Aeropuerto Internacional Martín Miguel de Güemes	Salta, Salta	54	39	3	4
Aeropuerto Internacional General Enrique Mosconi	Comodoro Rivadavia, Chubut	47	47	5	1
Aeropuerto Comandante Espora	Bahía Blanca, Buenos Aires	47	47	5	1
Aeropuerto coronel Felipe Varela	San Fernando del Valle de Catamarca, Catamarca	47	47	5	1
Aeropuerto Brigadier General Antonio Parodi	Esquel, Chubut	47	47	5	1

Emisiones de CO_2 producto del consumo eléctrico (FE)

Siguiendo los lineamientos de la IPCC [32], los utilizados por distintas organizaciones validadas a nivel internacional como ACI (Airport Council International) en su programa ACA (Airport Carbon Accreditation) se utiliza como base la normativa internacional [33] para el cálculo de las emisiones producto del consumo eléctrico en cada aeropuerto bajo análisis. El método de cálculo aplicado consiste básicamente en (Ecuación 4):

$$Emisiones\ (kg) = ef * cc$$

Dónde:

- *ef:* factor de emisión del CO_2 *(kg de* CO_2*/kWh)*
- *cc: Consumo eléctrico anual (kWh)*

Al igual que ACI, se adoptó un factor de emisión aceptado y validado en distintos estudios [34], el cual surge de la matriz energética propia de cada país. El valor adoptado para Argentina es de 0.391932833 ($kgCO_2$/kWh).

Resultados

Se presenta a continuación los resultados obtenidos mediante la aplicación de la metodología mencionada (Tabla 4):

Tabla 4 - Toneladas de CO_2 emitidas en los Aeropuertos bajo análisis, Escenario 2018
Fuente: desarrollado por el Autor

	SABE	SACO	SAZS	SASA	SAVC	SAZB	SANC	SAVE
Consumo eléctrico	10.642	3.895	937	1.126	424	296	196	61
GAV	24.983	6.891	2.194	2.140	1.147	651	190	184
Aeronaves	328.193	86.643	43.917	29.398	15.098	57.744	6.284	2.013
GSE	2.208	631	276	237	205	473	39	19
Total	**366.026**	**98.061**	**47.324**	**32.900**	**16.874**	**59.163**	**6.710**	**2.277**

De manera comparativa se presenta en la siguiente imagen las emisiones de CO_2 de los aeropuertos bajo análisis con mayor y menor operaciones y pasajeros transportados anualmente (Figura 7).

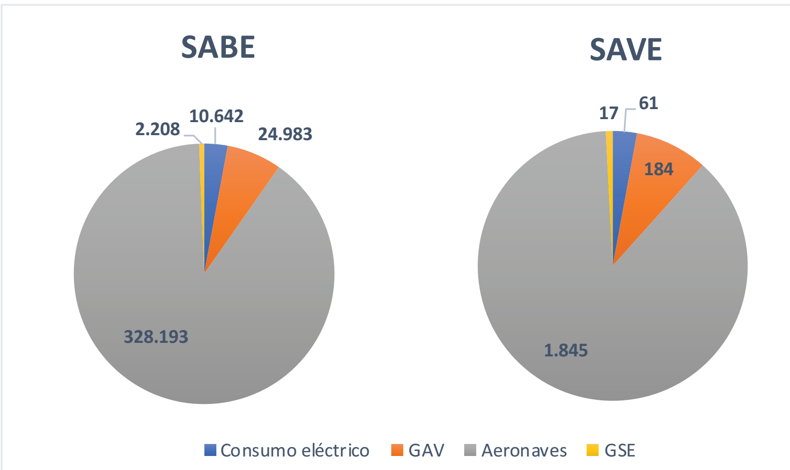

Figura 7 - Toneladas de CO_2 emitidas en Aeroparque (SABE) y el Aeropuerto de Esquel (SAVE). Escenario 2018
Fuente: desarrollado por el Autor

En la siguiente imagen se presenta los valores medios de las emisiones teniendo en cuenta las fuentes bajo análisis (Figura 8).

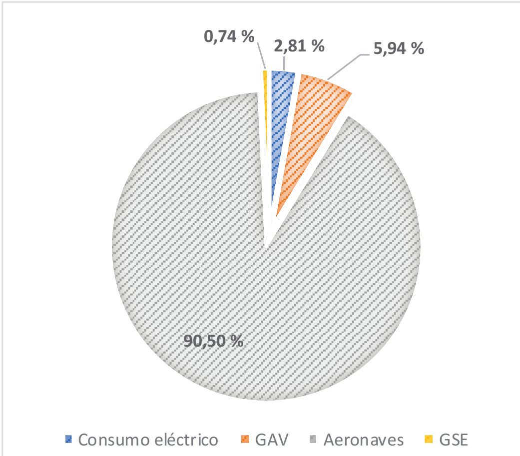

Figura 8 – Valores medios de emisión CO_2. Escenario 2018
Fuente: desarrollado por el Autor

Con el fin de obtener un índice de emisiones de CO_2 respecto a las operaciones y pasajeros transportados por año, se presenta en los siguientes gráficos un análisis comparativo para los distintos aeropuertos (Figura 9 y 10).

Figura 9 – Índices de emisión CO_2. Izq: según miles de pasajeros transportados. Der: según operación. Escenario 2018
Fuente: desarrollado por el Autor

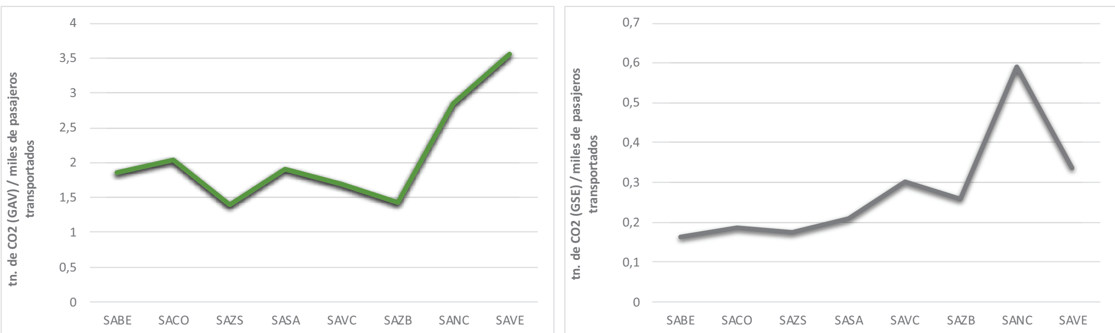

Figura 10 – Índices de emisión CO_2 según fuentes bajo análisis. Izq: GAV. Der: GSE. Escenario 2018
Fuente: desarrollado por el Autor

Conclusiones

A partir de los resultados obtenidos se puede observar como en la totalidad de los aeropuertos analizados, el aporte de dióxido de carbono debido a la operación aeronáutica ronda el 90%. Independientemente de la cantidad de operaciones, los pasajeros transportados y del tipo de aeropuerto, dicha fuente es la causa principal de las emisiones analizadas. Como se presenta en la Figura 10, únicamente en las fuentes caracterizadas como GAV y GSE se presenta un leve aumento en el índice desarrollado. Analizando los resultados obtenidos, se observa como los aeropuertos con menos de 500 mil pasajeros transportados (10 mil operaciones por año), poseen casi el doble de las emisiones en dichas fuentes.

Debido a la cantidad de variables que influyen en las emisiones de cada una de las fuentes, es difícil su completa caracterización con el fin de obtener resultados parciales que permitan obtener conclusiones a priori. Por ejemplo, es posible mejorar los resultados obtenidos analizando horarios de apertura del Aeropuerto, hay casos aquí estudiados en que el aeropuerto sólo abre unas pocas horas con el fin de abastecer una u dos operaciones por día. Si bien el análisis de 8 aeropuertos permite tener un orden de magnitud de las emisiones por fuente, es importante incluir más aeropuertos para mejorar los índices aquí desarrollados.

Para completar el inventario de emisiones gaseosas producto de la actividad aeroportuaria es necesario el análisis de aporte contaminante de otras fuentes presentes en el aeropuerto ya sean: estacionarias, móviles, discretas o continuas, según tipo y características de operación (según modelos de gestión) en el contexto de las configuraciones de las infraestructuras e instalaciones de la parte aeronáutica, en la parte pública, y en los elementos de apoyo al aeródromo. En el presente informe no se han analizado las fuentes de emisiones que consumen energías alternativas como puede ser: gas natural, biomasa, entre otros. El valor representado por las emisiones de los vehículos de asistencia es coherente con los estudios realizados previamente, sin embargo, podrían ser más precisos si se contara con un inventario de la flota para cada aeropuerto, el consumo de combustible total por los GSE, el número de horas de funcionamiento para cada tipo de servicio y de uso histórico, el tiempo de funcionamiento de cada unidad, entre otros.

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Air Transportation Sustainability Strategies: Technological, Operational, Economic, Social and Environmental.

Planning and Policy Economic Strategies

Comparing proximity for couples of near airports: different case studies on city - airports

Alessandro Massaro - a.massaro.a@gmail.com
University of Parma

Silvia Rossetti - silvia.rossetti@unipr.it
University of Parma

Abstract
Evaluating proximity's influences the development of small Airport-Cities in European Remote Regions. Different couples of city-airports will be studied to understand if the proximity could be an advantage for the investments.
The methodology examinates the changes in the plans of the different Airport-Cities given by the touristic traffic and how they affect the GDPpc of the regions and the cities in which they are placed, using the GIS evaluation to enhance urban areas performance. Ordinary Least Squares regression (OLS) to enhance the relationships among the different expectations of each analyzed city and Geographically Weighted Regression (GWR) to verify the model for every single studied airport.
Enhancing the relationships among the different expectations of each analyzing city and to verify the model for every single studied airport, the search tries to evaluate what are the benefits deriving from near airports for the remote Regions of Europe.

Keywords
Airport-City; Distances; Urban Development; Economic Development

Comparing proximity for couples of near airports: different case studies on city-airports

1. Airports, cities and economic development

1.1 Airport-city development: a quick overview

From the existing literature on this topic, it emerges clearly that airports and city development are strongly intertwined [1], [2], [3], [4]. In this paper, we underline the relationships between the touristic traffic of some airports[1] and the related development of the cities in which they are placed. The chosen case studies regard different remote regions of three different countries (Italy, Norway, Cyprus), considering couples of near airports [5]. To describe the differences among the different couples of airports we have utilized a GIS software, underpinning the differences on each network system derived, then on the different touristic and city economic development [6] [7], [8] [9]. Managed by the GIS analytical evaluation, the purpose of this paper is to give support to the different theories about the development of couples of near airports, using geographic tools to support economic and financial planning. The paper adopts a transversal approach, focused on the regional planning point of view, but instrumental for the airport development, so for airliners market and for urban planning.

1.2 Couples of airports of medium and small size

The paper focuses the analysis on four couples of near airports, two from the South of Italy (Bari and Brindisi in the Apulia Region; Palermo and Trapani in Sicily), one in the North of Norway (Bødo and Narvik in Hålogaland) and the last one in the Republic of Cyprus (Larnaca and Paphos). By this way, different remote types of islands and regions are included in the analysis to assess the different weight of the touristic traffic on the economic development of different couples of city-airports and to help the evaluation about the diverse types of perspective growth. Since in every couple of airports, there is one bigger airport, we gave different indicators to the different relation systems: competition and cooperation are always defined by the specific region in which every airport is placed. So, in the GIS tool, we referred to different population catchments areas and this is in the target of the different economic patterns derived. For each couple of airports, the GIS system analyzes the distance between airports and facilities, improving travel times before and after the investments in the terrestrial and in the aerial route network system, discovering the future population catchment areas and highlighting the differences.

1.3 The adopted comparing growth methodology

The influence of and on the different types of distances were analyzed both from the physical and from the regulatory point of views. Therefore, travel distances from, to and into the regions were compare to the distances among the different cities and airports development plans in the deregulation processes. From the consequent grid, the distances with a stronger impact on economic development were choose to compare the different areas.
The adopted GIS system derives from the evaluation of the specific cultural territorial systems [10], [11], [12], [13] and their proper relationships with the economic and financial systems [14], [15], [16], arguing to estimate the geographical patterns of the financial evaluation [17], [18], [19] and, defining specific direct linkages between aerial and terrestrial routes. The infrasctructural network system was shaped to carry out accessibility analysis,

[1] The analyzed airports follows, the Country ISO Code (International Standardization Organization), the International Air Transport Association code and the International Civil Aviation Organization code are specified: 1) Bari Airport (IT, IATA: BRI, ICAO: LIBD), or Airport Karol Wojtyla, formerly Palese-Macchie Airport; 2) Brindisi-Papola Casale Airport (IT, IATA: BDS, ICAO: LIBR) or the Salento Airport; 3) Falcone Borsellino Airport (IT, IATA: PMO, ICAO: LICJ) or simply Palermo Airport, formerly Punta Raisi Airport; 4) Vincenzo Florio Airport Trapani-Birgi (IT, IATA: TPS, ICAO: LICT), also known simply as Trapani Airport; Bodø Airport (NO, IATA: BOO, ICAO: ENBO); Harstad/Narvik Airport, Evenes (NO, IATA: EVE, ICAO: ENEV); Larnaca International Airport (CV, IATA: LCA, ICAO: LCLK); Paphos International Airport (CV, IATA: PFO, ICAO: LCPH).

estimating the overserved and underserved parts of each city and country. By this way, the system highlights the accessibility patterns changes related to the investments made and in perspective, spatializing the analogies and divergences among the different couples of airports. The research is not complete yet, and some couples could be added to stress the results and the final considerations about the meaning of the comparison made. However, this paper represents a first assessment. Data about the average population density were mapped to understand the territorial average of population Gross Domestic Product (GDPp.i). Thus, investments on the transport system were used to locate the new areas covered by the services and the likely attraction areas, and their weight in the evaluation of development. Improving the numbers of couples gives to the system the possibility to evaluate the needs of Public Service Obligations (PSO) to guarantee the equilibrated survival of each airport in the growth, and, in other terms, to assess if the cooperation and competition can be sufficient to design a common development [20], [21], [9]. Travel times and speed path were used to describe every route, terrestrial, maritime (coast ship) and aerial. The frequency of population transported by the different transportation modes types became the tool to understand how much catchment areas change during the year and according to the weight of tourism in different airports. Once again, comparing the differences among the couples, it is also possible to derive new possibilities for the aerial route system management.

2. Different couples of airports around Europe: case studies analysis

2.1 Elements about the case studies chosen

Table 1 – *Main features of the analysed airports and of the areas in which they are located*
Source: Authors

SPECIFICATIONS	COUPLES OF AIRPORTS			
	BRI	PMO	BOO	LCA
	BDS	TPS	EVE	PFO
Size of the Area (kmq)	12.500 [1]	10.500 [2]	44.800 [3]	12.800 [4]
Density Population in/kmq (2018 average)	263,12	189,42	10,42	133,87
GDPp.i. (2016 average)	17.565	7.679	41.614	32.002
Distance among the Airports (km)	112	70	170	105
Distance from city-center (km)	9,00	22,40	1,00	5,70
	1,00	11,60	31,00	5,00
PAX (2018)	4.685.996	5.163.103	1.903.944	8.067.037
	2.320.839	1.492.228	739.220	2.872.391

[1] The area correspond to the whole Apulia Region without the administrative territory of the Province of Foggia; [2] The area correspond to the three administrative territories of the three Provinces of Trapani, Palermo and Agrigento; [3] The area, the largest, is between Trømso and Bodø, with Narvik in the middle, part of the study considers 1/3 of that; [4] The entire island.

The couple of airports (Table 1) involved in the analysis were chosen to give an exaustive panorama of the European network system in its remote regions, developing a research activity that begun in 2018 [22], [23], [24]. Specifically, the analised case studies belong to different countries, with different airport systems, and with different economic indicators regarding the touristic traffic and the economic growth. The case studies in the remote region of South Italy assess for the same country, the differences between two airports on the land managed by only one company (Apulia Airport managing Bari and Brindisi Aiport) and two airports on an island (Palermo Airport and Trapani Airport, in Sicily, the major island in the Mediterranean sea). On the other hand, the example of Northern Norway involves two airports on the coast and their links with a lot of other smaller airports on the close Lofoten Islands, in a country with a continuos growth of GDP p.i.. In the last case study, the airports of Cyprus show a great example of touristic flow directly associated to an island (the third largest in the Mediterranean sea).

2.2 Italian Airports: Bari and Brindisi (Apulia Region)

The first couple of airports is located in the south-eastern part of Italy, in the cities of Bari and Brindisi. Italian airport system is well described in the National Transport Plan [25], which takes into consideration the particular geographic shape of the country. In the Apulia Region the four airports (Figure 1) with passenger traffic are all managed by Aeroporti di Puglia (Apulian Airports) for the period 2012-2040. The most important feature of the system is its strategic location in the Mediterranean sea and the most recent passenger traffic growth related to the two airports in this analysis, where Bari Airport has twice the traffic flow of Brindisi Airport. There is a plan related to the specific functions of any airport of the Apulia Region. The Company has a good financial statement, probably thanks to its regional but independent market dimension. Some different issues, related to the cash flow and maintenance costs, could be an asset to the same topic. Municipalities' involvement in the decision making process could be enforced, solving mobility issues to enlarge the investment capability for the airports growth, above all for the Brindisi airport equilibrate growth and for the related under-served Salento territory.

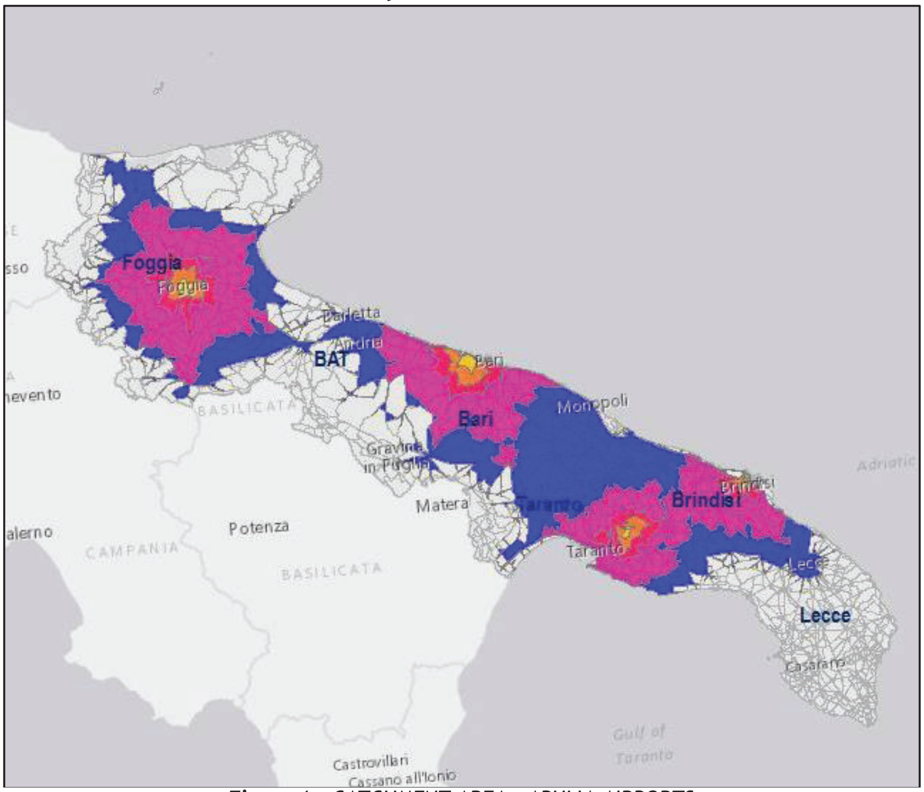

Figure 1 *- CATCHMENT AREA - APULIA AIRPORTS*
Source: Authors

2.3 Italian Airports: Palermo and Trapani (Sicily Region)

Palermo and Trapani airports are managed by two different companies in which the Region has the predominance. In the biggest island of the Mediterranean sea, there are two of the most important airports of Italy: Palermo and Catania (Figure 2). Over the huge difference with Palermo, Trapani Airport managed an impressive growth in recent years, related to the Low Cost Carrier (LCC) Ryanair. The same LCC finds a good market in Palermo as well. Since last year Ryanair abandoned Trapani Birgi Airport for some territorial administrative issues, also related to the geographical and administrative location of the Birgi Airport. However, the presence of Ryanair in the last decade underpin the capability of Trapani Touristic traffic and strengthed the linkage between the growth of airport traffic flow and the growth of the economy of the two provinces of Trapani and Marsala. Nowadays, the survival of the Trapani airport could be linked to the unserved middle south areas of the whole region. By this way, the last financial statement of the Airgest ltd has a positive growth in recovering the quick indebdment.

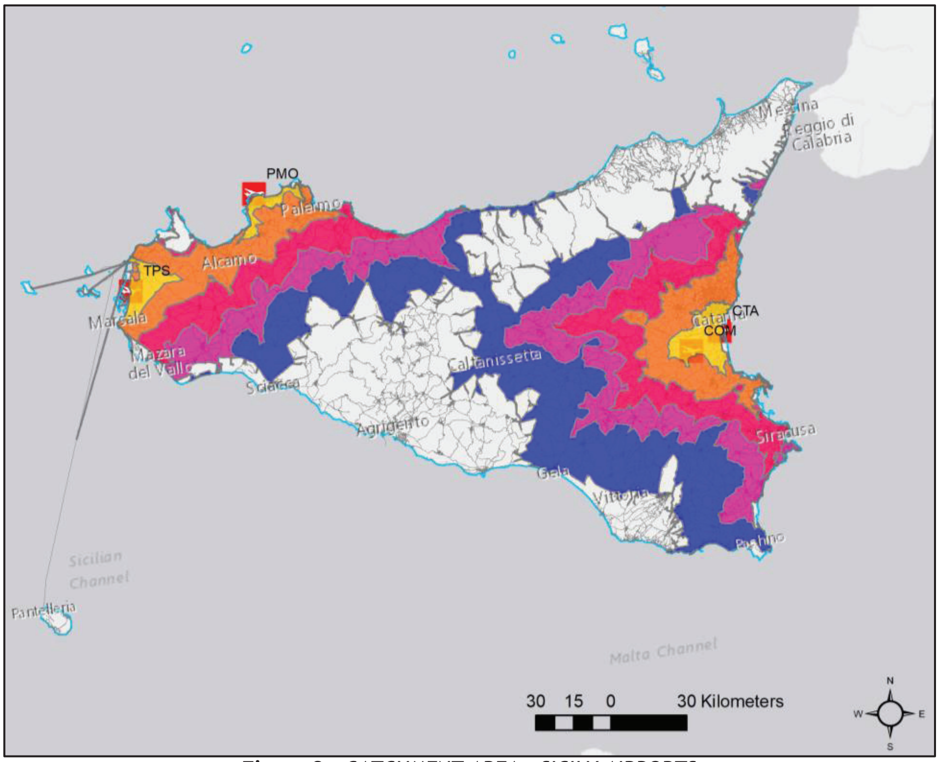

Figure 2 *- CATCHMENT AREA - SICILY AIRPORTS*
Source: Authors

2.4 Norwegian Airports: Bodø and Narvik (Hålogaland Region)

In the Hålogaland, a part of Nordland and of Trøms Regions, the Nordern Norwegian Airport system becomes thicken, increased by the traffic of two airports (Bødo and Trømso), even in an area of low population density, but with a huge regional GDP p.i.. Considering also the other two smaller airports in the area with a bigger touristic traffic flow in the last decade, the system could be divided in two couples: Trømso and Bardufoss on one side; Bodø and Narvik on the other side. Furthermore, there are connections with other seven smaller airports in the surroundings (Figure 3). The company that manages almost all the airports of Norway is Avinor ltd, that participates in the important investments on the Bodø airport and Bodø city redevelopment plan, following the core of the Norway Transport Plan decisions. Avinor has a good financial statement, one of the best, but a lot of airports and airliners are terminated in the whole country in the years. The recent investments in the route transport system end to advantage the shortest journey to the airport. In this direction, Narvik risks being one of the more requested places in the future, when the Lofoten road system will be modernized. The issue becomes relevant if it is related to the risks for the Bodø investments, because it could defeat the modernization of the roads.

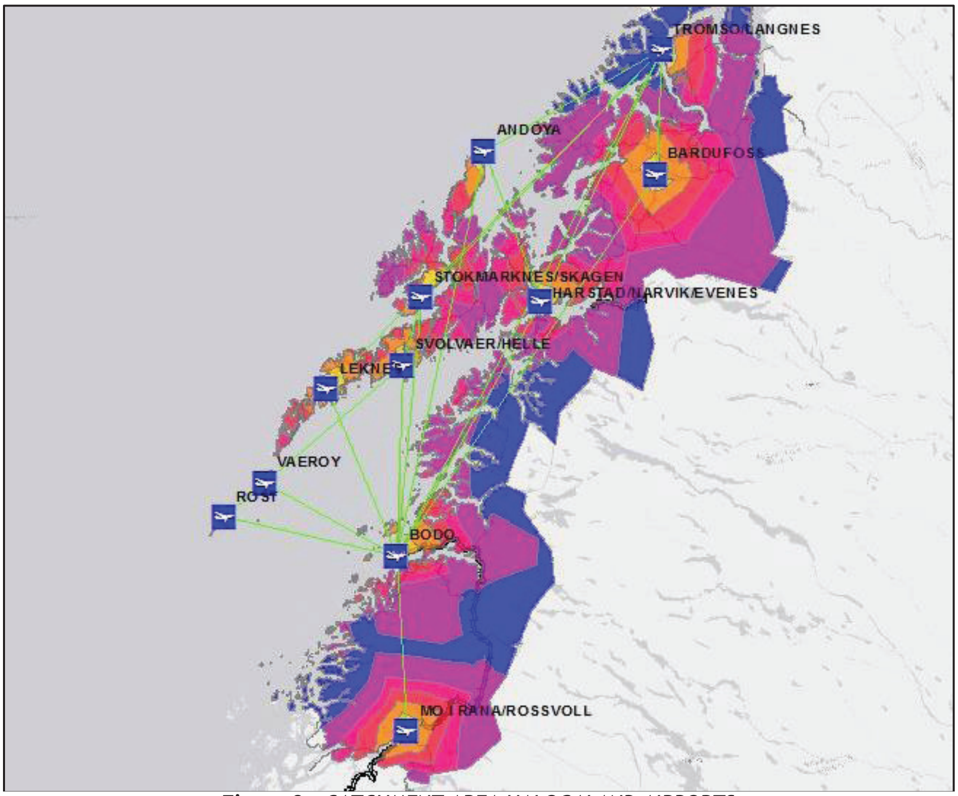

Figure 3 *- CATCHMENT AREA HALOGALAND AIRPORTS*
Source: Authors

2.5 Cyprus Airports: Larnaca and Paphos (Greek Cyprus Area)

In the area controlled by Cyprus Government (Greek Cyprus Area), the third largest and most populated island of the Mediterranean Sea, two airports with constant growth in the last years coexist: Larnaca and Paphos (Figure 4). The growth was managed without a National Transport Plan. But due to geographical conformation of the Island the roadway, shipway and air transport systems' development improved. The airports are managed by an international consortium of 9 shareholders, the Hermes Airport Ltd (concession agreement with the Republic of Cyprus), a company registered in Cyprus. France's Bouygues Batiment International is the owner of 21.99% of Hermes Airports. The passenger traffic flow of the two airports is bigger than all the other couples analyzed in this paper. In the last year, the two airports have carried almost 11 millions of passengers (8,067,037 Larnaka and 2,872,391 Paphos). The relevant growth appears as a result of competition among the shareholders, as between the bigger ones, France and British Companies. But, competitiveness enlarges the weight of market and the relative foreign investments can be crucial for tourism development. However, a coordinated general plan for transports for the entire island is needed.

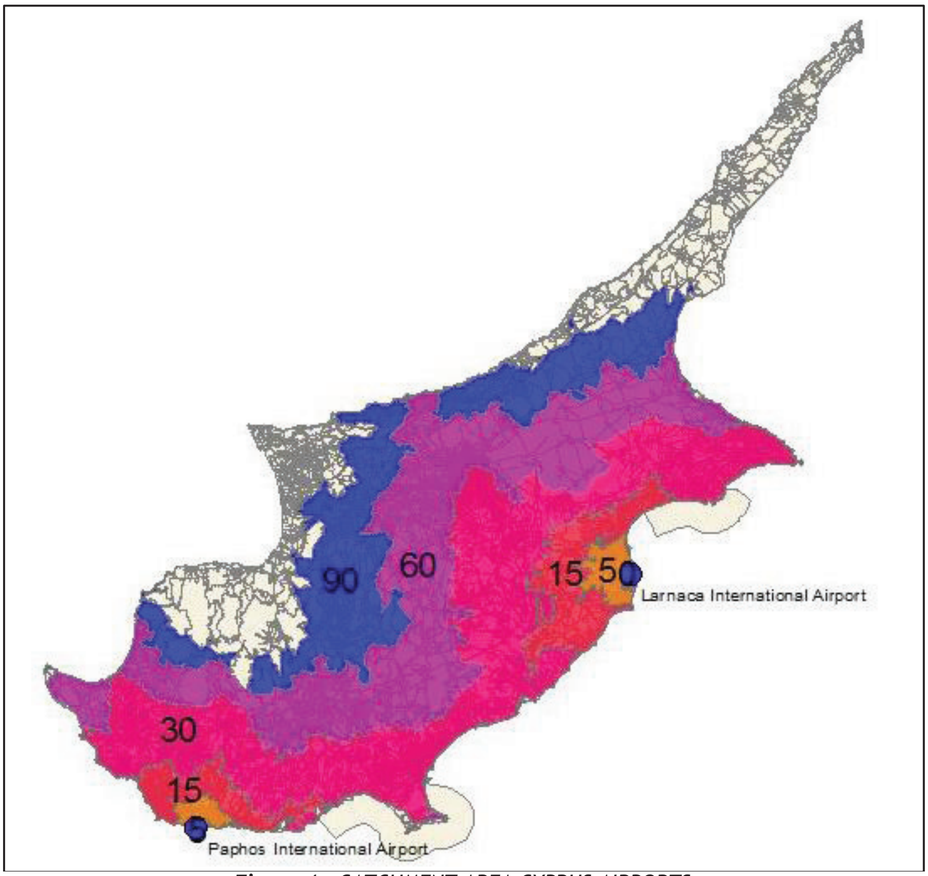

***Figure 4** - CATCHMENT AREA CYPRUS AIRPORTS*
Source: Authors

3. Distances and Urban Development

3.1 Couple’s relationships

The analysis of the different couples of airports focused on some useful elements, and tools for further evaluations. In order to the assess the economic weight on airport dimensions, the percentage of the touristic traffic flow by transport and distances between airports, help to understand the touristic dimension in each country, underpinning the differences between every couple of airports analyzed.

One step below, travel-time measurements and catchment areas help to discover the shortest distances between airports, urban areas and the surrounding opportunities like hospitals, ports, and main tourist facilities. The accessibility approach estimated travel times regards the different trajectories before and after the investments on airports and network infrastructures. Moreover, in this way it was possible to understand the relationships between the different transport systems, giving an evaluation in order to the specific needs of the different areas analyzed.

Giving an answer to the weight of most involved areas, the percentage of investments have been related to the dimension of the involved catchment areas. Thus, differences between the percentage growth of expenditures in the years in transport system and investments in transport system have been managed as a first step in depicting possibilities for the under served areas.

Following dimensions of involved catchment area explicated by shape area, inhabitants density, municipalities, GDP p.i, have been used to describe the settlements, highlighting similarities and differences.

The features regard the different planning systems and indicators of evaluation, at last, have been used to understand the most similar features for each couple, related to each investment's plan (as well as ongoing plans).

3.2 Evaluation of the results

Patterns of GDP p.i.,airports catchment area and hospitals catchment area are used for the evaluation of investments. Intersections between the different time buffers show the interactions among the different catchment area, and the weight of population density indicates the relationships among the different needs (healthcare demand and travel speed demand).

Evaluation of peaks and overserved areas and relative measurement of underserved areas are useful to understand the needs of planning perspectives.

Planning systems and cooperation are the mainstream of the entire GIS evaluation conducted, which divides functions into different areas, determining the flow of investments, the needs of PSO and the weight of cooperation, as well as the different shapes of route system utilization. Within this framework, the value of overlapped zones acquires extreme importance, subordinated to specific constraints and related particular laws. Even more, it is useful to detect the role of each smaller airport in every couple.

Differences between PSO and airports competition becomes the element to assess the functioning of the system and the weight of relationship among each airport couple in each specific economic system.

Route density, location-allocation demand for tourism and health are at least utilized measures.. Route density helps in detcting the most utilized parts of each region, modelized on the specific transport use. In Hålogaland, for example, it becomes most important the system of aerial routes between the different airports, instead of in Sicily, where the density of terrestrial routes acquires the main role. Location allocation for tourism facilities is related to the capability of the area to absorb the impact of tourism development, and highlights the most relevant corridors for investments in the real estate too. So, improving the number of needs, we used the health demand, to link the airport's cooperation to the underserved areas.

3.3 A qualitative S.W.O.T. Analysis

As a results of the conducted analysis, a qualitative SWOT analysis was drafted and it is shown below (Table 2). The analysis considers the different indicators to highlight the common elements on the four airports couples analyzed.

Table 2 – *Qualitative S.W.O.T. Analysis*
Source: Authors

Strengths	
Traffic PAX growth	The increase of passenger traffic is an asset for the business of every couple
Geographic Situation	Every couple has a central location in its particular country system. The couples of airports are in remote regions, but their isolation stress their main role in the specific area
Export Statement	Positive value of the export business gives both Trapani and Marsala a relevant role in the Siciliy Region
Smallers' Capacity Building	With their specific location the smaller airports of every couple can be improved: the possibility of using undeveloped areas and to improve the runways development appear an evidence
History	In every couple of airports there is a strong linkage between the city and its airport's history
Weaknesses	
Accessibility	All the airfields suffers from limited accessibility. Also in the analyzed areas the transportation infrastructure is not sufficient to the accessibility development.
Setting up network connections	Disproportional surge in tourist traffic as well as a shortage of transport infrastructure create a barrier to keeping part of the

	transit tourist flows
Smaller Building capability	The terminal and the apron of the smaller airports of every couple should be adapted to the needs
PSO	Many airports needs PSO to survive
Opportunities	
Comprehensive Networks building	Systems of different airports show the possibility to cooperate in growing impact assessment, subdividing functions and roles, and understanding the needs of their placement areas
Terminal Building	Despite of the last adjustment, the Terminals of smaller airports needs to be settled for the growth and the role
Network attractiveness	A joint management for both airports may satisfy more effectively the urge of the area for the airlines business, thus triggering a key role for smaller airports of the couples
Transport Linkage	To link between port and/or railway station to the Airports could change the attitude, but it should be accompanied by a better public transport service, which could be easily assured by bus. So we could differentiate the couples, understanding the landscape attitudes, but the investments should be addressed to strength the role of every airport in each couple, targeting different catchment areas using specific needs.
NATO Base	NATO activities can bring additional traffic demands to the Airport
Environmental development	The Airports are situated close to the Sea, on different distances from the urban centers of the cities. Despite the heterogeneous scale of distances, further resources could be mobilized integrating economic development with valuable landscape, under a comprehensive policy of tourist resource development
Threats	
Empiric attitude and short period interventions	The business catchment area strategy finds its basis in new tourist routes. A problem-solving strategy apparently depends on economic reasons only.
Unbalanced Managerial Systems	The four couples are affected by unbalanced managerial systems, where there is the predominance of private interests, as well as where there is the predominance of one only superordinate owner
Underestimate of environmental risks	In each couple of airports there are risks without a direct linkage to plans, or not completely addressed by investment solutions
Further urban development in dangerous areas closed to the runways	At least one airport for each couple present close areas, and this stresses the dangerous impact, an obstacle for those areas to become integrated in the city
Military Aviation	All the couples are affected by military problems

3.4 Conclusions

This paper underlined the relationships between diverse couples of close airports and evaluated the relationships between distances and urban development. Diverse planning systems are experienced in different areas and the constraints increase the specific characters of every area. Obviously, investment perspectives are focused on the overcoming constraints, but the absence of a comprehensive design plan stresses the overlapping effects, above all on the airports' fringe areas. The case of Cyprus, without a National Transport Plan, is emblematic on this stage, where nowadays still resist areas without rights and where tourism impact risks to be fatal on the environmental future. With other shades, the other couples of airports are affected by unbalanced planning systems. Even if the Apulia Airport System seems to be different, with the strategic ownership of the whole number of the civil airports in only one stock company, the effects of the private ownership affected the relationships between the airport and the city (Brindisi). The needs of a balanced planning system are also clear in the opposite model, in Norway, where centralized superordinate ownership participates in the investments on the road system and it seems that could be an advantage. But, the investments on roads have caused airports and airliners closure in the recent past, so more attention have to be put in the territorial dimension of a more balanced system. Solving problems for an airport and a city must press the collaboration among the two airports, giving positive effects to the airline competition. The analysis on the Sicily Airport System underlines, more than the others, the importance of the underserved areas and the economic evaluation about the most distant clusters of the catchment area. Therefore, it seems that the strengthening of the relationships between the different airports of each couple can give more possibilities to an equilibrate growth. The methodology should contain

diverse functions for the two airports, to give more possibilities to airliners in market diversification, using the local strongest transport system as a tool to enforce the cooperation linkage and enlarge the GDPp.i. capability growth.

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Infrastructure investment analysis under uncertainty: an application to airport planning

Álvaro Costa - afcosta@fe.up.pt
CITTA - Research Centre for Territory, Transports and Environment, Faculty of Engineering, University of Porto
Carlos Oliveira Cruz - oliveira.cruz@tecnico.ulisboa.pt
CERIS, Department of Civil Engineering, Instituto Superior Técnico, Universidade de Lisboa
Mario Coutinho dos Santos - mcsantos@autonoma.pt
University Autonoma of Lisbon
Rui Neiva - ruimiguelneiva@gmail.com
Ricardo Energy & Environment, Harwell

Abstract
Investing in large transport infrastructures, as is the case of airports, is a risky venture exposed to significant uncertainty factors. Ridership volatility is one of major concerns for authorities, public policy makers, regulators, investors, and other stakeholders.
Traditional airport planning paradigms, based on master plans and deterministic forecasts, seem inappropriate to deal with highly volatile environments. To try to overcome those sources of uncertainty, and consequently of risk, concepts like flexible design of projects have arisen. In highly volatile markets, airports should dynamically adjust to a changeable environment, and create reliable links to the air transportation value chain. This paper analyzes the economic value of a flexibly design.
Our analysis was conducted under a real option framework, and was empirically implemented in a Portuguese airport case study, and estimates the value underlying the flexibility in the design of different airport subsystems.
The model can be regarded as a support system, able to help decision makers and project managers in strategic and tactical decisions regarding airport infrastructure project design, construction, and operation. The main contribution is a real application of the concepts and the results were endorsed by the public policy in the choice of the airport capacity expansion.

Keywords
Real options; Flexibility; Airport design

Infrastructure investment analysis under uncertainty: an application to airport planning

I. Introduction

After World War II, airlines were mostly state-owned, operating in a highly regulated and relatively stable and predictable environment. Under these institutional and market conditions, airlines and airport owners alike, could assume future development commitments based on long-term forecasts, because conditions would not deviate significantly from what they had been in the past [1].Exogenous economic shocks in the 1970s, induced substantial changes. Because of deregulation, airlines began facing more intense competition, which lead during the last decades, to bankruptcy filings, reorganizations and even liquidations. Likewise, airports started competing for airline increasingly deregulated traffic [1], [2]. Traditionally, the development planning of infrastructure projects, such as airports, has been mostly based on master plans supported on civil aviation forecasts [3]. However, increased deregulation and liberalization in civil aviation markets, the emergence of low-cost passenger carriers (LCC), among other factors, may have rendered this deterministic approach inappropriate and even imprudent. Therefore, a new approach able to incorporate flexible design, development and valuation of airport infrastructure and their subsystems projects to cope with uncertainty, is needed (e.g., [1], [4], [5]). Decision-making on airport projects has been predominantly based on the standard discounted cash flow (DCF) analysis. This static, deterministic, and inflexible approach to investment valuation, clearly overlooks economic value creation associated with managerial flexibility post go-decision actions. To overcome the limitations of this capital budgeting model, the paper examines the effects of incorporating managerial flexibility in the economic valuation of infrastructure projects under uncertainty, through the lens of a real option analytical framework, studying the case of an airport capacity expansion investment in the Lisbon metro area.[1] Results of the analysis show that flexibility associated with real options in large-scale capital-intensive projects, may improve the accuracy of the economic valuation of such projects. The paper is organized as follows: the following section discusses issues related to airport development and valuation. Section 3 presents the background for applying options pricing theory. Model specification and parametrization, and results are presented in Section 4. The paper ends offering a summary of conclusions and some public policy considerations.

II. Airport development and valuation under uncertainty

Master planning is a standard practice in airport design [8].[2] A major problem associated with this approach lies in demand forecast which, as abundant anecdotal evidence suggests, typically (and sometime grossly), overestimates future traffic, which usually induces non-negligible implications in terms of negative externalities [9]. The traditional method of designing complex engineering systems, such as an airport master plan, too often focus on a deterministic view of the environment in which the system operates. In an uncertain world, flexibility is a major attribute that can result in the success, or not, of a project, though. It can take advantage of unexpected upside opportunities, and/or reduce exposure to downside risks [10].
The higher the uncertainty on a project value-drivers, the more valuable is the flexibility to adjust to unanticipated changes on the set of assumptions underlying the go decision on the project. Therefore, it is especially valuable for major, unique, irreversible, and long-term investments, which future prospects are more difficult to forecast [11].[3]

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[1] According to [6] «the assumptions and conditions necessary to justify the use of real options techniques are the same as those that support the use of DCF analysis—and that the real options method can be used in any setting where DCF is appropriate». Please refer to a standard corporate textbook at MBA level, e.g., [7], for more details on DCF investment project valuation.
[2] This approach is an accepted practice by, e.g., International Civil Aviation Organization (ICAO), and the International Air Transport Association (IATA), encompassing the development of traffic forecast and a plan to suit the forecasts [1].
[3] Smit [5] for example, argues that «many airport expansion investments, such as runways or terminals, are large and lumpy, so that investment decisions require an important tradeoff between flexibility and pre-commitment».

Capital budgeting literature document that the free cash flow (FCF) is one of more widely used DCF valuation techniques (e.g., [12], [13], [14]).
Valuing long useful life projects, funded with variable capital structure and under complex structured finance arrangements, as is typically the case of airports, with the FCF valuation framework may «result in serious valuation errors» [15].[4]
In valuing highly leveraged long lived projects funded under variable capital structure, as is typically the case of transport infrastructure projects, it may be helpful using an alternative DCF model able to mitigate some of the bias implications of variable financial leverage (e.g., [17]).
In this framework, the FCF discount rate invariability assumption is clearly violated, suggesting the literature, among others, the capital cash flow model as an alternative approach to overcome that FCF debility (e.g., [17]). In this paper, we used both FCF and CCF approaches.

III. Real options framework

The development of financial asset option-pricing theory, provided the impulse for the application of the concept to investment in real assets.[5]
Firstly addressed in [22], the real options theory builds on an analogy with financial options, as shown in, e.g., [14], [23], [24]).[6]
The real option approach to valuation may be advantageous in relation to DCF valuation, namely, because of the effect of the positive relation between the volatility of the underlying asset and option value. Moreover, and contrary to the DCF approach, where the longer time horizon the higher the project’s uncertainty and lower the project’s expected value, the value of a real option increases with its maturity [25].[7]
Overall, the importance of using real options approach is to calculate the value of flexibility in present value terms, which is highly important for system designers. Allowing comparing the value of flexibility with its cost, they can make an informed, analytic judgment about whether or not a specific flexibility feature should be incorporated into the design [27].
Despite its promise, the effectiveness of real option analysis application to real-world cases may be affected by a number of limitations (e.g., [28]. Most of those limitations come from violations of the strong and restrictive set of assumptions underlying option-pricing models, and / or from theoretical difficulties. Limitations include, but are not limited, to: (i) tradability and liquidity considerations associated with both the underlying and / or real assets; (ii) volatility estimation; (iii) difficulty or impossibility in assembling a replicating portfolio making unfeasible using arbitrage valuation; and (iv) the option exercise instantaneous nature. Therefore, results from real options analysis should be cautiously interpreted because they may not be valid.
Another limitation is associated with [18] and [19] option pricing model, which are only adequate for valuing options that are exercised at expiration date (European options), in addition to both models assuming that underlying asset prices are invariable and exhibit constant volatility.

[4] Referring to the use of a single discount rate in valuing a project, Brennan and Schwartz [16] suggest this is «...tantamount to assuming that the risk of the project is constant over its life».
[5] Black and Scholes [18] and Merton [19] are widely acknowledged for their pioneering work on option pricing theory. Myron Scholes and Robert Merton were awarded the 1997 Nobel Prize in economics for their contributions in European options valuation. Cox *et al*. [20] derived a discrete-time model, based on binomial lattices, useful in solving for the value of early-exercise American option. For further details on option pricing theory and valuation see, e.g., [21].
[6] Options on real assets differentiates from the options on financial assets in terms of the nature of the contractual underlying asset.
[7] Real option valuation method compensates for the uncertainty inherent in investments by risk- adjusting cash flows and discounting them at a risk-free rate. On the other hand, DCF compensates for this uncertainty by adjusting the discount rate. Adjusting cash flows forces analysts to be more explicit about assumptions underlying the projections and eliminates interminable discussions about the appropriateness the discount rate [26].

IV. The model

In order to evaluate the benefits of considering flexibility when designing and managing an airport, developed two scenarios. The first, the inflexible scenario, the airport is considered to be constructed in single construction phase, with a maximum annual capacity of 50 million passengers (MPax). The second, the flexible scenario, the airport is built in different phases, according to the demand needs.
The model assumes no restrictions, environmental, space availability, etc.) for building a greenfield airport of this size.
In both scenarios, we considered two types of airports: low-cost airports (LCA), primarily intended to serve LCC, and full-service airports (FSA), to serve all kinds of traffic, but mainly used by full-service carriers. The distinction between the types of airports is used to accommodate the differences in cash flows patterns generate for the airport by the operation of each type of airline.
In the flexible scenario, an airport with 15 MPax capacity for full service and 5 MPax capacity for LCC is opened in year 0, and is upgraded, in 5 MPax increments, when the occupation exceeds in 90% capacity in the case of a full service airport, and 95% in the case of a low-cost airport.[8]
In order to evaluate the different scenarios, it was necessary to forecast traffic for the future, which led to a range of expected future cash flows for a period of 31 years (from year 0 – when the airport opened – to year 30). The starting demand at year 0 was established to be 4MPax. If the maximum capacity of 50 MPax was exceed in a year (or several), it was assumed that the airport continued to serve only 50 MPax, even if the demand was higher.
To valuate flexibility, we modeled passenger demand for each airport type as a binomial lattice and estimated the probabilities at each node. If there was a need for an airport expansion at a certain node, the necessary investment would be made 2 or 3 years before, depending on the type of airport.
After forecasting the expansions, we estimated the expected periodic cash flow as the weighted average of the cash flows by their probabilities, at each node of the lattices. We applied the discount factors for both the FCF and the CCF models, to compute the expected NPV values for years 0, 10, 20, and 30, and the corresponding option value, which is the difference between the NPVs of the inflexible and the flexible scenarios (5).
Finally, we ran Monte Carlo simulations conducted to estimate the sensitivity of the final results to changes in the input variables.

IV.1 Investment Costs Specification

Table 1 below presents the aggregated costs for the flexible subsystems considered in the-model.

Table 1 – Investments by airport type and capacity lumps
Source: Adapted from [29]

	Total Investment Needs (million Euros)	
Capacity (MPax)	Full-Service Airport	Low-Cost Airport
5	-	292
10	-	365
15	987	446
20	1.190	538
25	1.402	643
30	1.819	863
35	2.090	936
40	2.293	1.017
45	2.505	1.109
50	2.750	1.214

Costs include: the construction of two runways, each one with a capacity of 25 MPax, the second

[8] The construction of these upgrades will start 2 for a low-cost and 3 years for a full-service airport, before reaching the defined trigger points.

runway being constructed after the 25 MPax capacity is fully occupied; terminal areas, including luggage processing facilities, and offices; technical equipment, such as control tower, police station, and firemen headquarters; support systems, including parking lots, and fuel storage facilities; environmental systems, such as, air, water and noise monitoring systems; and unexpected costs. All site-specific costs, like raising a rampart before construction and other foundation works, real estate costs, and accessibility costs are not included in the estimates.
These investment costs estimates were adapted from the report Evaluation of the economic merit of the solution “Portela+1” (hereafter, [29]), which estimated the investments needed to build a second airport in the Lisbon metro area.[9]
This model assumes that the costs of expanding the airport in the future are the same as expanding it now, which can be considered a simplification, but the addition of changing variables (such as increasing environmental costs and taxes, due to the foreseeable environmental constraints in the next decades), would add an unnecessary layer of complexity to the model, and the choice was to keep the model as simply as possible with only one risky variable (traffic demand).

IV.2 Traffic Forecasts
A central component in real options valuation, with vast implications in the performance of the binomial lattices, is the accuracy in estimating the traffic growth rate (v) and corresponding volatility (σ^2), measured by the variance.
The estimation of those two variables was performed using data for a first sample of European airports from 1993 to 2007, drawn from Eurostat. Airports with one or more years of missing data and with less than 100.000 passengers in 1993, were dropped for the sake of data consistency. We end up with a sample of 30 airports, with 11,11 percent of average annual traffic growth rate and 16,55 percent of volatility. A sample for the 2002-2007 sampling period, was built under the same missing data and airport size constraints resulted in a sample of 221 airports, exhibiting an average annual traffic growth rate 8,11 percent and volatility of 4,38 percent.
Since we did not expect growth rates to continue growing indefinitely at the same pace, we used in the analysis the following parameters on these variables: (*i*) For the first decade of the analysis time horizon: annual growth rate, 8,11 percent, and volatility 4,38 percent; (*ii*) For the second decade, the annual growth rate, 6,08 percent (25% lower), and volatility 5,47percent (25% higher); and (*iii*) For the final decade, the annual growth rate declined further 25% to 4,56 percent, and volatility increased further 25% to 6,84 percent.
Expected growth rates and volatility for low-cost airports were estimated based on the values obtained for all airports (low cost traffic), not only on actual low-cost airports, because the database would be too small to have statistical significance:
For the first decade it was considered an annual growth rate and volatility that double the ones for the FSA (16,21% and 8,75% for the annual growth rate and the volatility, respectively); In the second decade, the annual growth rate was only 50% higher than the one for the FSA (9,12%, 43,75% lower than in the first decade); In the final decade it was 25% higher (5,70%, 37,50% lower than in the second decade).
The volatility followed the same rule in the LCA as it did in the FSA, with an increase of 25% per decade, resulting in a value of 10,94% for the second decade, and 13,67% for the third decade.

IV.3 Cash Inflows and Outflows
Cash inflows resulting from passenger traffic were estimated based on data by [29] for Lisbon airport, assumed as proxy for full-service airport), and Faro airport assumed as proxy for low-cost airport. Those inflows included not only revenues directly attributed to passenger movements, but also other revenues, like aircraft taxes. All those inflows were then aggregated into an inflow per passenger ratio, representing the total revenue per passenger generated by the airport.

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[9] Original title in Portuguese: “Avaliação Económica do Mérito Relativo da Opção “Portela + 1” - Estudo de impacte da localização de um novo aeroporto na região de Lisboa”.

Table 2 – Expenses and revenues by Airport Type
Source: [29]

		Expenses (€\Pax)	Revenues (€\Pax)	Margin (€\Pax)
Type of Airport	Full-Service	7,20 €	11,07 €	3,87 €
	Low-Cost	7,17 €	9,56 €	2,39 €

This calculation resulted in ratios between operating expenses and revenues for the two types of airports considered in the paper: 65% for full-service airports; 75% for low-cost airports. Results are reported in Table 2.

Margin per passenger, was considered constant throughout the entire life of the project. Although it can be argued that expenses per passenger may vary during the operation of the airport, maintenance costs, for example, are usually lower when the airport is the first years of operation, but it was assumed that airport managers would be able to fully reflect any cost increases in revenues.[10]

IV.4 Model Specification and Parameterization

For valuation purposes we estimated the discount rate under the following assumptions: (i) Risk-free rate (r_F): proxied by the yield-to-maturity of 30-year Portuguese Treasury bond on May 13, 2009 (4,642%); (*ii*) The cost of debt (k_D): the risk-free rate plus a spread of 2,0%; (*iii)* Income tax rate: was estimated as 27,5%; (*iv*) Level of financial leverage: 67% based on [30]; (*v*) Market risk premium: 6,50% (in January 2009) as estimated by Professor Aswath Damadoran; Asset beta The asset beta (β_A) was assumed as 0,5877 as estimated in [31].

IV.5 Binomial Lattices Inputs

Using the data from the traffic estimates we to estimate the increase factor, *u*, decrease factor, *d*, and increase and decrease probabilities, *p* and 1-*p*, respectively, for both types of airports considered (Table 3). The time factor, Δt, was assumed to be one year.

Table 3 - Binomial lattices data (authors' estimates)

	Type of airport					
	Full-Service			Low-Cost		
Period (years)	0 - 10	11 - 20	21 - 30	0 - 10	11 - 20	21 - 30
Annual Growth Rate (v)	8,11%	6,08%	4,56%	16,21%	9,12%	5,70%
Volatility (σ^2)	4,38%	5,47%	6,84%	8,75%	10,94%	13,67%
Time factor (Δt)	1	1	1	1	1	1
Increase Factor (u)	1,23	1,26	1,30	1,34	1,39	1,45
Decrease Factor (d)	0,81	0,79	0,77	0,74	0,72	0,69
Probability Increase Factor (p)	0,69	0,63	0,59	0,77	0,64	0,58
Probability Decrease Factor (1-p)	0,31	0,37	0,41	0,23	0,36	0,42

[10] Assuming that there are no economies of scale on the increase of the number of passengers, combined with the constant construction costs, makes the number of passengers the only risky variable in the project.

V. Results

NPVs estimated for using the two discounted cash flow models– especially the full service one – show that both airports are economically unprofitable in a time horizon of 31 years (Figure 1).

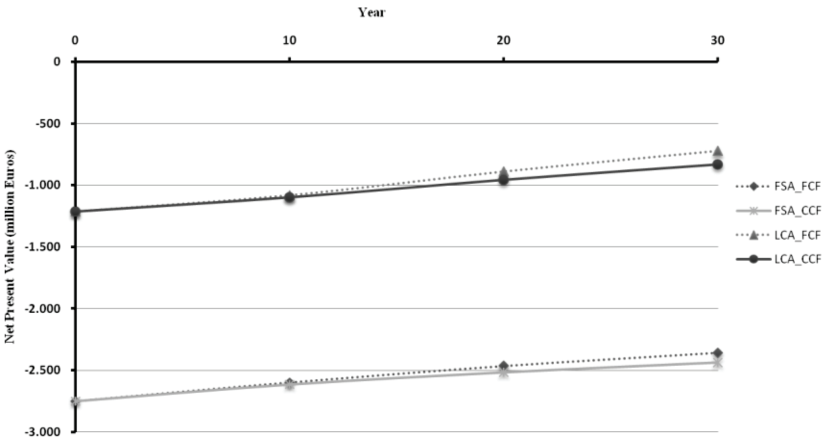

Figure 1 – Results for the inflexible settings with both valuation models

With the annual growth rates considered, the full-service airport, would not have its capacity exceed during the period considered. In the low-cost airport, with its initial growth rate of 16,21%, capacity would be exceed in year 23, operating at full capacity for 7 years, which translates into higher NPVs in the final decades. Remarkably high construction costs combined with relatively low net profit ratio (25% for the LCA and 35% for the FSA) pave the way for the achieved results.

V.1 Flexible scenario

Using binomial lattices, it was possible to forecast passenger activity in the 31 years considered, along with the probabilities associated with each forecast (Figures 2 and 3), which is a more dynamic approach, compared to the deterministic forecast explained earlier.
This approach leads to some extreme results in the final year of the lattice, but the median results represented more than two thirds of the probabilities for each of the two lattices considered. The remaining values (both very high and very low) have lower probabilities associated. Nevertheless, the results obtained from these lattices should be analyzed with care, since in some cases they might not represent the real world accurately.

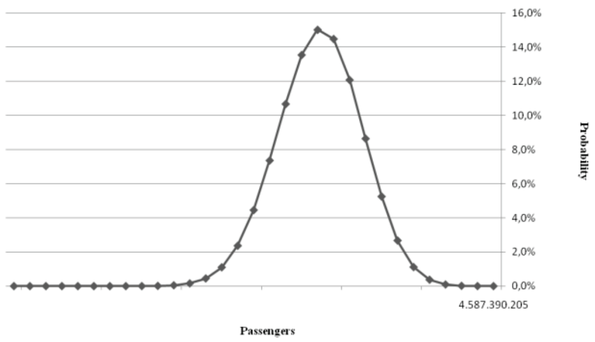

Figure 2 – Probabilities for passenger activity in year 51 for a full-service airport (top value of 43.817.953 Pax, with 15,03% probability)

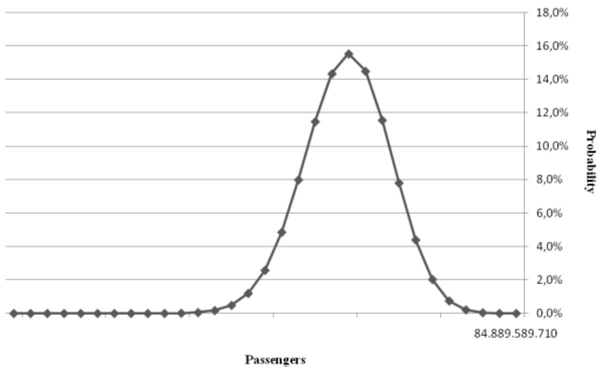

Figure 3 – Probabilities for passenger activity in year 51 for a low-cost airport (top value of 228.836.340 Pax, with 15,53% probability)

After applying all the assumptions and restrictions already mentioned when the model was explained in the preceding chapter, it was then possible to estimate the expected NPVs for both FCF and CCF models, over the 31 years considered (Figure 4).

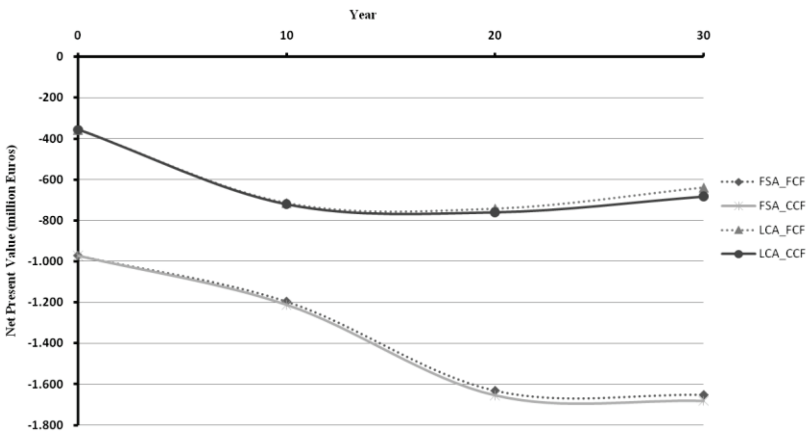

Figure 4 – Results for the flexible setting, for both valuation models

Once more, the projects seem highly unprofitable, although not as much as in the inflexible scenarios, which may be a corroboration that developing an airport in a flexible way can add value to the project.

V.2 Option value

To assess the value of considering flexibility when developing an airport, the value of that option must be computed. In our model, that option value is estimated as:

$$NPV_{inflexible\ scenario} - NPV_{flexible\ scenario}.$$

Results are presented in Figure 5, below.

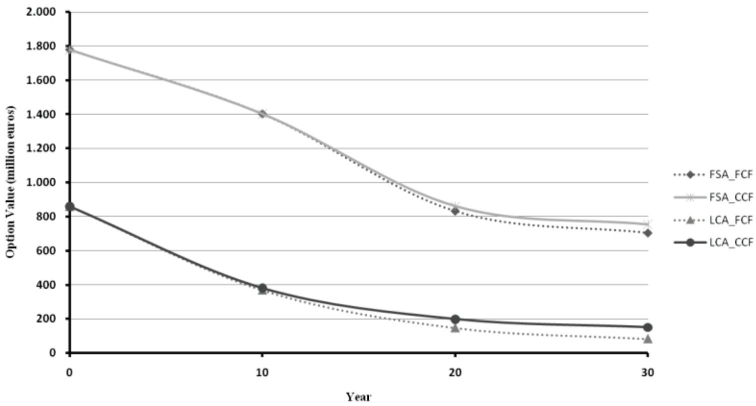

Figure 5 - Option Value

As exhibited in Figure 5, the option of waiting before investing in an over dimensioned airport is always rational, at least in financial terms. This is especially true in the first years of operation, when the airport is expected to function well below the maximum capacity of 50 MPax. After the first few years of operation, the option value starts to decline, but remains positive through the entire period considered (in the final year the minimum option value is 147 million Euros for the LCA valued by the FCF model, and the maximum option value is 861 million Euros for the FSA valued by the CCF model).

V.3 Option value sensitivity to the annual growth rate

To determine how the option value is affected by the annual growth rate, a sensitivity analysis was conducted regarding the initial annual growth rate for each kind of airport and determine how the option value at the final year reacted to that variation.

Keeping the volatility constant, the annual growth rate for the first decade was changed, ranging from 0% to 25%, in 5% increments. The annual growth rate for the following decades followed the same rule as in the base case scenario, i.e., for the FSA, the annual growth rate for the second decade was 25% lower than in the first decade, and in the third decade was 25 lower than in the second decade; for the LCA, the annual growth rate for the second decade was 43,75% lower than in the first decade, and in the third decade was 37,50 lower than in the second decade. Results are presented below (Figure 6).

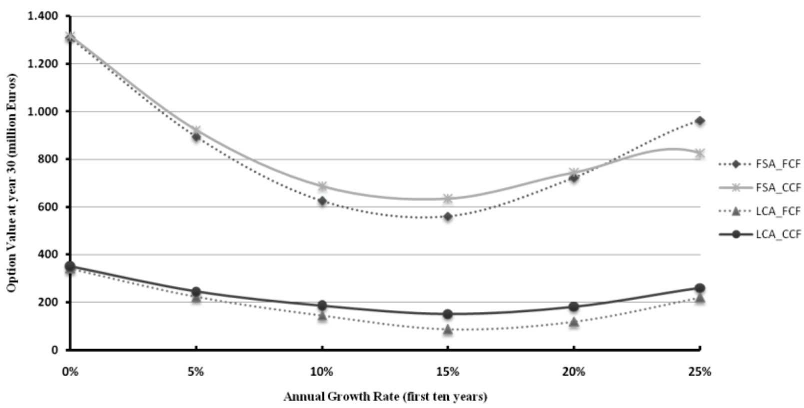

Figure 6 - Option value at year 30 for different annual growth rates

As Figure 6 suggests, the higher option value is achieved when the initial annual growth rates are lower.

For the FSA, the option value varies between the maximum of around 1.300 million Euros when the annual growth rate is nil, and the minimum of around 600 million Euros for a 15% annual growth rate:
For the LCA, the option value has a maximum of around 350 million Euros also when the annual growth rate is zero, and the minimums of 80 million Euros (FCF model)
and 150 million Euros (CCF model) are also achieved when the annual growth rate is 15%.
In both types of airports the option value starts to increase again when the initial annual growth rates are 20% or higher (which are more difficult to maintain in the long term), but never achieve such high values as the ones achieved in the lower end of the range of values considered.

V.3 Monte Carlo simulation
The selection of the random variables to be used in Monte Carlo simulations was conducted through a sensitivity analysis measuring the impact of a 15% individual variation in the key variables. Total costs, inflows and outflows proved to be the most sensitivity variables in almost every setting and were chosen to run the simulations.
Since some of those variables tend to vary together in a systematic manner, they are correlated, a number of numeric correlations were established. The exact assessment of the value of those correlations was not needed, since their purpose is not to produce high statistical accuracy but rather restraining the model from generating grossly inconsistent scenarios in large scale. With that principle in mind, the following correlations were established:
A positive correlation of 0,950 between all partial investment costs, i.e., if a partial investment has an increase in costs the following partial investments have a very high probability of having also an increase. For example, if the initial investment on the FSA is 1200 million euros instead of 987 million, there is a high probability that the next expansion for 20 MPax will cost more than the estimated 203 million euro;
A positive correlation of 0,800 between the partial investment costs and the outflows, i.e., if investments costs increase, the outflows (which in this model is a percentage of the inflow values) have a relatively high probability of increasing and profit will consequently decrease. Using the same example as before, if the initial investment in the FSA increase to 1200 million euros, operating expenses also have a tendency to increase, therefore outflows would have a value slightly higher than the initial estimation of 65%, and the net profit ratio would be lower than 35%.
Although there might be a correlation between investment costs and inflows (if investment cost increase, taxes for using the airport would probably also increase), it was decided not to include it in the simulation, since it might counter-balance the correlation between investment costs and outflows (if operating expenditures increase due to higher investment costs (for example, a 10% increase in costs leads to a 5% increase in operating expenditures), management could raise taxes (by 5% in this example) to increase inflows and maintain net profit ratios in the same level as before, which would lead to a situation very similar to the initial condition).
A way of avoiding this counter-balance effect would be to set a correlation coefficient between investment costs and inflows lower than the coefficient between investment costs and outflows (which is probably true since it might be difficult to reflect the increasing investment costs into the taxes the airport receives – if taxes increase too much passengers and airlines would simply avoid the airport, so there is a limit to increasing their value). Using a correlation of 0,500 between investment costs and inflows lead to variation in simulation final results less than 0,5% different from the simulation without that correlation, so it was decided to exclude it from the simulations ran.
The final correlation possible between this set of variables was between outflows and inflows, which was already set in the model (outflows are defined as a percentage of inflows), so there was no need to set a new correlation. Because of the complex nature of the variables at hand, and considering that the purpose of running Monte Carlo simulations is not to obtain the exact probability of achieving positive NPVs, but only to give a rough estimate whether that is possible or not, there is no need to correctly assess the probabilistic distribution of the variables.
Therefore, simple triangular distributions, where the likeliest value is the deterministic value used in the previous valuations and the minimum and maximum values are a 15% variation of

that value (the same variation used in the sensitivity analysis) were used. After the definition of the variables to be used in the simulation, their correlations and their probabilistic distribution it was possible to run the Monte Carlo simulations. A total of 100.000 trials of each variable were run.
A summary of the results of the Monte Carlo simulations ran for the FSA is presented in Table 4.

Table 4 – Monte Carlo simulations for full-service airport.

Statistics	FCF Inflexible	CCF Inflexible
Minimum	-2.970.822.175 €	-3.008.838.549 €
Mean	-2.356.663.131 €	-2.435.437.033 €
Maximum	-1.773.017.597 €	-1.889.446.523 €
Statistics	FCF Flexible	CCF Flexible
Minimum	-2.253.882.142 €	-2.275.412.405 €
Mean	-1.653.508.856 €	-1.682.905.556 €
Maximum	-1.089.734.719 €	-1.137.148.598 €

Using the mentioned correlated assumptions, with their triangular distributions, the probabilities of achieving positive NPVs are far from positive. Even in the best-case scenario (flexible scenario valued by the FCF model) NPV is lower than -1000 million euros and achieves values as low as -2200 million euros.
Table 5 presents the results for the low-cost airport.

Table 5 – Monte Carlo simulations for a low-cost airport.

Statistics	FCF Inflexible	CCF Inflexible
Minimum	-1.344.733.390€	-1.355.590.615 €
Mean	-721.587.323 €	-832.379.249 €
Maximum	-170.066.346 €	-366.302.003 €
Statistics	FCF Flexible	CCF Flexible
Minimum	-1.303.348.882 €	-1.311.735.848 €
Mean	-638.802.410 €	-683.928.963 €
Maximum	-52.086.623 €	-171.081.955 €

Opposite to the full-service airports, flexible low-cost airport projects appear to have small probabilities of becoming close to the break-even point. If capital expenditures costs are reduced and net profit ratios are increased, these airports may have a chance of becoming profitable.

VI. Conclusions

Uncertainty is now a major concept in almost every aspect of our society. Recent global crisis have highlighted the importance of flexibility, from the decisions we make in our personal life, to the huge investments governments commit themselves to make.
Airports, and the aviation sector in general, have been affected by other internal changes, like the still ongoing liberalization of the sector throughout the world, which makes an already unpredictable world into a tough challenge for planners. This paper tried to tackle uncertainty, by considering flexibility when developing and managing an airport project. That flexibility, already put into action in various fields in the industry, was then evaluated by the real options theory, which aims exactly to assess the value underlying such flexible designs. By developing a model, authors aimed to demonstrate the value of waiting before investing huge amounts of money into an infrastructure that has the chance of not being used in full capacity for years.
The results produced by the model, although being very simple and, thus, only rough estimates of real cash flows, might be a proof, by comparison, that waiting for more information before

committing to an investment might be a good idea, especially in a case where high levels of capital expenditures are needed. Our results also suggest that this waiting option becomes especially valuable when lower traffic growth rates are expected.
Using data mostly based on studies regarding Portuguese airports investments and results, the model showed that although less unprofitable, constructing a flexible airport is not still a very good investment, since the huge amounts of investment money needed are not followed by large net profit ratios during operation, thus creating largely unattractive investments for project owners.
These results might suggest that the current plans to build a completely new airport in the Lisbon region should be revised, and should include ways of reducing capital expenditures and simultaneously improve profit margins (perhaps by building a simpler airport or even adapting an existing one, while maintaining the current airport open for the time being, and only close if it is truly necessary), to ensure that the project has higher possibilities of generating economic value. Although with direct effects on the airport's competitiveness, airport charges can also be used to increase revenues.

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Adaptación de la Regulación de servidumbres aeronáuticas para su integración en el entorno

Ángel París Loreiro - angel.paris@upm.es
Universidad Politécnica de Madrid
Antonia Pacios Álvarez - antonia.pacios@upm.es
Universidad Politécnica de Madrid
C. Alejandro Di Bernardi - cadibern@ing.unlp.edu.ar
Universidad nacional de La Plata
Pedro Blanco Núñez - pedro.blanco@upm.es
Universidad Politécnica de Madrid
Sergio F. Pitrelli - spitrelli@gmail.com
Universidad Nacional de La Plata

Abstract
El objetivo es definir una propuesta de alcance en la Regulación por parte de los Estados sobre Servidumbres Aeronáuticas, teniendo en cuenta los requisitos de seguridad operacional, y la compatibilidad con las construcciones e instalaciones propiciadas por el desarrollo económico.
Se partirá de la reglamentación internacional sobre superficies limitadoras de obstáculos (aeródromo, operación y radioeléctricas). Como los Estados son responsables de desarrollar la regulación nacional sobre servidumbres se tomará como partida el caso de España, con el análisis de casos representativos. Se revisará el proceso de establecimiento y definición, y se comparará con la situación en otros países. Como resultado, se identificarán los problemas y las oportunidades.
Se debería identificar con precisión una propuesta de alcance de regulación en materia de servidumbres aeronáuticas que, garantizando la seguridad de las operaciones aéreas, agilice los procesos de análisis por parte de la autoridad aeronáutica, y minimice las dificultades para el desarrollo de la actividad económica en las zonas afectadas. Caso representativos, que deberían verse beneficiados, serían el aprovechamiento del terreno en islas o el desarrollo de los parques eólicos.
La normativa técnica en un mundo tan dinámico como el de la aviación civil se encuentra en permanente evolución. Ello dificulta la regulación por parte de los Estados en algunas materias como el de las servidumbres aeronáuticas. Nos encontramos con regulaciones estatales que no consiguen seguir el paso de la normativa internacional. El trabajo pretende ayudar a gestionar y disminuir este desfase, cuyo tratamiento ha sido escasamente abordado.

Keywords
Servidumbres aeronáuticas; Regulación; Seguridad Operacional; Obstáculos

Adaptación de la regulación de las servidumbres aeronáuticas para su integración en el entorno

Resumen

Los estados son responsables de desarrollar la legislación nacional que define el proceso de establecimiento de las servidumbres aeronáuticas, conforme a las normas internacionales de la aviación civil. Se pueden llegar a definir hasta tres tipos de superficies limitadoras asociadas a las servidumbres aeronáuticas: aeródromo, radioeléctricas y operación.

Las servidumbres aeronáuticas son necesarias para proteger las operaciones aéreas de la presencia de obstáculos en su trayectoria e interferencias radioeléctricas a las ayudas a la navegación aérea, contribuyendo a la seguridad operacional del transporte aéreo. Por otro lado, también deben ser una herramienta que sirva para establecer un marco técnico donde se posibilite una integración racional de las infraestructuras aeronáuticas y operaciones aéreas en su entorno.

Una regulación demasiado restrictiva entorpece esta integración en el entorno, principalmente del aeropuerto, haciendo difícil su aceptación como un bien social para la comunidad a la que sirve. También pueden limitar el desarrollo económico de zonas donde el uso del suelo para la actividad humana sería más necesario. Un caso singular es el aprovechamiento del terreno en islas o el desarrollo de nuevas iniciativas de parques eólicos, fundamentales para aumentar la producción de energía sostenible.

En este contexto, el presente estudio tiene como objetivo valorar el alcance que sería recomendable que tuviera la legislación de los estados sobre servidumbres aeronáuticas, analizando la problemática de la extensión de las distintas servidumbres: de aeródromo, radioeléctricas de operación, de las asociadas de los obstáculos de gran altura y parques de aerogeneradores, el tratamiento de las actividades singulares que afecten a las operaciones aéreas, o la inclusión o no de unas servidumbres específicas de ruido aeronáutico.

Planteamiento

Las servidumbres son un concepto jurídico-legislativo. Si bien están relacionadas con las directrices técnicas de la normativa internacional, presentan una inercia en su reglamentación que puede provocar ineficiencias en su gestión.

Es un proceso en el cual los estados son soberanos para definir las condiciones que estimen oportunas. A diferencia de la armonización que se sigue en el ámbito técnico, especialmente en un medio de transporte con un carácter transnacional tan marcado como el aéreo, en el ámbito jurídico-legislativo de reglamentación de las servidumbres, podemos encontrar diferentes aproximaciones por parte de los estados en virtud de su problemática particular.

El proceso de establecimiento de las servidumbres aeronáuticas debe, por lo tanto, no sólo considerar la necesidad de salvaguardar la seguridad de las operaciones aéreas, sino también la de establecer un marco racional para integrar las infraestructuras y dichas operaciones en su entorno particular.

El exceso de celo por parte de las autoridades aeronáuticas, tanto en la delimitación de las servidumbres aeronáuticas como en los procesos administrativos para la autorización de construcciones en áreas de servidumbres, generará ineficiencias que pueden volverse en contra del objetivo inicial.

Organización de aviación civil internacional

OACI establece [Referencias 1 a 8] Normas y Métodos Recomendados sobre definición de las superficies limitadores de obstáculos, diseño de operaciones, datos aeronáuticos, etc. También establece directrices relacionadas con los procedimientos para la gestión de los obstáculos.

En relación con las superficies limitadoras de obstáculos de aeródromo, en el caso más desfavorable se extienden hasta 15.000m desde los extremos de las pistas.

En cuanto a las superficies limitadoras radioeléctricas, merece atención el Documento 15 *European Guidance Material on Managing Building Restricted Areas*, por cuando ha venido a solucionar recientemente el problema de definir consistentemente dichas superficies.

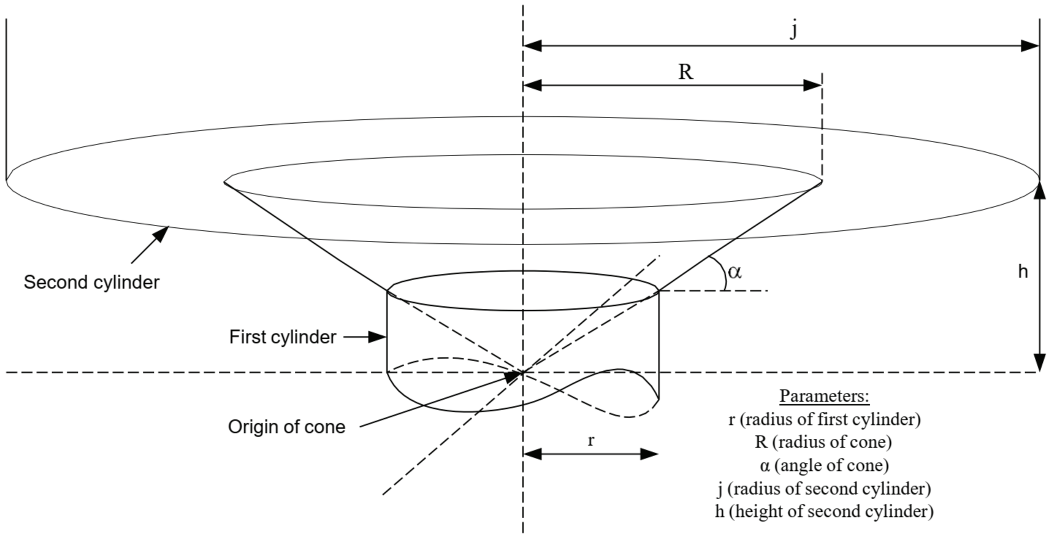


figura 1. Superficies BRA omnidireccionales [5]

La dimensión exterior, “j”, más crítica es 15.000m para un CVOR en presencia de aerogeneradores, al igual que para PSR y SSR. Para el resto de instalaciones omnidireccionales, sin presencia de aerogeneradores, la distancia quedaría reducida a 3.000m desde la antena.

Además de la definición técnica de estas superficies, son especialmente importantes las directrices que OACI establece en el Documento 9774 *Manual de Certificación de Aeródromos* [8] para su vigilancia.

Si bien OACI reconoce la soberanía de los estados en el proceso de establecimiento de las servidumbres aeronáuticas, sí define unas responsabilidades claras por parte del operador aeroportuario [8] conforme a la filosofía general de que los estados delegan en los explotadores responsabilidades sobre al control de obstáculos, conservando sus facultades de supervisión.

El Documento 9774 no entra en el control que el Estado tiene que exigir a sus administraciones urbanísticas, por cuanto en ese ámbito serán soberanos para establecer los mecanismos que consideren más oportunos

Reglamentación europea

Desde el punto de vista técnico, el Reglamento (CE) 139/2014 [11] define las superficies limitadoras de obstáculos de forma coherente con las establecidas en el Anexo 14 de la Organización de Aviación Civil Internacional. Para la definición de otro tipo de superficies limitadoras se debe recurrir, necesariamente, a las estipulaciones de la OACI.

Desde el punto de vista del procedimiento para hacer efectivas las servidumbres aeronáuticas no existe, y tampoco es previsible que la Unión Europea lo disponga, ningún reglamento de desarrollo para proporcionar orientación a los estados. El motivo es que dicha orientación sería demasiado general para poder llevarla a la práctica, y por tanto de escasa utilidad, dada la diversidad de la orografía y de operadores aeroportuarios en los países miembros.

La única referencia europea que proporciona algunas indicaciones generales sobre este procedimiento sería el Reglamento (CE) 216/2008 *sobre normas comunes en el ámbito de la aviación civil y por el que se crea una Agencia Europea de Seguridad Aérea* [9]. Pese a su enfoque, necesariamente general, es una referencia que deben seguir los estados en su ordenamiento jurídico para el establecimiento de las servidumbres.

Establece que la necesidad de que el gestor recabe la información necesaria de las Administraciones Públicas competentes, normalmente serán las locales y urbanísticas, para la adopción de las medidas de garantía precisas para la plena efectividad de las servidumbres aeronáuticas. Es deber del Estado facilitar a dicho gestor tales datos, precisamente para cumplir con las obligaciones que se le imponen.

Información de partida del terreno

Es posible que el ánimo de sobreprotección de los estados en su legislación tuviera su origen, al menos en parte, en la dificultad de disponer de una información precisa y actualizada del terreno y de los obstáculos a la navegación aérea. Por ejemplo, en España existen entre 6.000 y 8.000 obstáculos por encima de 100m.

Indudablemente, tanto el Anexo 15 de la OACI, como el Reglamento (CE) nº 73/2010, han supuesto un importante avance en el establecimiento de unos requisitos de calidad de los datos aeronáuticos.

La iniciativa más relevante en el ámbito que nos ocupa es la eTOD, *Electronic Terrain and Obstacle Data*, representación digital del terreno y los obstáculos cumpliendo los requisitos aeronáuticos para el diseño de procedimientos o herramientas, aire y tierra, como EGPWS, TAWS, A-SMGCS, MSAW, etc.

El eTOD será una herramienta imprescindible para la gestión de obstáculos, por lo que se requiere a los estados que aseguren su confiabilidad, de acuerdo con unos requisitos particulares que se establecen para 4 áreas distintas [15]. Las directrices europeas [10 y 15] indican que los estados deben:

- Identificar el organismo encargado de gestionar la base de datos de obstáculos.
- Identificar las agencias nacionales con datos disponibles de obstáculos por encima de 100m, y comparar su información con los datos existentes en la base de datos de obstáculos para identificar los omitidos.
- Dependiendo de la extensión de estos obstáculos, identificar y contactar con el propietario para obtener todos los metadatos asociados.

- Establecer la obligación legal para que el propietario de estos obstáculos proporcione toda la información requerida y, en caso contrario, contemplar las medidas sancionadores pertinentes..

Sería desaprovechar tiempo y recursos el determinar todos los obstáculos construidos, ampliados o demolidos en un área si, a pesar de penetrar una superficie limitadora, fueran significativamente más pequeños que los de su entorno. En estos casos, se puede argumentar que, desde un punto de vista aeronáutico, no es necesario supervisar los cambios de dicha área.

Por lo tanto, lo lógico sería que el área alrededor de un aeródromo se divida para identificar en cada parte un tamaño mínimo de obstáculo (probablemente sólo considerando la altura). Los obstáculos que superen dicha altura deberían ser los monitorizados.

En línea con lo expuesto, con el objetivo de coordinación de la captura de datos LIDAR del terreno en el territorio español, el pasado 3 de julio se firmó en España un convenio entre la Autoridad Aeronáutica (DGAC), el prestador de Servicios de Información Aeronáutica (Enaire), el principal operador Aeroportuario (Aena), el Instituto Geográfico Nacional (IGN9 y el Centro Nacional de Información Geográfica.

Tratamiento de las servidumbres en España

El Decreto 584/1972 es la referencia legislativa en materia de servidumbres aeronáuticas en España. A pesar de haberse actualizado, conforme a la evolución de la normativa internacional en materia de aviación civil en sucesivas ocasiones, la última en 2013, presenta algunos problemas que merecen una reflexión.

El Decreto define tres tipos de servidumbres aeronáuticas básicas: de aeródromo, radioeléctricas y de operación. También hace referencia a servidumbres relacionadas con limitación de actividades o de objetos de más de 100m sobre el terreno.

La primeras, las de aeródromo, pese a tomar como referencia una clasificación de pistas de vuelo diferente de la establecida por OACI según el número de clave, coinciden con las superficies limitadoras de obstáculos definidas en el Anexo 14 y en el Reglamento (CE) nº 139/2014.

Las segundas, las radioeléctricas, pretenden garantizar el correcto funcionamiento de las instalaciones aeronáuticas de comunicaciones y ayudas a la navegación aérea, y se han actualizado conforme a [5]. Por su extensión y configuración, son las que suponen una menor afección a su entorno urbano, al estar más concentradas.

Las terceras, las servidumbres de operación, tienen por objeto garantizar la seguridad en las diferentes fases de las maniobras de aproximación por instrumentos a un aeródromo, y son específicas de la ayuda que se utilice como base del procedimiento de aproximación. Las áreas, así como las superficies en el espacio, de estas servidumbres varían de acuerdo con las características técnicas de las ayudas y de los mínimos que aterrizaje que correspondan.

Las servidumbres más extensas son las de operación y son las que presentan, por lo tanto, un mayor conflicto con su entorno urbano. También son las más singulares en su definición, al no estar directamente asociadas a una referencia normativa internacional concreta.

Pará ver el orden de magnitud de su extensión, si nos centramos en las dimensiones exteriores, longitudes y anchuras, de las áreas que se definen [12] la servidumbre más crítica sería la correspondiente a la maniobra basada en ILS. define el área de aproximación intermedia hasta 15.750m hacia afuera de la radiobaliza exterior, o de la ayuda correspondiente a la trayectoria de aproximación prevista, y 14.800m de anchura, 9.300m desde la trayectoria del lado del viraje y 5.500m en el otro. A efectos prácticos, si la radiobaliza exterior está situada entre 4 y 7 millas náuticas del umbral, podemos decir que la longitud de esta servidumbre es de unos 30km desde el umbral.

Procedimiento de efectividad de las servidumbres

El procedimiento para hacer efectivas las servidumbres en España ha ido evolucionando desde la promulgación inicial del Decreto 584/72 hasta la actualidad. La última modificación de dicho Decreto, mediante el Real Decreto 297/2013 [14], responde a directrices establecidas por la Comisión Europea en el Reglamento (CE) 216/2008 [9].

La redacción definitiva del Real Decreto 584/72 fue laboriosa, pues el Consejo de Estado de España formuló observaciones de calado mediante su informe Ref. 1044 de 2012 [13], encaminadas, sobre todo, a asegurar el cumplimiento con las directrices europeas.

El Consejo de Estado de España condicionó muy importantemente la redacción del Real Decreto 297/2013. La línea fundamental de la modificación estableció claramente la imposibilidad de delegar el proceso de hacer efectivas las servidumbres aeronáuticas en las autoridades urbanísticas, exigiendo que la autoridad aeronáutica llevara todo el control del proceso.

Se establece la automática rectificación del Plan Director (o Maestro) de un aeropuerto en caso de que se publique un Real Decreto de establecimiento de servidumbres aeronáuticas de dicho aeropuerto, integrándose en el mismo.

En el caso de los instrumentos urbanísticos de planeamiento, como están vinculados al cumplimiento de las servidumbres aeronáuticas, dicha integración no puede ser automática y se tendrían que adaptar con la conformidad de la autoridad aeronáutica.

En este sentido, el silencio administrativo de la autoridad aeronáutica, para hacer efectivo su deber activo de vigilancia, se entenderá normalmente como denegación. Se requiere un informe previo por parte de la autoridad aeronáutica, siendo preceptivo y vinculante.

Se distinguen dos situaciones [12 y 14]. La primera será el caso de los proyectos de planes o instrumentos de ordenación urbanística o territorial, o los de su revisión o modificación, que afecten a los espacios sujetos a las servidumbres aeronáuticas, se prevén seis meses para que la autoridad aeronáutica emita un informe previo, preceptivo y vinculante, y que , en caso de no informar, se entenderá que el informe es disconforme. La segunda sería el caso de instrumentos de planeamiento que desarrollen planes previamente informados favorablemente, la autoridad aeronáutica dispondrá de tres meses para pronunciarse y, en caso de que no lo haya hecho, se entenderá emitido informe en sentido favorable[1]. Este procedimiento sólo será aplicable en los casos en los que expresamente la Autoridad Aeronáutica lo hubiera establecido en su informe previo al planeamiento que se desarrolle.

Como vemos, en ningún caso se deja abierta la opción de que se pueda continuar la tramitación de los proyectos, en caso de que la autoridad aeronáutica no haya emitido el informe previo. La única concesión es que se entenderá emitido si transcurrido el plazo no lo haya sido. De esta forma, se evita generar una situación urbanística con derechos consolidados contraria al cumplimiento de las servidumbres, lo que depararía en casos innecesarios de posible responsabilidad. [13].

Se observa también que la necesidad del informe previo, preceptivo y vinculante, aplica a todo instrumento de planeamiento, pues las determinaciones específicas que pueden afectar realmente a la

[1] obsérvese que siempre se contempla la existencia del informe, *se entenderá emitido informe favorable*.

plena efectividad de las servidumbres aeronáuticas se concretan precisamente en los instrumentos urbanísticos de desarrollo.

Efectivamente, el Consejo de Estado dejó patente que establecer una excepción en la existencia del informe previo de la autoridad aeronáutica supondría incumplir el deber de control urbanístico que se impone en el Reglamento (CE) 216/2008.

Problemática de la gestión las servidumbres aeronáuticas en el caso de España

España presenta una relieve bastante diverso y una orografía elevada, características ambas que otorgan una dificultad singular a la definición y vigilancia de las servidumbres aeronáuticas:

- Los sistemas montañosos ocupan prácticamente la mitad del territorio, con una altitud media de 660m, siendo uno de los países más montañosos de Europa, por detrás de Suiza, Austria, Grecia, Andorra y Liechtenstein.
- Su perímetro de costas es de 7.268km, con un total de 33 aeropuertos localizados a una distancia menor de 50km de la costa. Ello implica que existe un aeropuerto cada menos de 150km de longitud de litoral. Además, se da la circunstancia de que en las zonas costeras se concentra prácticamente la mitad de la población española. También cuenta con dos archipiélagos, donde son especialmente relevantes las características anteriores, especialmente en el Canario por su origen volcánico.

Según el Ministerio de Fomento, en la actualidad, las afecciones aeroportuarias alcanzan aproximadamente 30.000km^2 en todo el territorio español, afectando a más de 815 municipios. En términos porcentuales, sí sólo tenemos en cuenta los aeropuertos civiles vemos que sus servidumbres afectan a un 6% de la superficie del país y a un 10% de sus municipios.

Vemos, de acuerdo con lo anterior, la gran superficie que suponen estas servidumbres. Si consideramos algunas regiones españolas con importante densidad de población, se genera necesariamente mucha actividad para la autorización urbanística, especialmente en el área de las servidumbres de operación.

Observemos, por ejemplo, los casos de los Aeropuertos de Madrid y de Palma de Mallorca. Los contornos en azul corresponden a las servidumbres de operación y los contornos de color rojo a las servidumbres de aeródromo y radioeléctricas, definidas de acuerdo con [12].

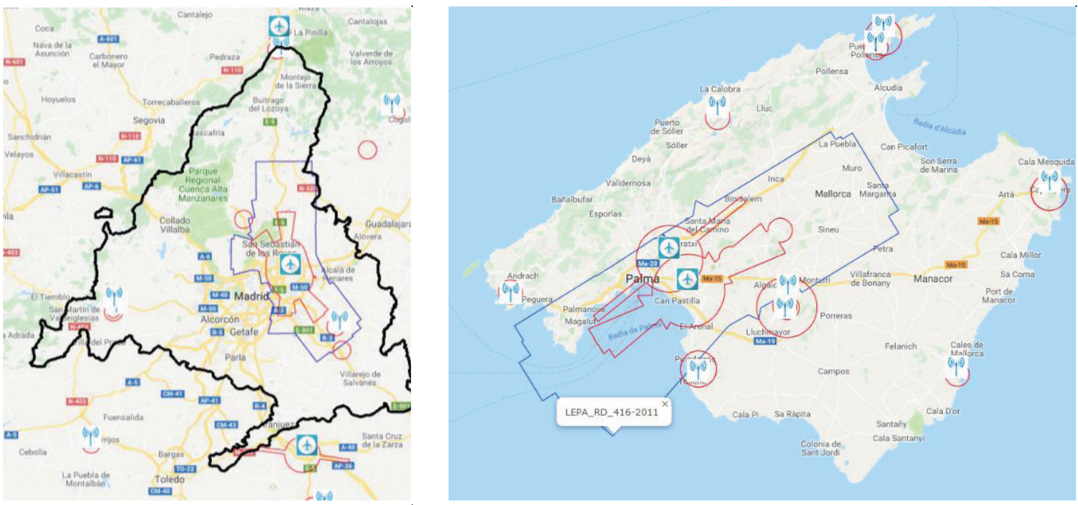


Figura 2: Aeropuertos de Madrid y Palma de Mallorca (DGAC y elaboración propia)

La provincia de Madrid tiene un superficie de 8.022km^2, mientras que el área de sus servidumbres de operación es de unos 1.320km^2, el 16.5%. En el caso de Palma de Mallorca, hablando exclusivamente del área terrestre, las servidumbres de operación afectan a 772km^2 de los 3.640km^2, un 21.2% de la superficie de la isla. Adicionalmente, debido a la ubicación habitual de los aeropuertos, muchos de ellos están situados en zonas limítrofes a la costa, donde la concentración de actividad es mayor, lo que redunda en un mayor conflicto entre el desarrollo urbano y las servidumbres.

Un ejemplo representativo de este último caso sería el litoral catalán de las provincias de Tarragona y Barcelona, condicionados por la servidumbres de los aeropuertos de Reus y Barcelona-El Prat, respectivamente. Vemos que, prácticamente, la totalidad del litoral estaría sometido al proceso de autorización de desarrollo en área de servidumbres aeronáuticas.

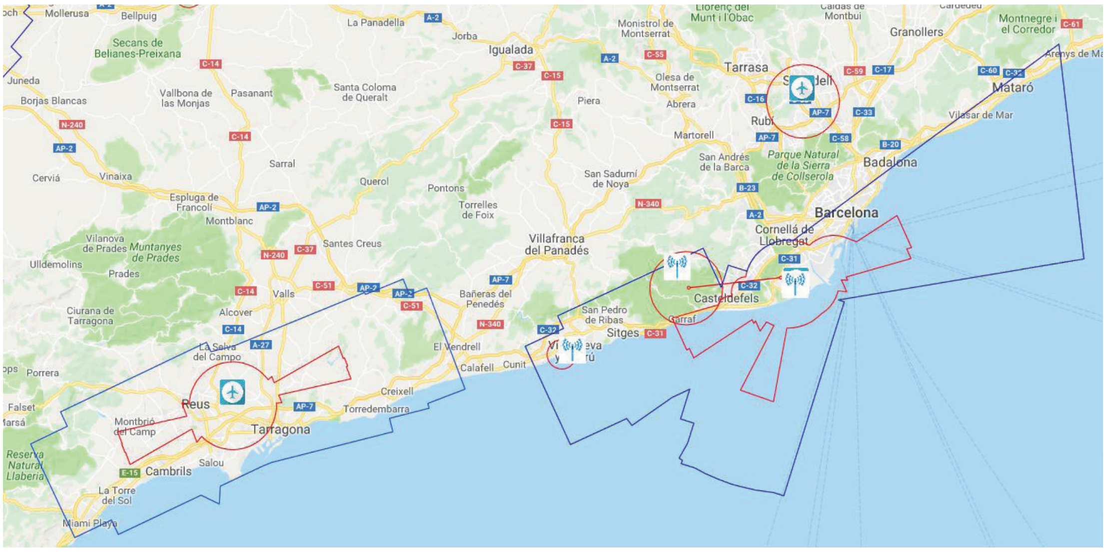


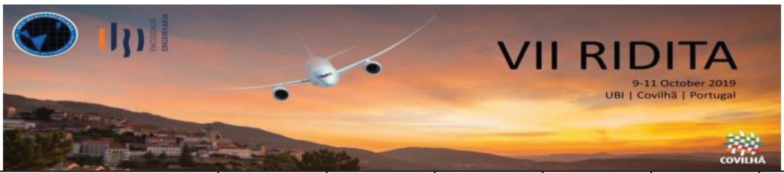
Figura 3: Aeropuertos de Reus y Barcelona (DGAC y elaboración propia)

Si el análisis lo extendemos a otros de los principales aeropuertos españoles, se puede apreciar la importancia de la afección[2]:

Tabla 1 (DGAC y elaboración propia)

Parámetro	**MAD**	**BCN**	**PMI**	**BIO**	**AGP**	**ALC**	**LPA**	**TFS**
Servidumbres de Aeródromo y Radioeléctricas								
Área (km^2)	360,3	246,0	206,9	253,8	199,2	158,8	134,5	175,7
Perímetro (km)	119,8	108,4	94,8	126,7	101,3	82,8	75,4	73,3
Longitud Característica (km)	32,0	32,0	33,2	32,2	30,1	30,0	27,1	27,0
Anchura Característica (km)	11,3	7,7	6,2	7,9	6,6	5,3	5,0	6,5
% superficie terrestre	100%	40%	64%	92%	63%	71%	49%	52%
Servidumbres de Operación								
Área (km^2)	1.320,3	1.494,1	1.154,5	1.361,1	1.003,1	966,6	811,0	265,7
Perímetro (km)	199,6	236,8	170,3	193,2	173,2	122,8	146,7	118,0

[2] MAD: Madrid, BCN: Barcelona, PMI: Palma de Mallorca, BIO: Bilbao, AGP: Málaga, ALC: Alicante, LPA: Las Palmas, TFS: Tenerife-Sur



Parámetro	MAD	BCN	PMI	BIO	AGP	ALC	LPA	TFS
Longitud Característica (km)	54,1	75,6	62,1	72,7	65,9	55,2	58,1	47,8
Anchura Característica (km)	24,4	19,8	18,6	18,7	15,2	17,5	14,0	5,6
% superficie terrestre	100%	22%	67%	78%	64%	60%	19%	23%
Relación Servidumbres ADRE/OP								
Área ADRE/OP (%)	27%	16%	18%	19%	20%	16%	17%	66%
Perímetro ADRE/OP	60%	46%	56%	66%	58%	67%	51%	62%
Longitud Característica ADRE/OP	59%	42%	53%	44%	46%	54%	47%	56%
Anchura Característica ADRE/OP	46%	39%	34%	42%	43%	30%	36%	117%
% Terreno adicional por OP	73%	84%	82%	81%	80%	84%	83%	34%

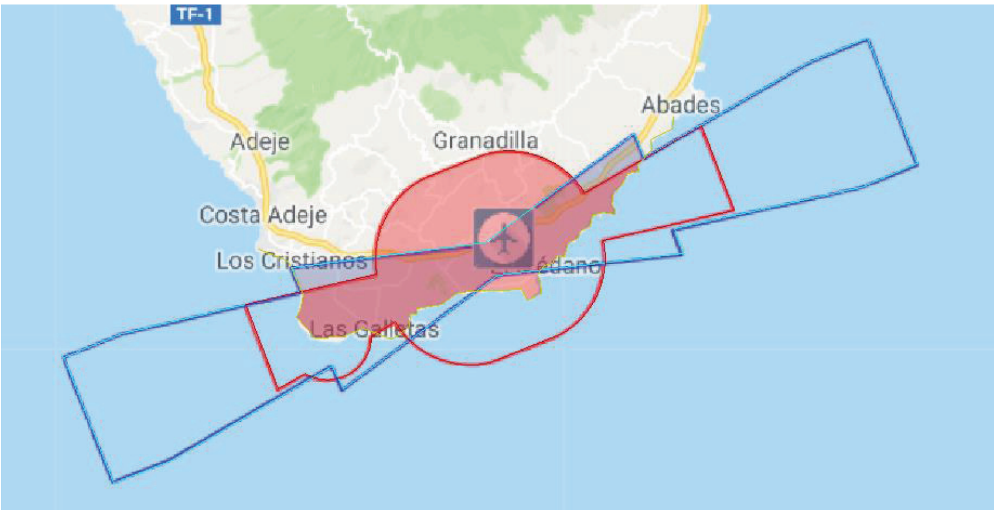


Figura 4: Aeropuerto de Tenerife Sur (DGAC y elaboración propia)

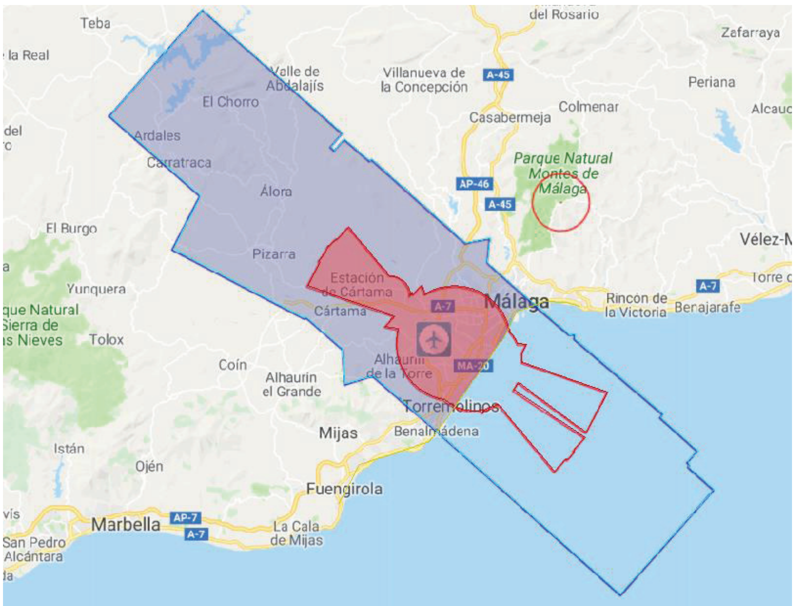


Figura 5: Aeropuerto de Málaga (DGAC y elaboración propia)

Se observa que, debido al imperativo legal de que la autoridad aeronáutica debe emitir informe previo, preceptivo y vinculante, sobre los instrumentos de planeamiento urbanístico, y a que los aeropuertos se suelen concentrar en las proximidades de las áreas de mayor concentración de población, el volumen de trabajo al que se tiene que enfrentar la Autoridad es muy importante.

Efectivamente, siempre que se esté dentro del área bajo el contorno de las servidumbres, es preciso informar por parte de la Autoridad Aeronáutica. Muchos casos no presentarán problemas, situándose incluso las construcciones varias centenas de metros por debajo de la superficie de las servidumbres, pero se generan dos problemas motivados por el proceso:

- El número de actuaciones urbanísticas que requieren autorización por parte de la autoridad aeronáutica es elevado, aunque a posteriori se compruebe que no generan afecciones a las servidumbres. Ello conduce a que los promotores tengan la tentación de eludir el proceso por la demora que pueda suponer su autorización.
- La autoridad aeronáutica tiene dificultades para identificar los casos realmente críticos dentro de todo el volumen de solicitudes que tienen que gestionar. Sería deseable gestionar menos casos, y que estos casos fueran los realmente importantes.

Nos encontramos ante un escenario en el que se maneja un volumen muy grande de información, y en el que no es sencillo discriminar para identificar lo realmente importante. En el análisis de obstáculos que pueden afectar potencialmente a las servidumbres aeronáuticas, no es tanto conocer todos los casos, sino los importantes y poderlos tratar adecuadamente. El intento de gestionar el vasto conjunto de posibles afecciones irrelevantes puede desviar valiosos recursos hacia fines poco necesarios.

Anualmente, la Autoridad Aeronáutica emite en España entre 7.000 y 8.000 informes de acuerdo, de los cuales más del 95% son favorables, y se realizan unos 700-800 informes de sobre planeamiento. Pese a este volumen tan importante, se sospecha que se solicita todavía mucho menos de lo que sería obligatorio.

La solución a esta situación se podría encaminar por dos vías concurrentes:

- Definición de unas servidumbres más contenidas y que respondan realmente a la necesidad.
- Elaboración de unos planes y proyectos urbanísticos que contemplen desde su origen los condicionantes aeronáuticos a los futuros desarrollos de dichos instrumentos urbanísticos.

En otros países de Europa con una orografía más benévola, como Alemania, se puede plantear un proceso más sencillo. Más que una restricción, las servidumbres aeronáuticas son un condicionante aeronáutico y urbanístico integrado en los propios planes urbanísticos de los municipios que se respeta al formular una nueva actuación.

En el Reino Unido el proceso es también más sencillo. Se aboga por un acuerdo previo entre el promotor urbanístico y el operador aeroportuario, o proveedor de servicios de navegación aérea. Sólo en caso de desacuerdo entre ambos se recurre a la Autoridad Aeronáutica.

En el caso de Francia, al igual que en España, se definen las servidumbres aeronáuticas mediante el *Code de l'aviation civile* y la guía técnica *Elaborathion des plans de servitudes aéronautiques* de la *Direction générale de l'aviation civile*. Se definen unas superficies limitadoras de obstáculos coherentes con las del Anexo 14 de OACI y unas superficies asociadas a las ayudas visuales.

Posibles enfoques para la solución del problema

Hemos visto que el procedimiento seguido genera una importante labor burocrática, no sólo por parte de la autoridad aeronáutica, sino también por parte de los promotores urbanísticos. Incluso, la justicia invalida frecuentemente planeamientos urbanísticos por defectos de forma si no se dispone del informe de la autoridad aeronáutica preceptivo para su aprobación.

Las posibles soluciones a la problemática deben provenir de parte de todos los agentes implicados:

<u>Por parte del operador aeroportuario</u>: Se debe ser consecuente con las decisiones técnicas que se adoptan en los aeropuertos, de la necesidad operativa de las mismas, y de las implicaciones que suponen en su entorno. Por ejemplo, si se pone en servicio un ILS CAT II/III se limitará el entorno de una forma más significativa, pese a que las compañías pueden mantener su aeropuerto de destino, sin desviaciones por razones meteorológicas.

<u>Por parte de la autoridad aeronáutica:</u> Es complicado reducir el procedimiento administrativo, dado que el Reglamento Europeo deja clara la necesidad de previo acuerdo al planeamiento urbanístico por parte de la autoridad aeronáutico.

Una solución más factible es reducir las servidumbres establecidas, concretamente las de operación. Ello no iría en contraposición con el contenido de la normativa europea e internacional.

Eliminar las servidumbres de operación según están actualmente definidas en España, se alinearía con lo establecido en otros países Europeos, y se reduciría en cerca de un 80% las superficies de las áreas afectadas por servidumbres.

Sin embargo, sería necesario garantizar la protección la maniobra de aterrizaje interrumpido. Para ello, las aproximaciones más inmediatas serían recurrir a una horizontal externa, ya prevista en [7], o diseñar una nueva superficie, como podría ser la resultante de prolongar la superficie cónica, menos exigente que la horizontal externa pero que cumple el objetivo.

<u>Por parte de las Administraciones con competencias urbanísticas:</u> Deben hacer un ejercicio de rigor en el que la legislación de rango superior sea respetada en todos los instrumentos urbanísticos de rango inferior.

Sería deseable no sólo disminuir el número de informes, sino que la autoridad aeronáutica recibiera un porcentaje más ajustado a la realidad de los planeamientos urbanísticos. De esta forma, se estaría en mejores condiciones de poder abordar los planeamientos más problemáticos. Sobreproteger no genera seguridad, genera indisciplina.

Algunas posibilidades en esta línea serían las siguientes:

- Indicar en los acuerdos de los informes de planeamiento urbanístico de alto nivel si sería necesario, y en qué casos, un nuevo acuerdo en los instrumentos de desarrollo. Lo ideal sería que en el acuerdo sobre el nivel más alto de planeamiento quede claro donde se debe solicitar autorización, y donde no, en los instrumentos de desarrollo futuros.
- En los instrumentos de desarrollo de las administraciones locales o municipios, el acuerdo debería incluir indicaciones que eviten análisis futuros. Por ejemplo, se pueden autorizar construcciones si no superan una determinada altura.

En las promociones urbanísticas concretas, se podría tratar de agrupar las autorizaciones individuales, que forman parte de la misma actuación conjunta. Por ejemplo, en un desarrollo de 300 viviendas se debería acordar una autorización global.

La realidad es que, en España, las áreas definidas como servidumbres aeronáuticas tienen una extensión muy grande. Al definir unas servidumbres de operación se incrementan las definidas inicialmente de aeródromo y radioeléctricas en porcentajes muy elevados, especialmente en los aeropuertos más importantes de la red y CAT II/III.

Tratamiento de otras servidumbres

Las servidumbres de actividades no están sometidas a superficies limitadoras, y están adecuadamente contempladas en la normativa nacional e internacional. Los explotadores de aeródromos vigilarán estas actividades para que no causen riesgos inaceptables para la seguridad aérea en los alrededores del aeródromo y adoptarán, dentro de su ámbito de competencia, las medidas de mitigación apropiadas.

En relación con los parques eólicos y elementos singulares de gran altura, en España se considera obstáculo a todo elemento singular que tenga una altura de más de 100m sobre el terreno, y requiere de una autorización por parte de la autoridad aeronáutica. El criterio es más crítico que el establecido por la normativa internacional, que fija dicha altura en 150m.

En España se ha producido un enorme desarrollo de la industria eólica en las dos últimas décadas, ocupando el 5º puesto en el ranking mundial. Se cuenta con 1.123 parques eólicos distribuidos en 807 municipios, un 10% de los municipios españoles, conformando un parque total de 20.306 aerogeneradores instalados [16].

Por otro lado, los aerogeneradores han visto aumentado su tamaño en los últimos años, siendo cada vez más habituales que las torres alcances los 100m de altura y el rotor los 80m de diámetro.

En Europa también es representativo el caso del Reino Unido pues, de la misma forma que ha sucedido en España, el desarrollo de parques eólicos ha tenido recientemente un importante impulso. La forma de garantizar la compatibilidad aeronáutica se realiza a dos niveles:

- A nivel estratégico, la CAA es representante de los intereses de la aviación civil en el Departamento de Energía y Cambio Climático (DEEC) y también es firmante de un Memorándum de Entendimiento, mediante el cual se compromete a trabajar juntamente con el DECC, NATS y los representantes de la industria de energías renovables para identificar medidas de mitigación e impulsar el desarrollo de estos proyectos.
- A nivel táctico se debe alcanzar un acuerdo entre el promotor del parque eólico y el proveedor de servicios de navegación aérea. Únicamente en caso de no alcanzar un acuerdo se recurre a la mediación de la CAA.

El caso de las servidumbres acústicas ha quedado discriminado del resto de servidumbres aeronáuticas. El motivo es que difieren en su finalidad, ya que las servidumbres acústicas vienen a determinar el nivel de inmisión acústica compatible con la garantía de la integridad personal e intimidad, en tanto que las aeronáuticas tienen por objeto garantizar la continuidad de la navegación aérea en condiciones de seguridad.

El RD 297/2013, en su disposición adicional única sobre servidumbres acústicas explicita que las servidumbres acústicas quedan fuera de su ámbito de aplicación y se regirán por su propia normativa.

Conclusiones

España presenta una relieve bastante diverso y una orografía elevada, características ambas que otorgan una dificultad singular a la definición y vigilancia de las servidumbres aeronáuticas.

Las servidumbres aeronáuticas de las infraestructuras de interés público están publicadas con rango legislativo. Se exige que se solicite autorización para cualquier nueva construcción que se realice en dentro del área de las servidumbres, aunque la construcción no penetre su superficie.

La autoridad aeronáutica emitirá un informe previo, preceptivo y vinculante, informando sobre la afección de las construcciones a las servidumbres. Se requiere una intervención activa de la autoridad aeronáutica con carácter previo para hacer frente a la indisciplina urbanística. El proceso de análisis de la información generada por las solicitudes de autorización en zona de servidumbres es prolijo, y requiere el análisis de una gran cantidad de información.

Las posibles soluciones se podrían encaminar en tres direcciones: racionalizar por parte de los operadores aeroportuarios las categorías de sus aproximaciones, reducir el área afectada por las servidumbres y flexibilizar el régimen de autorizaciones.

Se debe ser consecuente con las decisiones técnicas que se adoptan en los aeropuertos para la categoría de sus aproximaciones, justificando su necesidad rigurosamente pues pueden limitar su entorno de una forma muy significativa.

La propuesta de eliminar las servidumbres de operación supondría una reducción aproximada de un 80% en el área afectada. Sin embargo, se debería proteger la maniobra de aterrizaje interrumpido mediante una superficie una horizontal externa o una prolongación de la superficie cónica.

Esta propuesta debería vencer la inercia legislativa por parte de administraciones entre cuyas prioridades se encuentra en un lugar secundario la compatibilidad del desarrollo urbano con las operaciones aéreas.

La autoridad aeronáutica debería diseñar una metodología que, manteniendo el preceptivo acuerdo por su parte, simplifique el proceso actual.

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Regional airport site location: proposal of an objective decision making framework for the Brazilian public sector

Cláudio Jorge Pinto Alves - claudioj@ita.br
Aeronautics Institute of Technology
Carlos Müller - cmuller1954@gmail.com
Aeronautics Institute of Technology
Giovanna Miceli Ronzani Borille - ronzani@ita.br
Aeronautics Institute of Technology
Marcelo Xavier Guterres - guterres@ita.br
Aeronautics Institute of Technology
Evandro José da Silva - evandro@ita.br
Aeronautics Institute of Technology

Abstract
Airport site selection requires consideration of several criteria through complex trade-offs. The literature and the practice provide valuable insights in terms of influencing factors and multicriteria assessment methods. However, subjectivity remains from the underlying assumptions.
The method consists of: i) airport site selection criteria, from literature review; ii) criteria classification in two categories: a criteria may be either eliminating or scoring; iii) selection of appropriate metrics for every selected criteria; iv) assessment of public available databases, regarding selected criteria; v) proposal of an airport site identification method, applying eliminating criteria; vi) proposal of a ranking method, applying scoring criteria by means of an AHP method.
National public sector decision makers recognize that such methodology has the potential to improve the allocation of federal budget for new regional airports, in terms of implementation time and political friction. Several Brazilian regions rely on air transportation, given the continental dimensions and underprovided ground infrastructure. New airports may be expected in the country, as the regional economies develop and the airport funding is made available.
This research aims at developing a methodology to reduce subjectivity in the process of regional airports site selection in Brazil. In order to reduce AHP subjectivity, measured data will be favored against experts input when possible. The proposed methodology is well-timed for Brazil practice and fills a literature gap towards a more objective airport site selection decision process.

Keywords
Airport site selection; Multicriteria assessment; Analytic hierarchy process; Public sector

Regional airport site location: proposal of an objective decision making framework for the Brazilian public sector

1. Problem statement

Brazil is a continental country with a disperse occupation pattern and poor road and rail infrastructure. As a result, air transportation is crucial for the country's economy, defence and accessibility. Regional airports have been historically ran by local governments, either states or municipalities with federal capex contribution.

Given local interests and the federal role in funding, regional airports infrastructure decisions are taken in a complex environment, with several technical, political and economic inputs. While the federal government might be in charge of specific air transportation infrastructure, such as runways and air navigation services, the local governments use to provide road access, water supply, among others. The decision problem regards the expansion or construction of new airports and the supporting infrastructure.

In some instances, the existing airports are remote from existing demand generating centres, hindering air transportation development. In other cases, existing airport infrastructure is not considered eligible for improvements, due to unfavourable topography or urban encroachment. In such cases a new airport site must be found.

Airport site selection is a customary, but still challenging task for worldwide governments and companies. There are numerous criteria to be taken into account, requiring multidisciplinary teams to go through complex and sometimes subjective trade-offs.

This paper proposes a methodology for regional airports site selection based on GIS (Geographic Information Systems) technology and multicriteria decision making. This method, hereafter referred to as MESA (Metodologia de Escolha de Sítios Aeroportuários, in Portuguese, which means Airport Site Selection Methodology), has been applied to a real case in Brazil. The envisioned model deals only with a micro scale problem: the decision to build an airport to serve a city or group of cities has already been made. The initial search region is then restricted to some tens of kilometres.

1.1 Objectives

The purpose of this study is to propose a methodology for regional airport site selection in the Brazilian context. Such methodology is intended to be sound under technical criteria and reduce subjectivity in the decision making process.

It is assumed that the decision to build the airport to serve a given city or group of cities has already been made.

1.2 Article structure

Section 1 presents motivation and the context of regional airport site selection in the Brazilian case. Section 2 addresses the literature on facility site selection, bringing insights on airport site selection from sectors such as energy production and waste disposal. Under Section 3, the proposed site selection decision framework is disclosed. Sections 4 and 5 discuss the study results and conclusions, respectively.

2. Analysis of the literature on facility site selection

The problem of facility site selection is a legacy, albeit current topic for scholars and practitioners. Logistic issues such as transportation costs and response time are the most prevalent topics in the literature. However, there are industry specific topics related to facility location as in the case of wind farms, nuclear power plants and airports, to name a few. Next topics bring a concise perspective on facility location problems.

2.1 Airport location problems

Classic textbooks such as [1] and [2] refer to airport site selection as a multicriteria, multidisciplinary problem, but any methodology is given.

Aviation bodies such as [3], [4] and [5] do not provide standards or guidelines for a systematic airport site selection process.

Research on scientific literature returned no results for airport site selection method. The next topics in this section serve a dual purpose: provide the reader with a broader perspective in the field of facility site selection; and explore the literature to promote new approaches for the airport site selection problem.

2.2 Classic facility location problems

In logistics and supply chain problems, transportation costs are crucial factors. The classical gravitational model as presented in [6], accounts for the distance between consumers and suppliers, as well as the amount of goods (mass or volume) and the transportation fare. Facility position is addressed in a continuous 2D basis.

As the continuous model becomes unrealistic, a discrete site selection model can be applied. MIP (Mixed Integer Programming) is usually employed to assess facilities already identified in terms of costs and other factors. A comprehensive approach on discrete site location models may be found on [7], encompassing p-medians model, capacitated facilities, network covering problems, routing problems, among others.

Although continuous and discrete network models are important in terms of transportation network design, airport sites are complex transportation nodes, requiring high investment, and strict operational criteria. As a result, industry specific issues must be incorporated on the airport site selection process.

Section 2.3 deals with site selection problems on an industry specific perspective. The studies were searched at Science Direct web portal by combining terms such as “site selection”; “infrastructure” and “facility”. The studies were selected by their apparent relevance to the methodology proposed in the present research. Hence, the following literature discussion is not intended to be exhaustive.

2.3 Facility location problems in different industries

As discussed in [8], wind farm location must consider several economic, environmental and social factors. This study, developed in the Nigerian context, is methodologically based on GIS (Geographic Information Systems) and a type-2 fuzzy analytic hierarchy process. The whole country is considered as the study area. The considered criteria are used to exclude some areas (eliminating criteria) and also to prioritize the most suitable ones (scoring criteria). The criteria are organized in the Table 1.

Table 1-Criteria used in a Nigerian wind farm location study
Source: Authors of [8]

Role on methodology	Category	Criteria	Rejection Threshold
Scoring/Eliminating	Economic/Technical	Wind speed (m/s)	<4.4 m/s
		Terrain slope (%)	>15%
		Proximity to gridlines (m)	<250m
		Proximity to roads (m)	< 500m or >10.000m
	Environmental/Social	Urban Areas proximity	<2.000m
Eliminating	Environmental/Social	Land cover	-
		Protected areas	500m buffer
		Rivers/Water bodies	200m buffer
		Airport proximity	<5.000m
		Important Bird Areas	300m buffer

As described in [8] a buffer is applied for environmentally protected areas and neighbouring airports. Scoring factors are given eliminating thresholds in order to avoid the burden of considering areas that are not expected to be selected. The summarized methodology framework involves the following steps: determination of assessment criteria; collection of experts' opinion; collection of map data; calculation of criteria weights; generation of the candidate sites maps and extraction of unsuitable areas. The final result is a map of the areas with a colour scale for wind farm site suitability.

A similar approach is applied in [9] for nuclear power plant site selection in Turkey, employing GIS technology and multicriteria decision methods. A coloured map is generated after several eliminating and scoring criteria are processed. The study designated criteria are shown in Table 2.

Table 2-Criteria used in a Turkish nuclear power plant location study
Source: Authors of [9]

Role on methodology	Criteria
Scoring/Eliminating	Capable faults
	Seismicity
	Existence and sufficiency of cooling water
	Population
	Elevation and Flood Level
	Topography and Slope
	Environmental sensitivity
Eliminating	Proximity to national borders
	Proximity to hazardous facilities
	Proximity to transport infrastructure
	Proximity to electrical grid

On a methodological point of view, [9] differs form [8] due to use of WLC (Weighted Linear Combination) for criteria analysis. This method is quite straightforward and consists of direct weight assignment to each criterion.

As proposed in [10], a coloured map was prepared from AHP (Analytical Hierarchy Process) and GIS for a landfill site selection process in Turkey. The method is similar to [8] and [9]: some areas are excluded and the others are given weights. An interesting buffering technique is employed through GIS processing: areas are classified by proximity and weights are given for each class. This technique dismisses classical AHP expert alternatives pairwise comparison This is a step toward subjectivity reduction, but there is still an underlying decision about class structure.

The method proposed in [11] considers economic, social and environmental criteria in wind farm location in South Korea. The method splits the social and environmental criteria in soft and hard sets. The hard criteria are employed for elimination of areas. On the other hand, the soft criteria are disposed in a binary map layer, depicting areas of possible conflicts of land use. The economic criteria are studied in terms of NPV (Net Present Value) and the results are depicted in a coloured map layer. By comparing NPV and soft constraints in a single map, it is possible to identify the most favourable sites in the feasible area.

2.4 Remarks on the literature analysis

Current airport literature presents a gap in terms of airport site selection methods, despite the problem is acknowledged in classical textbooks. By moving the problem on hand to a broader perspective, namely the facility location problem, one can find a wide body of literature.

From the classic facility location literature, analytical models can be found to cope with transportation costs, facility fixed costs, network covering, among others. These models fail to represent local airport environment in the scope defined for the herein proposed method.

Studies about facilities as wind farms, landfills and nuclear power plants present interesting approaches that eventually can be adapted for the airport site selection in the micro level. The discussed studies make use of GIS technology for generating maps by which different layers can be analysed. Some layers are used to eliminate areas, while others relate to suitability for a given facility.

Facility specific location studies use to employ multicriteria methods, along with GIS technology. They account for local factors, but there is any indication of whether a given area in the map can actually lodge the facility. See Figure 2 discussion to understand this idea.

3. MESA Framework

The goal of the proposed methodology, MESA, is to provide a regional airport site selection process when the region to be served has already been defined. The process is intended to be technically sound and as objective as possible. This section presents the proposed framework, which provides the grounds for the next steps of the MESA development.

Figure 1 exhibits the four phases of MESA framework. By following those phases, the method can be created and revised or adapted in the future.

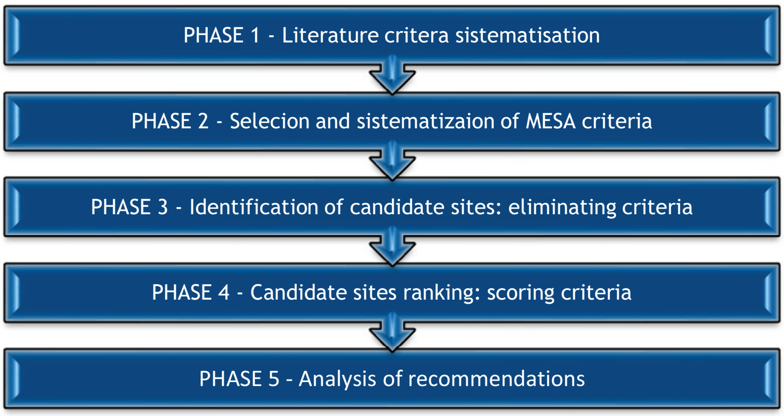

Figure 1 – MESA framework
Source: The authors

Phase 1 concerns literature research in order to find out the possible criteria for airport site selection. Contributions from practitioners are relevant in this phase, as well as scientific articles.

Phase 2 relates to criteria selection. As the scope of the method under development is stricter than the analysed literature, there is a need for criteria selection and systematisation. Besides that, new criteria might be added, given the envisioned objectives for the method under development.

Phase 3 relates to the establishment of proper selection/rejection thresholds and the sequence for the elimination of areas. MESA relies on site identification, rather than the continuous spatial approach applied to the studies discussed under section 2.3. Hence, a point in space is only feasible if the surrounding points are also feasible and able to form together a unitary geometry. This concept can be better understood from Figure 2. Consider the figure is a raster map where 0 (purple) stands for eliminated areas and positive values stand for feasible areas. The higher the pixel value, the better the score is. Now assume that the searched arbitrary site must be 2 pixels in size. In this case, the 2 yellow pixels in the northeast corner are impractical, despite their high scores. MESA accounts for this rule, as the candidate airport sites are identified manually from the map.

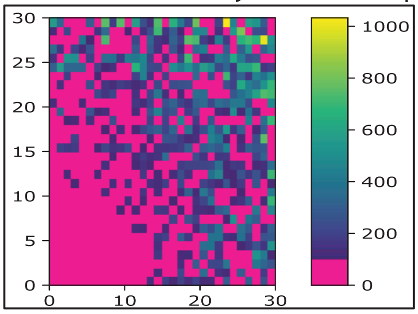

Figure 2 – Raster illustration: continuous versus unitary approach
Source: The authors

Phase 4 regards candidate sites ranking. Given the scoring criteria, a method is required to produce the proper scores for every candidate site.

The MESA departs from this very concise and generic framework, evolving for the specificities of the next sections.

3.1 MESA Phase 1

From [1], [2], [12] , [13], [14], [15], [16], [17], [18] e [19] airport site selection criteria were obtained, as shown in Table 3,totalizing 24 criteria.

Table 3-Airport site selection criteria, sorted by frequency in the literature, in a group of ten points
Source: The authors, from several sources

Acronym	Description	[1]	[2]	[12]	[13]	[14]	[15]	[16]	[17]	[18]	[19]	Freq.
WAY	Existence of roads	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	10
OBS	Obstacles to airspace	✓	✓	✓	✓	✓	✓	✓		✓	✓	9
DIM	Dimension of the site		✓	✓	✓	✓	✓	✓		✓	✓	8
DSC	Social induced development	✓	✓	✓		✓		✓	✓	✓	✓	8
MET	Meteorology (winds)	✓	✓	✓	✓		✓	✓		✓	✓	8
NOI	Noise	✓	✓	✓	✓	✓	✓	✓			✓	8
URB	Urban development proximity	✓	✓	✓	✓	✓	✓	✓			✓	8
ASP	Airspace Conflicts		✓	✓	✓		✓	✓		✓	✓	7
CRY	Cost of runway implantation	✓	✓	✓				✓	✓	✓	✓	7
DIS	Distance to city trip production	✓	✓	✓	✓		✓	✓			✓	7

[continues]

Acronym	Description	[1]	[2]	[12]	[13]	[14]	[15]	[16]	[17]	[18]	[19]	Freq.
GEO	Geology	✓	✓	✓	✓		✓	✓			✓	7
AOU	Availability of Utilities	✓	✓	✓	✓			✓			✓	6
CBD	Cost of terminal implantation		✓	✓				✓	✓	✓	✓	6
DEC	Economic induced development		✓	✓				✓	✓	✓	✓	6
IMP	Impacts over environment	✓	✓	✓				✓			✓	6
TOP	Topography: related to earthworks	✓	✓		✓		✓	✓			✓	6
CLD	Cost of land		✓	✓				✓		✓	✓	5
DAN	Dangers (as smoke, birds, etc.)	✓	✓		✓		✓			✓		5
ENV	Protected areas (environment, cultural,etc.)	✓	✓	✓				✓			✓	5
TRP	Public Transportation		✓	✓	✓			✓				5
PUB	Public support of local communities			✓							✓	2
COP	Cost of airport operations									✓		1
SEC	Security issues								✓			1
SUP	Suppliers availability in the region										✓	1
TEC	Technological trends									✓		1

3.2 MESA Phase 2

From the Table 3, the 24 criteria were analysed in order to produce the MESA criteria. It is important to discuss the supporting rationale for the analysis:

- MESA is intended for a region restricted to kilometres or tens of kilometres. As a result, any criterion that is not expected to vary within this geographic region should not be considered;
- Some criteria correlate and must be eliminated to simplify the decision process;
- Some criteria are too complex and must be split to better reflect site options.

With this rationale in mind and the justifications of Table 4, MESA is proposed with 15 criteria.

Table 4-MESA criteria analysis
Source: The authors

Acronym	Description	Action	Justification
WAY	Existence of roads	Grouped	In regional airports, access is made mainly by road, which means that an airport with neighbor roads is expected to be accessible. TRP and WAY were grouped to form ACE
OBS	Obstacles to airspace	Kept	A new airport should be free of obstacles, maximizing its efficiency
DIM	Dimension of the site	Kept	Candidate site must be wide enough to lodge the airport
DSC	Social induced development	Removed	As the region is small enough, airport existence will induce the same effect at any location
MET	Meteorology (winds)	Kept	
NOI	Noise	Kept	
URB	Urban development proximity	Kept	
ASP	Airspace Conflicts	Kept	
CRY	Cost of runway implantation	Removed	Geology and Topography correlated
DIS	Distance to city trip production	Kept	
GEO	Geology	Kept	
AOU	Availability of Utilities	Kept	
CBD	Cost of terminal implantation	Removed	Geology and Topography correlated
DEC	Economic induced development	Removed	Same as DSC
IMP	Impacts over environment	Kept	*[continues]*

Acronym	Description	Action	Justification
TOP	Topography: related to earthworks	Split	Split into TAL e TVL
CLD	Cost of land	Removed	This criterion is left for final decision after site rankings
DAN	Dangers (as smoke, birds, etc.)	Kept	
ENV	Protected areas (environment, cultural, etc.)	Kept	
TRP	Public Transportation	Grouped	In regional airports, access is made mainly by road. The existence of roads allows development of transportation in the future airport. TRP and WAY were grouped to form ACE
PUB	Public support of local communities	Removed	Not frequent in literature
COP	Cost of airport operations	Removed	As the region is small enough, airport site will induce the same cost
SEC	Security issues	Removed	Not frequent in literature
SUP	Suppliers availability in the region	Removed	Not frequent in literature. Obs.: in remote regions this criterion might become important
TEC	Technological trends	Removed	Not frequent in literature and very difficult to account for
ACE	Accessibility to airport	New	TRP and WAY were grouped
TAL	Topography: Maximum elevation difference	New	TOP was split into TAL e TVL
TVL	Topography: earth work volume	New	TOP was split into TAL e TVL

The next phase of MESA is to establish the thresholds and sequence through which improper areas will be eliminated from the search.

3.3 MESA Phase 3

From the Table 4, the 9 eliminating criteria were extracted:

Table 5-MESA final eliminating criteria
Source: The authors

Acronym	Description	Thresholds	Justification
OBS	Obstacles to airspace	Every candidate site should be checked for ICAO Annex 14 ([20]) airspace protection surfaces.	Brazilian regulations are quite similar to Annex 14.
DIM	Dimension of the site	A geometric shape that accommodates airport ultimate development plan.	In MESA, a rectangle is used to represent such geometry.
MET	Meteorology (winds)	The geometric shape must be oriented according to wind rose limits.	
URB	Urban development proximity	2km from the urban landscape.	Based on the group experience.
ASP	Airspace Conflicts	20 km for operations under IFR (Instrument Flight Rules), preventing closer proximity to nearby airports. Outer horizontal surfaces of nearby aerodromes cannot overlay.	Keeping these areas free of overlays does not guarantee independence of flight procedures. Obs.: based on ICAO Annex 14 ([20]).
IMP	Impacts over environment	Any area to be avoided for environmental reasons in addition to ENV criterion.	
DAN	Dangers (as smoke, birds, etc.)	20 km from landfills or equivalent facilities.	Distance from landfills is defined by Brazilian regulations ([21]).
ENV	Protected areas (environment, cultural, etc.)	Conservation areas (e.g. national parks), and Permanent Protection Zones (PPZs) are strictly avoided.	As defined by Brazilian legislation, these areas are strong restrictions. *[continues]*

Acronym	Description	Thresholds	Justification
TAL	Topography: Maximum elevation difference	A maximum of 20m in difference of elevation inside the candidate site, according to DIM.	This threshold might be adjusted depending on local topography conditions.

Afterwards data collection, the process depicted in Figure 3 is applied. This will produce a map of feasible regions from which candidate sites can be identified. The sequence follows a simple heuristics: the simpler geoprocessing with impact on larger areas is prioritized.

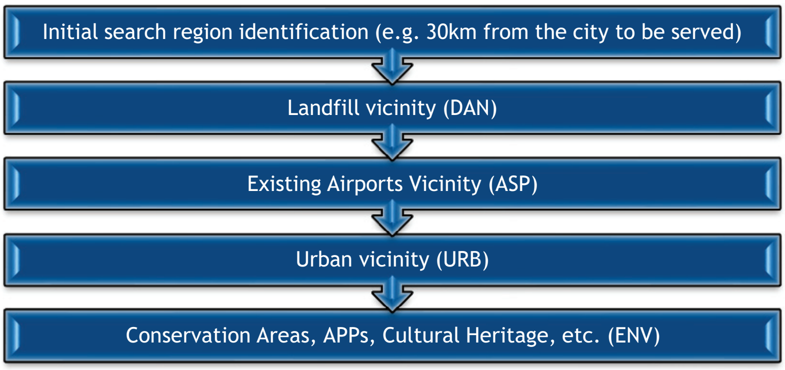

Figure 3 – MESA Phase 3- Initial search region reduction
Source: The authors

Once original region is reduced progressively without any need for site identification, there are some criteria that require the specific site to be identified. The identification process is manual in this version 1.0 of MESA. Basically, the site geometry is drawn and fitted in the feasible region of the map. Figure 4 illustrates this process.

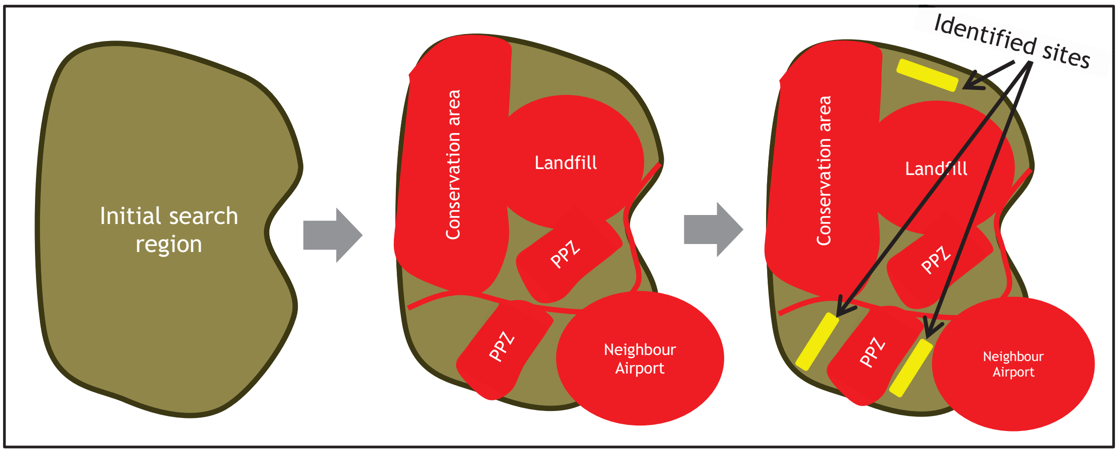

Figure 4 – MESA Phase 3- Illustration of initial search region reduction and site identification
Source: The authors

The number of sites to be identified depends on a trade-off: too many sites would require a lot of work on phase 4 (which in turn requires field surveying); fewer sites would lead to a limited number of options for final decision makers. Besides that, it is possible that many candidate sites are abandoned throughout field investigation, as long as critical issues are verified. Figure 5 depicts the process involved in site identification.

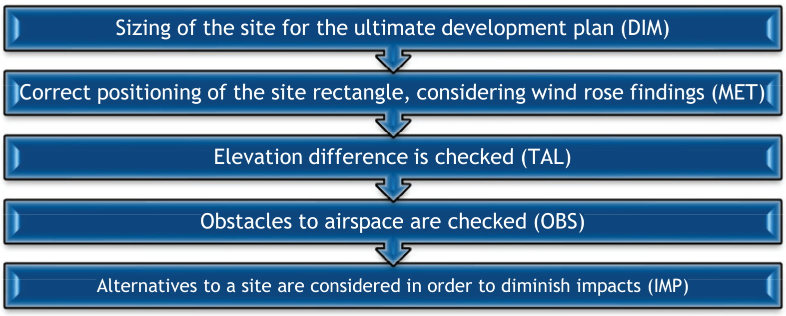

Figure 5 – MESA Phase 3- Site identification
Source: The authors

Since the candidate sites are identified, MESA phase 4 is undertaken.

3.4 MESA Phase 4

From the Table 4, the scoring criteria may be taken, as summarized in Table 6. Only 2 criteria are intrinsic to airport site (on-site criteria). The other 4 keep some relation with the airport surrounding environment.

For compliance with study initial goals, MESA intends to be as objective as possible. For this reason, every criterion of Table 6 was defined considering the underlying possible quantitative measures.

Table 6-MESA final scoring criteria
Source: The authors

Acronym	Category	Description	Measures
NOI	Off-site	Noise	Number of buildings affected by the candidate site
DIS	Off-site	Distance to city trip production	Distance to demand centroid (s) in km
GEO	On-site	Geology	3 different points of soil area locally surveyed according to DCP (Dynamic Cone Penetrometer) technique
AOU	Off-site	Availability of Utilities	Distance to power grid in km
ACE	Off-site	Accessibility to airport	Euclidean distance to the closest public road
TVL	On-site	Topography: earth work volume	Estimation of total earthwork in m^3

The six selected site classification criteria presented above are considered to be the most relevant for the regional airport site selection process in Brazil. One may ask for other classification criteria, such as land based transport availability, for instance. Careful thought has been given to all such alternative criteria. In this case one must realize that the land accessibility criteria and the distance to the demand generation centre criteria helps in the understanding of the land based transport availability. The first takes into account the distance from the site to the available road grid and the second takes into account how far the site is to town. Considering that in Brazil the main access mode to airports is by automobile (86.8% when considering personal car, taxi, rental and app vehicles, leaving public and other means of transport to account for only 13.2%) these two classification criteria should suffice for that matter. Furthermore, the use of public transportation in Brazil is small even at airports in large cities such as Rio de Janeiro (Santos Dumont Airport with 5.3% bus access), São Paulo (Congonhas Airport with 5.8% bus access), Curitiba (Afonso Pena Airport with 11.0% bus access) and Porto Alegre (Salgado Filho Airport with 13.0% bus access), according to the latest available survey [23].

In this phase of MESA, more detailed information is necessary. All the criteria, except GEO, can be studied in office if enough aerial and/or satellite data is available. Notwithstanding, field visits are recommended in phase 4 to confirm previous office work. The criterion GEO requires field visits to get soil data as long as soil bearing capacity data is usually published under too coarse scales. After the site visits are completed and the collected data are treated, weights must be given in order to compare criteria of different natures. From the literature, plenty of multicriteria methods could be applied.

MESA adopts AHP technique under AIP (Aggregation of Individual Priorities) paradigm, as discussed in [22]. Under this technique, experts are heard about pairwise judgements of the decision criteria. Once criteria are already weighted, one can gather the measures of Table 6 and rank the candidate sites.

It is recommended that the team of experts contains at least 8 members, sufficiently diversely distributed, comprising sectors such as, airport construction, airlines, airport regulation, regional development, transportation planning, economics and the academy. At least half of the experts are required to be airport design or airport construction experts. In order to reduce decision bias, it is recommended that the candidate sites are not disclosed to the experts before judgements are carried out .

MESA team developed a web app to collect expert inputs online. This is a possible strategy to prevent experts from going through a persuasion campaign, as direct experts contact is avoided. Figure 6 shows the app in current version. The expert is informed about inconsistencies on runtime and his (or her) final weight appears graphically on the screen.

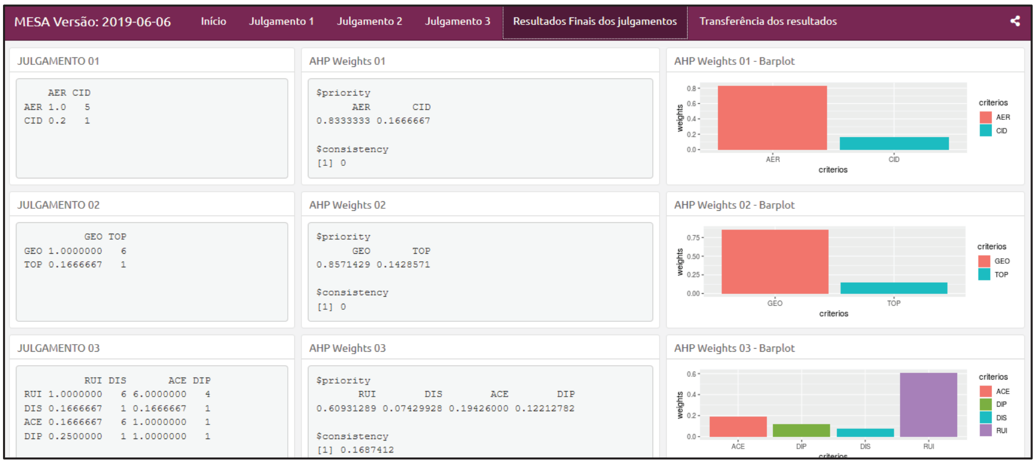

Figure 6 – MESA Phase 4- AIP app
Source: The authors

3.5 MESA Phase 5

After the sites are ranked, a report must be prepared, containing all the results and assumptions. MESA is not intended to make a final decision, but rather support decision makers with technical information. Field visits are of utmost value for gathering all the complementary information and in order to verify the office assumptions and findings.

4. Discussion of results

MESA is going through its first application in a regional airport in Brazil. Phase 3 is already completed and phases 4 and 5 are scheduled to be completed in 2019. It is possible that adjustments arise during the next phases, but the proposed framework can already be considered effective, given the feedback from stakeholders.

From the application case, it was found that combining GIS with classical techniques is a powerful tool for airport site selection. Through MESA, the team has been able to remotely analysing a region, processing land exclusions and identifying candidate sites so far. The identified sites were presented to the local government and field surveys were undertaken. Field data confirmed GIS office work with sufficient accuracy. Social and environmental impact of identified sites seems to be minimal in the studied case. Our expectation is that one of MESA identified sites will become in fact a regional airport in Brazil, judging from the sites suitability.

5. Conclusions and future work

Besides the envisioned objectivity and technical quality, MESA is demonstrating to be a powerful tool to reduce environmental and social impacts, as the candidate sites incorporate such concerns from the very beginning of the process. Possibly, the main gain of the method is the use of GIS technology, bringing together dozens of layers in a systematic and objective decision process. Another contribution comes from the fact that experts are not required to directly judge alternatives, as direct measures are applied.

A weak point of MESA is its dependence on remote sensing data. However, such data is central on minimizing social and environmental impacts, leading to a streamlined airport design process. As the World gets more connected and more digital, one can expect that data quality and availability will improve over time. However, this cannot be taken for granted. It is important that public decision makers add some efforts in GIS data collection, processing and distribution, as several sectors can benefit from it.

This work has at least 3 relevant possible future developments:

I. Automation of site identification in MESA phase 3, reducing tedious work and augmenting the number of alternatives to be studied.
II. Investigation of different sequences in the decision making process, in order to optimize computational time; and
III. Development of a sensitivity analysis procedure for MESA phase 4: as the expert inputs and marginally changed, what happens to candidate site rankings?

MESA GIS efforts are out of the scope of this paper and will soon be addressed in a specific publication.

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Air transport as an instrument of territorial cohesion: the case of time availability in the Canary Islands (Spain)

Jose Angel Hernandez Luis - jose.hernandez@ulpgc.es
Universidad de Las Palmas de Gran Canaria

Abstract
The main objective is to implement a methodology for the analysis of the hourly accessibility of an air traveler, based on the fact that it is as important as the fare, connectivity or availability of seats.
We carry out a methodological analysis in which the availability of time resulting from a door-to-door system is studied (between 2006 and 2019). The basic principle is that the round trip air is done on the same day. This helps us to assess the degree of territorial cohesion, taking an island system as an example (the Canary Islands), since for the islands, hourly accessibility is essential.
From the point of view of the results, we discover that the inhabitants of the islands with less demographic and economic weight, demanding a greater degree of air transport, have notable deficiencies in terms of time accessibility, leading to significant extra costs attributable to overnight stay at destination, proposing alternatives.
This work presents the partial results of a project prepared for the Government of the Canary Islands, where, among others, a methodology for calculating the availability of door-to-door time was developed.

Keywords
Planificación del transporte aéreo; Accesibilidad horaria; Cohesión territorial; Insularidad

Air transport as an instrument of territorial cohesion: the case of time availability in the Canary Islands (Spain)

Introduction

The main objective of this research is focused on the access of citizens of the Canary Islands to travel to other islands by plane, regardless of their island of residence. We measure this accessibility in travel times, such that we assess inter-island air travelers' ease to reach the functional places (essentially, administrative and/or commercial) of other islands and to return on the same day to the island of origin, in order to avoid high costs—or loss of time—involved an overnight stay at the destination.
In this sense, many European cities have implemented transportation policies to solve the problems faced by citizens when using public means of transport, in particular, trying to reconcile transportation timetables with the accessibility to the functional places. The present work is along these lines, applying a similar methodology but for a discontinuous territory such as islands.
We start from the basis that inter-island transport is extremely important for islands (Eurisles, 1996; Rutz & Coull, 1996; Hoyle, 1999; Sjølander, 1999; Sambracos & Rigas, 2007) and, in particular, for the Canary Islands (Sri International, 1992; Hernández Luis, 2004, Ramos Pérez, 2015). Inter-island transport is used very much for industrial, commercial, business, and health matters, administrative issues, etc., and therefore, many inter-island trips are taken on a single day. By the same token, inter-island transport—and not only by air, but also maritime transport—is very susceptible to changes of schedules, seat availability on certain days and hours, a minimum of spare time at destination to allow returning on the same day, etc. All these factors reveal certain quality indices and have a direct impact on the socio-economy of the Islands. These indices, among others, result in the philosophy of the *Trans-European Network of Transports*, which integrates of the citizens of the European Union at all levels, beginning with the improvement of accessibility, especially for the peripheral regions (Coccossis & Nijkamp, 1995; European Commission, 2011; European Commission, 2011).
Finally, in the present work, we first make a brief sketch of the territorial framework of the Canary Islands, and then present air transport in the Islands as a fundamental tool for the development of the archipelago. Therefore and, above all in inter-island transport, time availability is vital for territorial cohesion. We indicate a methodology for its calculation between island capitals, based on the door-to-door system, taking as example the winter schedules of the different aircraft operators between 2006 and 2017.

Literature review

The importance of air transport for island systems is essential because the islands are clearly at a disadvantage when compared with continental territories. We highlight several works that reveal the importance of air transport, as well as the complementarity between maritime and air transport (Gobierno de Canarias, 1985; Ray, 1985; Rutz & Coull, 1996; Hernández Luis, 2006; Polydoropoulou & Litinas, 2007; Rigas, 2009). The particularity of the islands is compounded by their obvious territorial discontinuity, accompanied by their remoteness, to which is generally added the total absence of raw materials, causing the islands to rely even more on transport systems. This has been shown in diverse literature, among which we emphasize the following works: Brookfield (1980), Coccossis and Nijkamp (1995), Eurisles (1996), Gobierno de Canarias (1998), Cross and Nutley (1999), Hoyle (1999), Button and Taylor (2000), Bowen (2000), Fundación Tomillo (2001), Guillaumin (2001), Ramos Pérez (2001), Hernández Luis (2002), Yamaguchi (2007), Tsekeris (2009), Hazledine and

Collins (2011), Minato and Morimoto (2011), Kille, Bates and Murray (2013), and Ramos Pérez (2015).
Aside from the island or continental spaces, increasingly more contributions emphasize travel times and their implications for people's availability (Hernández Luis, 2002; Liu & Zhu, 2004; Yamaguchi, 2007; Jain & Lions, 2008; Rigas, 2009; Chang, 2010; Lei & la Iglesia, 2010; Benenson, Martens, Rofé & Kwartler, 2011; Grubesic & Fangwu, 2013; Price & Matthews, 2013; Chowdhury, 2015).
However, and more specifically, some works have analyzed the impact of the availability of public transport on certain functional places, such as businesses or administrations, conditioned primarily by their opening hours and their compatibility with the public transport schedules (Nutley, 1983; Rodríguez, 1989; López Lara, 1990; Niemeier, 1997; Nutley, 1998; Cross & Nutley, 1999; Hernández Luis, 2000; Nutley, 2005; Yamaguchi, 2007; Neutens, Delafontaine, Schwanen & Van de Weghe, 2012). Thus, this work is presented following these lines, and we have especially taken into account the accessibility of the insular spaces of lower socio-economic weight, such as the so-called outlying islands of the Canary Islands (Lanzarote, Fuerteventura, La Gomera, El Hierro, and La Palma), because their inhabitants have the greatest need to travel to the central islands of Tenerife and Gran Canaria, in view of the lack of specialized commercial, health, or administrative services on these islands.

Brief territorial framework of Canary Islands

The Canary Islands have increased their population by 120% in the past 50 years, reaching 2.1 million inhabitants in 2015. This, together with the increase of income and the transfer of active population from the primary to the tertiary sector, has contributed to a dramatic increase of inter-island mobility.
In any event, the distribution of the population and wealth within the archipelago varies considerably. This uneven distribution has relevant implications for external transport because the *hinterland* of each island determines the transport demand. However, some islands, such as La Gomera or El Hierro, require minimum service levels, which, due to their small population and economic volume, would not in principle justify an improvement of the offer of air transport with these islands, although such improvement is very important with a view to the territorial integration of the archipelago.

Table 1-Canary Islands, 2015
Source: Canary Institute of Statistics.

Islands	Population	Foreign tourists*	Gross Added Value (%)
Tenerife	888,184	4207,403	42
Gran Canaria	847,830	3271,941	42
Lanzarote	143,209	2193,291	6
Fuerteventura	107,367	1966,634	5
La Palma	82,346	125,958	4
La Gomera	20,783	——	0.5
El Hierro	10,587	——	0.5
Total	*2100,306*	*11765,227***	*100*

* Only tourists come by plane. 2185,469 tourists arrived on cruise ships in 2015.
** The estimation of tourists on the islands of El Hierro and La Gomera is included.

Thus, Tenerife and Gran Canaria account for 83% of the population, the same as the gross added value. The remaining 17% is also unevenly distributed, because although more than 15% of the population is located on the islands of Lanzarote, La Palma, and Fuerteventura, the remaining percentage, not even 2%, is divided between La Gomera and El Hierro. The gross added value differs very little from these values.
However, we note that, as a function of the population volume, the outlying islands require a greater amount of air travel per inhabitant (Hernández Luis, 2004), due to the lack of certain services that are available to the inhabitants of the main islands of Tenerife and Gran Canaria.

Air transport as an engine of development in the Canary Islands

Air transport is essential for global economic development (Graham, 1998; Graham & Guyer, 1999; Reynolds-Feighana & Button, 1999; Button & Taylor, 2000; Gámir Orueta & Ramos Pérez; 2002), but even more so for the island territories, mainly due to their territorial fragmentation and also to their remoteness. These weaknesses can only be resolved with a means of rapid transport, such as aircraft, for the transportation of passengers and urgent goods.

Several studies emphasize the prominence acquired by transport in the islands (Brookfield, 1980; Metra/Seis, 1985, Murillo Fort, 1992; Eurisles, 1996; Gobierno de Canarias, 1998; Fundación Tomillo, 2001; Guillaumin, 2001; Ramos Pérez, 2001; Hernández Luis, 2002; Commission of the European Communities, 2005; Yamaguchi, 2007; Rigas, 2009; Hazledine & Collins, 2011; Minato & Morimoto, 2011, Ramos Pérez, 2015). However, in a society where information, freight, and passengers move at increasingly greater speeds, air transport is a fundamental part of this cog. In addition, many archipelagos already rely on almost completely on tourism (Hawai, Seychelles, Virgin Islands, Balearic Islands, etc.) and, due to their remoteness from the main emitting centers of tourism, air transport becomes a cornerstone for their development.

Inter-island air transport has increased considerably in recent years, doubling between 1998 and 2007, and it only regressed ostensibly since a decade ago, due punctually to the crisis as well as to the strong maritime competition on some very touristic routes, although there is a more recent trend of strong growth.

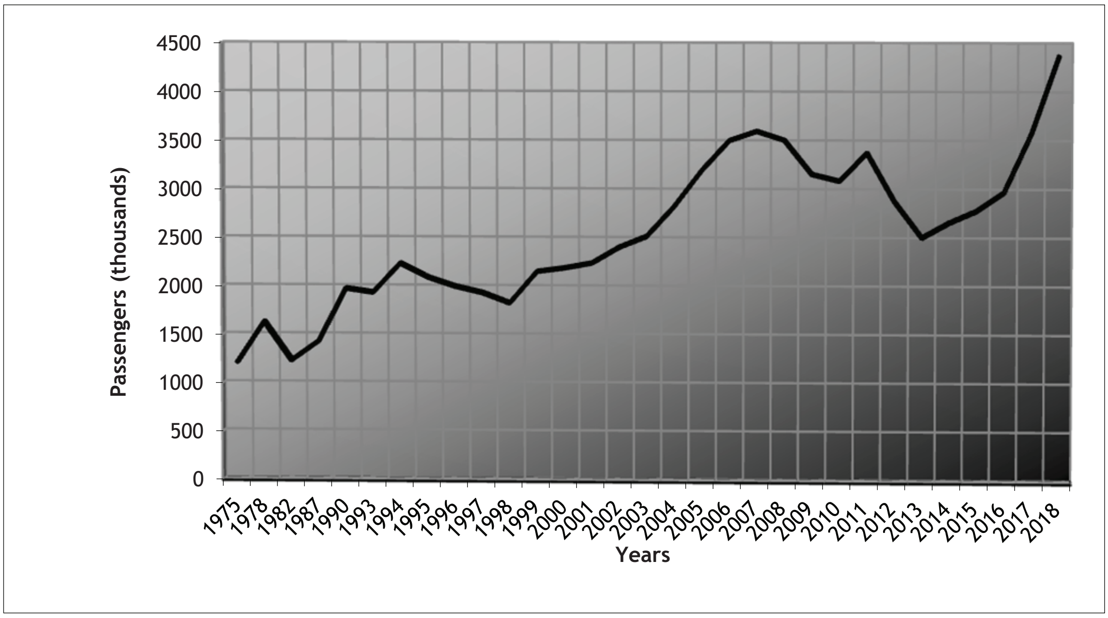

Figure 1 - Canary Islands: Inter-island airplane passengers (1975 - 2018)
Source: Instituto Canario de Estadística (1975 – 2015) & airlines (2016 – 2018).

However, between the islands in which ships' navigation exceeds two hours, air transport is far more competitive than maritime transport. For instance, in the year 2018, maritime transport between Lanzarote and Gran Canaria only moved about 125 thousand passengers, versus 800 thousand of air transport. On the other hand, between the two central islands of Tenerife and Gran Canaria, with fast ships with crossings of a little more than one hour, air travelers were 25% less than maritime travelers.

Table 2 - Regular passenger traffic in the Canary Islands in 2018 (return trips)
Source: Instituto Canario de Estadística

Línes	By air	By sea	Total
Gran Canaria-Tenerife	1090,893	1424,654	2515,547
Tenerife-La Gomera	53,006	1345,551	1398,557
Gran Canaria-Fuerteventura	645,368	668,608	1313,976
Lanzarote-Fuerteventura	----	1130,038	1130,038
Tenerife-La Palma	728,018	263,007	991,025
Gran Canaria-Lanzarote	795,908	122,993	918,901
Lanzarote-La Graciosa	----	437,700	437,700
Tenerife-Lanzarote	373,185	----	373,185
Tenerife-El Hierro	200,045	146,802	346,847
Tenerife-Fuerteventura	282,831	----	282,831
Gran Canaria-La Palma	151,864	----	151,864
Gran Canaria-El Hierro	45,706	----	45,706
TOTAL	*4366,824*	*5539,353*	*9906,177*

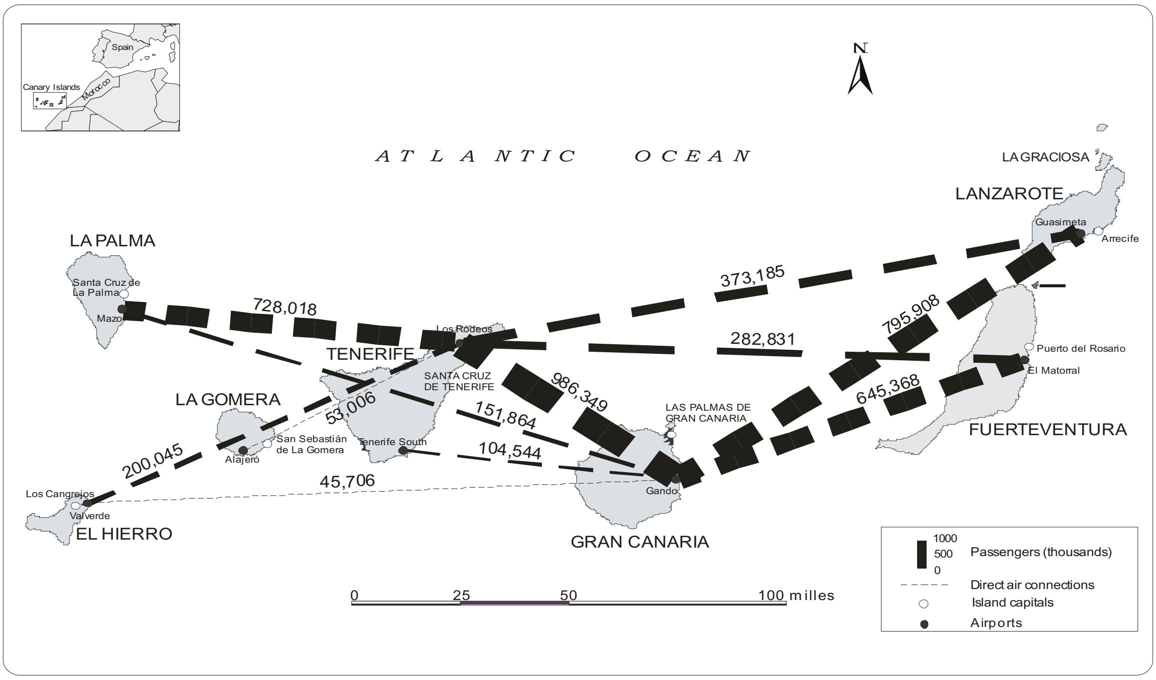

Figure 2 - Canary Islands: Passengers of regular airlines, 2018
Source: Binter Canarias, Canary Fly & Air Europa

The methodology

Availability is complex and different from the physical, temporal, economic, etc. point of view (Niemeier, 1997; Farrington, 2007; Bocarejo & Oviedo, 2012). Thus, in this work, where we focus on time availability, analysis of the official inter-island airline schedules is the basic tool to justify the territorial integration of the archipelago. It is a typology of availability that has not received as much attention as the physical or economic connectivity, although, as we shall point out, it is extremely important for the islands.

Time schedule availability or *"time availability"* at destination on an inter-island trip is important because it will influence the likelihood of an overnight stay on the visited island, with the attendant costs of accommodation, per diem allowance, and loss of working hours[1].

[1] In the Resolution of July 30, 1998, by which the inter-island public service obligations of the Canary Islands were approved, it was established in the Annex, section III, that, in the interisland routes "the schedules should allow users to make a round trip on the same day".

It is also essential for the flight frequencies to have some degree of dispersion throughout the day, to facilitate movements for which it is not necessary to remain all day at the destination. However, in general, round trips on the same day in the inter-island Canarian network are very frequent, reaching about 45% of all the trips between the two central islands, and 23% of the trips from the outlying islands (Murillo Fort, 1992), whereas, according to other more recent sources, these percentages are 48 and 27%, respectively (Ministerio de Obras Públicas [Ministry of Public Works], 2013), showing the importance of schedule planning.

To calculate the time availability for air transport, we have used the winter timetables from 2006 to 2019 (14 years) as reference and, in particular, the five working days of the last week of January, as on these working days, the passengers' appraisal of time is higher.

The proposed schedule accessibility has been expressed in the concept of *"time availability"* in a door-to-door system between island capitals, always counting the available time on the island of destination, which is we are really interested in.

We consider a theoretical model in which travelers go on the first flight and return to the island of origin on the last. *Time availability* is finally translated into percentages, the result of subtracting the time blocks employed in transportation (by air and on the ground at the destination) plus that of check-in and ground transportation on the return trip. All of this also takes into account the administrative (08.00-15.00 hours, i.e., 420 minutes) and commercial schedules (09.00-13.00 and 16.00-20.00 hours, i.e., 480 minutes). Therefore, 100% of the *"available time"* in administrative schedules for a resident of one island on another island means that he or she can reach the island capital of the visited island before 08.00 hours and can leave it after 15.00. The calculation of both time availabilities for the 14 years under consideration has required designing two matrices (one for the availability of the administrative schedule and one for the commercial schedule), each with 308 data, totaling about 616 data. Likewise, we note the intense work of annual monitoring of the schedules of the three airlines that have operated regularly between the Canary Islands during these twelve years (*Binter Canarias, Islas Airways, Canaryfly* and *Air Europa*).

The blocks of time of a passenger without luggage—which is the normal situation of an inter-island *commuter—*, were considered as follows: ground access by taxi to and from the island capitals to the airports of Northern Tenerife and Gran Canaria (30 minutes); to and from the island capitals to the airports of Lanzarote, Fuerteventura, El Hierro, and La Palma (15 minutes); to San Sebastián de La Gomera by taxi or rental car (45 minutes). To this we must add a minimum time of 40 minutes for check-in and boarding at destination on the return trip.

Finally, we have only considered those airlines with two or more daily flights in each direction because this is the prerequisite for the return trip on the same day. The Gran Canaria-El Hierro and the Gran Canaria-Southern Tenerife routes are therefore excluded, as well as Gran Canaria-La Gomera route, an inoperative line as of and including 2010.

Results and discussion

As already indicated, there are very many commuters in the inter-island Canarian air network, because 48% of the passengers between Tenerife and Gran Canaria return to the island of origin on the same day, and this reaches 27% for the remaining islands. But this last value would be higher if the schedules and the availability of seats allowed rotation on the same day. For this reason, and as a first step, we now present the offer of seats that, particularly, offer a round trip on the same day with more time availability at destination.

2006, these *public service obligations* were renewed, reaffirming the importance of schedule planning.

Table 3 - Availability of inter-island air seats in the Canary Islands per working day at times of increased demand in the winter timetable programming of 2018-2019*
Source: Binter Canarias, Canary Fly & Air Europa

Lines	Seats offered between 07.00-08.30 h	Seats offered at 20.00 h. & later
Gran Canaria-Tenerife-Gran Canaria	206	144
Tenerife-Gran Canaria-Tenerife	195	154
Gran Canaria-Lanzarote-Gran Canaria	206	144
Lanzarote-Gran Canaria-Lanzarote	123	165
Tenerife-La Palma-Tenerife	154	82
La Palma-Tenerife-La Palma	134	165
Gran Canaria-Fuerteventura-Gran Canaria	134	165
Fuerteventura-Gran Canaria-Fuerteventura	72	185
Tenerife-Lanzarote-Tenerife	72	21
Lanzarote-Tenerife-Lanzarote	72	93
Tenerife-Fuerteventura-Tenerife	72	0
Fuerteventura-Tenerife-Fuerteventura	72	72
Tenerife-El Hierro-Tenerife	72	0
El Hierro-Tenerife-El Hierro	0	0
Gran Canaria-La Palma-Gran Canaria	72	21
La Palma-Gran Canaria-La Palma	0	72
Total	*1.656*	*1.483*

* We only considered direct routes; those offering seats at those hours and those that have two or more daily one-way flights.

It can be seen from Table 3 that the situation is clearly different because, if the first four routes offer more than 500 daily round-trip seats at these times of increased demand, in the others, there are no seats in both directions at those hours, such as between Tenerife and La Gomera, whereas, in other cases, this requirement is still not met in one of the directions, such as between Tenerife and El Hierro.
The problem, in short, is the lack of time availability on the visited island (Hernández Luis, 2000). Thus, on the basis of the previously presented methodology, we reach the conclusion that time availability for travelers to deal with commercial or administrative issues between the two central islands using air transport can be considered acceptable, as it reaches 100% of the maximum time in which these functional places are open to the public. Moreover, on the line between Gran Canaria and Lanzarote and vice versa, as well as between Tenerife and La Palma and vice versa, the percentages are very close to 100%, as on these lines, there are aircraft that stay overnight on the smaller island, facilitating the earliest exit from it, thereby contributing to preventing the shortcomings of availability at the destination.

Table 4 - Time availability to the *capital cities* of other Canary Islands in air travel of a commuter on a working day (January, 2019)
Source: Binter Canarias, Canary Fly & Air Europa

	Time blocks of *outbound trip*		Time blocks of the *return trip*			Available time in open functional areas (%)	
Routes	Plane lands	*Arrives at the Capital*	*Leaves the Capital*	Arrival at the boarding point	Departure of plane	Administration	Commercial
Tenerife-El Hierro	08.35	*08.50*	*17.00*	17.15	17.55	88.10	62.50
El Hierro-Tenerife	09.35	*10.05*	*15.35*	16.05	16.45	70.24	36.46
Tenerife-La Palma	08.00	*08.15*	*19.20*	19.35.	20.15	96.43	91.67
La Palma-Tenerife	08.30	*09.00*	*18.50*	19.20	20.00	85.71	85.42
Tenerife-La Gomera	10.00	*10.45*	*16.25*	17.10	17.50	60.71	33.33
La Gomera-Tenerife	11.00	*11.30*	*15.50*	16.20	17.00	50.00	18.75
Tenerife-Gran Canaria	07.30	*08.00*	*19.50*	20.20	21.00	100.00	97.92
Gran Canaria-Tenerife	07.30	*08.00*	*19.50*	20.20	21.00	100.00	97.92
Tenerife-Fuerteventura	08.00	*08.15*	*19.35*	19.50	20.30	96.43	91.67
Fuerteventura-Tenerife	09.20	*09.50*	*18.00*	18.30	19.10	73.81	64.58

Tenerife-Lanzarote	07.50	*08.05*	*19.35*	19.50	20.30	98.81	94.79
Lanzarote-Tenerife	09.15	*09.45*	*18.00*	18.30	19.10	89.29	75.00
Gran Canaria-La Palma	08.10	*08.25*	*20.20*	20.35	21.15	94.05	100.00
La Palma-Gran Canaria	09.30	*10.00*	*18.45*	19.15	19.55	71.43	71.88
Gran Canaria-Fuerteventura	07.40	*07.55*	*20.35*	20.50	21.30	100.00	100.00
Fuerteventura-Gran Canaria	08.45	*09.15*	*19.10*	19.40	20.20	67.86	86.46
Gran Canaria-Lanzarote	07.40	*07.55*	*21.20*	21.35	22.15	100.00	100.00
Lanzarote-Gran Canaria	07.45	*08.15*	*20.00*	20.15	20.55	96.43	100.00

The most deficient cases are found in the lines connecting the islands of El Hierro and La Gomera, where time availability is less than 20%; for example, when a resident of La Gomera goes to Tenerife for commercial purposes, time availability is less than 40%, that is, less than three hours at the destination for business matters for a resident of El Hierro traveling to Tenerife. But as mentioned, the direction of the airline from the outlying islands to the central ones is always at a disadvantage, such that time availability is a handicap that seriously compromises the territorial integration of the Islands.

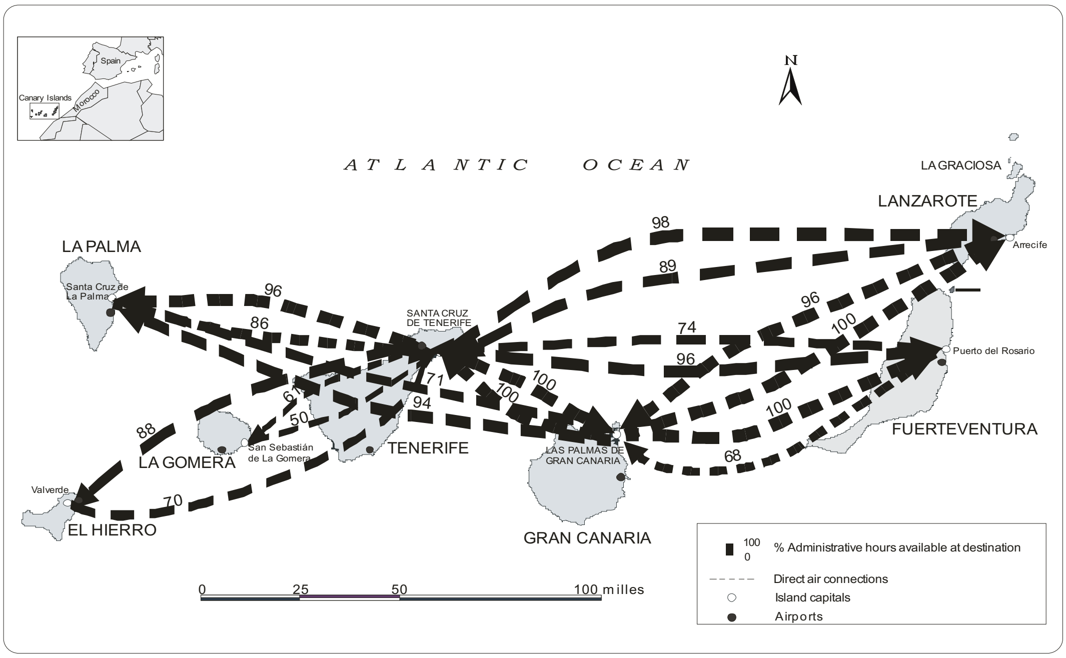

Figure 3 - Time availability at destination island capitals of the Canary Islands in air transport *for administrative purposes* in January 2019 (%)
Source: Binter Canarias, Canary Fly & Air Europa

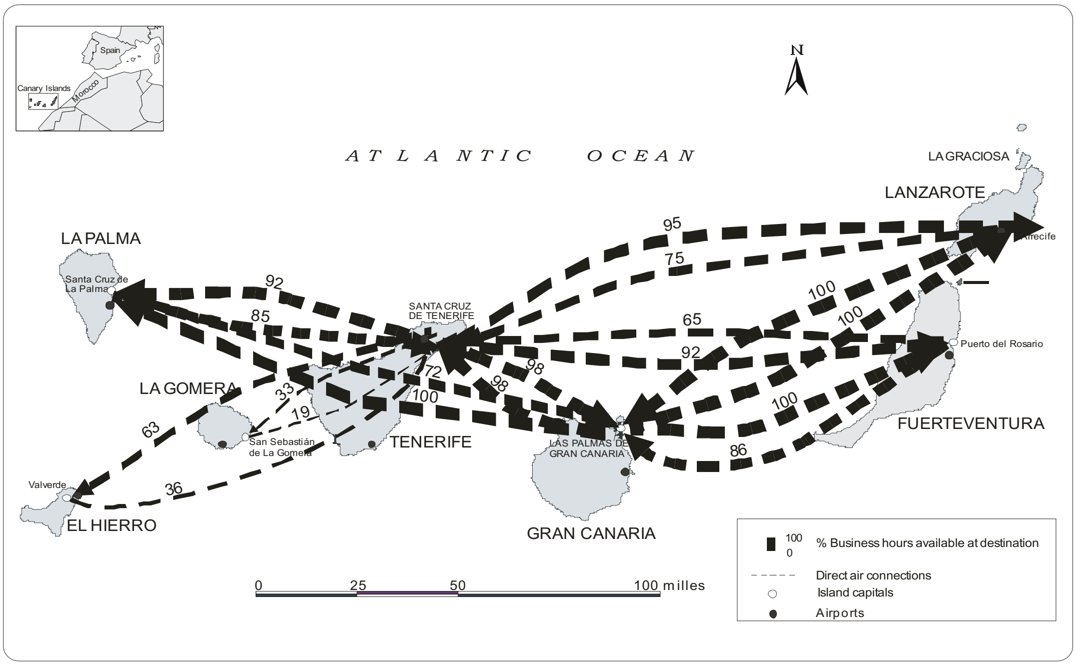

Figure 4 - Time availability at destination island capitals of the Canary Islands in air transport *for* commercial *purposes* in January 2019 (%)
Source: Binter Canarias, Canary Fly & Air Europa

From an evolutionary point of view, taking 14 years as reference and according to the winter timetable programmers of the airline operators, the main problem lies in the connections with the aforementioned islands of El Hierro and La Gomera, even with significant setbacks, such as the change of aircraft between Gran Canaria and El Hierro in 2008, using since then a 72-seat *ATR-72*, instead of the 19-seat *Beechcraft 1900*, involved switching from two daily connections in each direction to a single one. What happened in 2010 between Gran Canaria and La Gomera was more serious, as the aforementioned change of aircraft involved the suspension of the direct line and the transit of all those passengers through Tenerife, with the attendant costs of time and money.

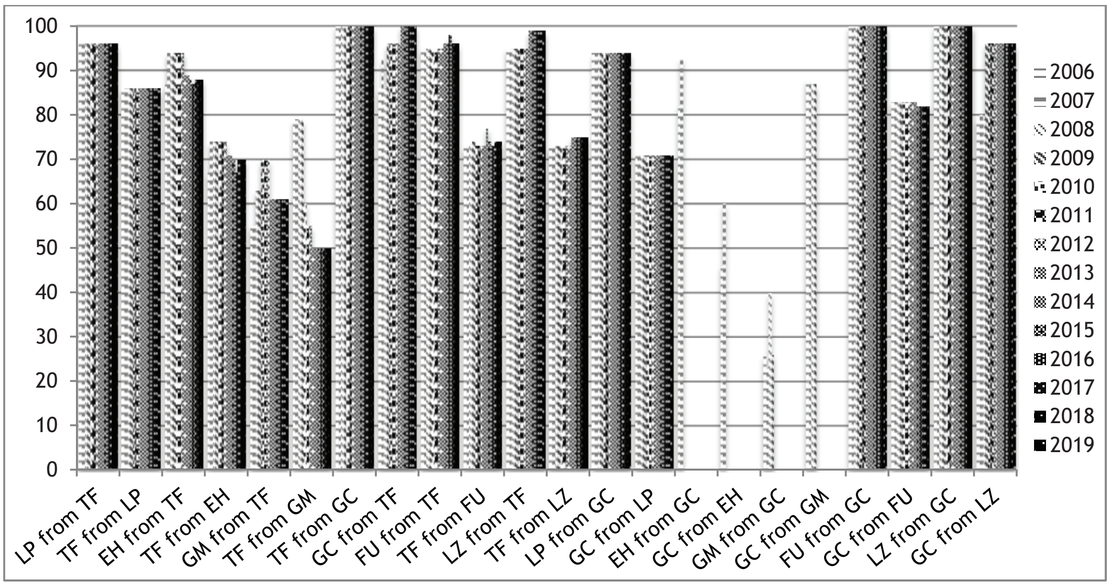

Figure 5 - Time availability on working days and during the *administrative* schedule in the capitals of the islands visited in inter-island air travel between 2006 and 2019 (%)
Source: Binter Canarias, Islas Airways, Canary Fly & Air Europa

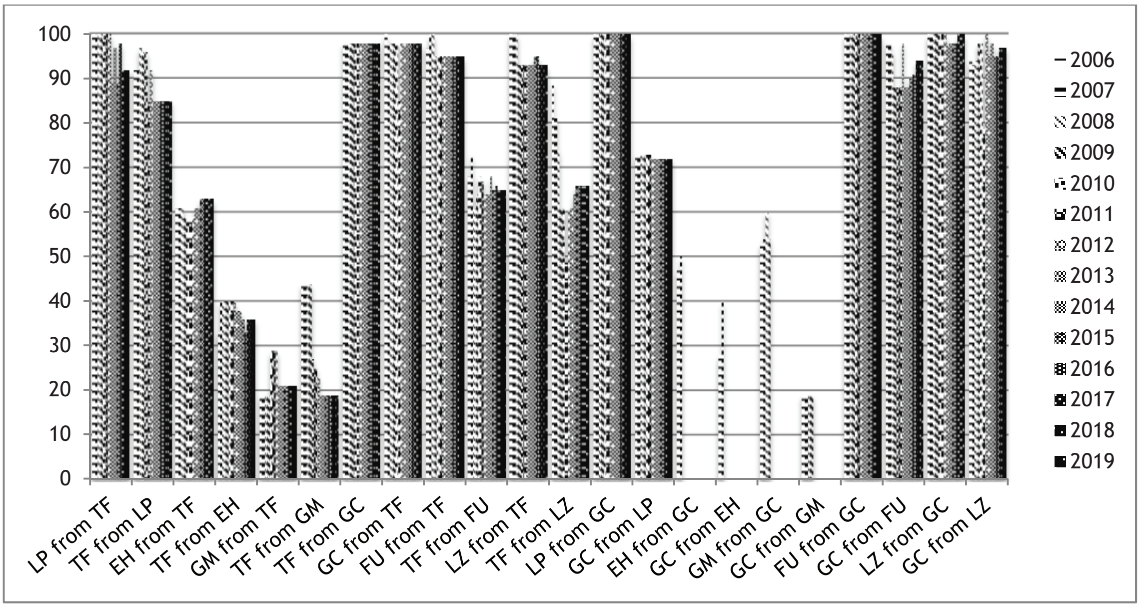

Figure 6 - Time availability on working days and during the *commercial* schedules
in the capitals of the islands visited in inter-island air travel between 2006 and 2019 (%)
Source: Binter Canarias, Islas Airways, Canary Fly & Air Europa

In particular, time availability at the destination below 40%—that is, approximately 3 hours or less during which the commercial and administrative functional places remain open to the public on the destination island capitals—has a high risk of failing to comply with the demands of more time by inter-island passengers. As shown in Figures 5 and 6, this risk is very high in the airlines with El Hierro and La Gomera and, above all, in the peripheral island-central island direction. This implies high costs (overnight stay, hotel, per diem allowance, loss of almost two working days at the island of origin, etc.). Thus, the airfare itself does not imply greater costs for these travelers but instead the costs inherent to an overnight stay at the destination due to a very poor time-table planning of the air mode, especially for the islands with lower per capita income and lower administrative and commercial services—precisely, the citizens of El Hierro and of La Gomera.
The solution to this inequality, which, as we have shown, has worsened in recent years, should focus on the improvement of timetable planning, starting with the schedules in which businesses and administrations are open. At the same time, operations with aircraft of less capacity on some routes of lower density would allow at least two daily connections in each direction, this being the minimum condition required for the round trip on a single day. Airfare, commonly used to evaluate economic affordability, is beyond the scope of this analysis of availability in terms of time with broad economic connotations.

Conclusions

Analysis of air accessibility is one of the basic tools to evaluate the territorial cohesion of island systems. In the Canary Islands, it is even more important when considering that, on the airline that connects the two central islands of Tenerife and Gran Canaria, 48% of the passengers make the return trip on the same day, a fact that shows that, essentially, people do not travel for leisure but for administrative and commercial purposes, etc.,
Thus, if the applied airfare is important—in which great progress was made in the last two decades for the sake of the mentioned territorial integration by increasing the deduction for residents from 10 to 75%—, increasing the offer of seats and flight frequencies has also helped. However, in terms of schedules, we have advanced very little, even with some setbacks. Operating at a very early hour in the peripheral island-central island direction is of vital importance for the smaller islands because, if this occurs at a late hour, the chances of

having to stay overnight at the destination increase exponentially, especially when the return flight frequency occurs at a very early hour in the afternoon. This is the case of air passengers of El Hierro and La Gomera who go to Tenerife because, for certain business matters, they do not even reach a 20% time availability of the schedule during which businesses are open to the public in the capital of Tenerife.

In short, time availability in the inter-island air transport of the Canary Islands is a factor key from the viewpoint of territorial integration because the costs attributable to poor timetable planning can involve a still greater expenditure for the passenger than the airfare itself. It will at least lead to disbursement at the destination of one night in a hotel, per diem allowance, and loss of working hours for two days. Thus, the methodological approach developed in this work aims to bring us closer to the impact caused by a very insufficient time planning for the passengers of certain islands which, moreover, coincide with the islands where the per capita income is also lower.

In short, the improvement of timetable planning, according to the commercial and administrative availability indicated in this work, as well as the employment of aircraft more adapted to the demand, would help improve time availability at the destination of the citizens of the smaller islands.

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Asociación de superficies limitadoras de obstáculos y franjas de pista

Sergio F. Pitrelli - spitrelli@gmail.com
Universidad Nacional de La Plata, Grupo Transporte Aéreo – UIDET GTA-GIAI, Departamento de Aeronáutica, Facultad de Ingeniería
Alejandro DI Bernardi - aledibernardi@hotmail.com
Universidad Nacional de La Plata, Grupo Transporte Aéreo – UIDET GTA-GIAI, Departamento de Aeronáutica, Facultad de Ingeniería
Angel Paris Loreiro- angel.paris@upm.es
Departamento de Sistemas Aeroespaciales, Transporte Aéreo y Aeropuertos, Universidad Politécnica de Madrid,
Pedro Nuñez Blanco - PBlanco@ineco.com
Departamento de Sistemas Aeroespaciales, Transporte Aéreo y Aeropuertos, Universidad Politécnica de Madrid
Alvaro Rodriguez Sanz - alvaro.rodriguez.sanz@upm.es
Universidad Politécnica de Madrid (UPM), Escuela Técnica Superior de Ingeniería Aeronáutica y del Espacio (ETSIA)

Abstract
En el presente se analiza la asociación de las SLOs con la franja de pista, superficies de aproximación, superficies de transición entre otros elementos y algunos interrogantes sobre la necesidad o no de esta asociación.
La seguridad operacional puede ser analizada a través del SMS, del SSP, mediante matrices de riesgo, estudios de evaluación de seguridad operacional, estudios de compatibilidad, estudios aeronáuticos o bien, mediante la aplicación del Anexo 14 Lo anterior es analizado observando las características de las SLOs a través de las diferentes ediciones del Anexo 14 (desde la tercera hasta la octava edición y la propuesta de modificación de 2020).
En la edición vigente del Anexo 14, se observan cambios relacionados con parámetros de diseño sobre la base de un cambio de conceptos respecto a la clave de referencia de aeródromo que se tenía. Los obstáculos que se analiza por medio de superficies limitadoras de obstáculos sigue permaneciendo, casi sin alteración, salvo por, la modificación de algunas dimensiones que son producto del cambio de dimensiones de la franja de pista.
Al modificar las dimensiones de franjas de pista, se han modificado como consecuencia los bordes internos de las superficies que en teorías están asociados a la misma. La contribución es un análisis de dicha asociación.

Keywords
Pistas; Franjas; SLOs; Seguridad Operacional

Asociación de superficies limitadoras de obstáculos y franjas de pista

Introducción

El presente trabajo tiene por objeto analizar algunas cuestiones de relativa importancia en relación con la gestión de la seguridad operacional [1] y la normativa asociada. En el contexto de una certificación de aeródromos [2], estos dos elementos son de vital importancia, ya que esto último implica la aceptación de las condiciones de operación del aeródromo por parte de la Autoridad Aeronáutica local. Generalmente, lo anterior implica el cumplimiento de normativa y/o recomendaciones o bien la aceptación de una brecha respecto del cumplimiento bajo la filosofía ALARP, (tan bajo como sea razonablemente practicable), esto se verá reflejado en la documentación del sistema de gestión de la seguridad operacional [3][4] y en los niveles aceptables del rendimiento en materia de seguridad operacional (ALoSP) por parte del Estado.

En ocasiones, el no cumplimiento de las regulaciones o reglamentaciones nos lleva a realizar estudios y/o evaluaciones de la seguridad operacional, para poder tomar decisiones con el sustento de análisis pormenorizados de una situación particular. Es decir que, al existir una brecha entre lo conceptualmente correcto y lo realmente existente es necesario un estudio que determine la situación y presente alternativas para cumplir con el nivel aceptable (ALoSP).

En este caso, nos referiremos al análisis de las relaciones existentes entre la franja de una pista (FP) y las superficies limitadoras de obstáculos (SLOs) asociadas a una pista, que se ven reflejadas en el Anexo 14 de OACI (An14), las cuales deberían reflejarse en forma de regulaciones o reglamentaciones locales por los Estados miembros de OACI.

Metodología

Debido a que las normas en muchas ocasiones no son explícitas en el sentido que no explican los conceptos que aplican, sino más bien, son una regulación de los mismos, por medio de definiciones claras. En muchas ocasiones quienes aplican estas normas no logran entender los conceptos que hay detrás de las mismas, es por ello por lo que en este trabajo el método es recorrer la normativa de aplicación a través de las diferentes ediciones de esta, identificando los mismos temas de análisis, en este caso nos referimos a franjas de pista y superficies limitadoras de obstáculos, para poder estudiar su evolución y lograr concluir acerca de la relación existente entre ellas.

Este proceso se ve reflejado en la siguiente Figura 1.

Figura 1 – Proceso metodológico.
Fuente: Autor

Desarrollo

Para poder estudiar la relación existente entre la FP y las SLOs, es importante analizar que ha ocurrido con estos conceptos y definiciones a lo largo del tiempo, por ello recurrimos a observar cómo se ha desarrollado esto a través de las diferentes ediciones del An14 [5][6][7][8][9][10].

La edición vigente del An14 es de julio 2018 (octava Ed), pero si observamos desde las primeras ediciones, podremos ver cómo fue la variación de los conceptos a lo largo del tiempo. En la Figura 2 se muestra como fue el desarrollo de los documentos mencionados a lo largo del tiempo y en relación con su volumen (cantidad de páginas) de cada uno.

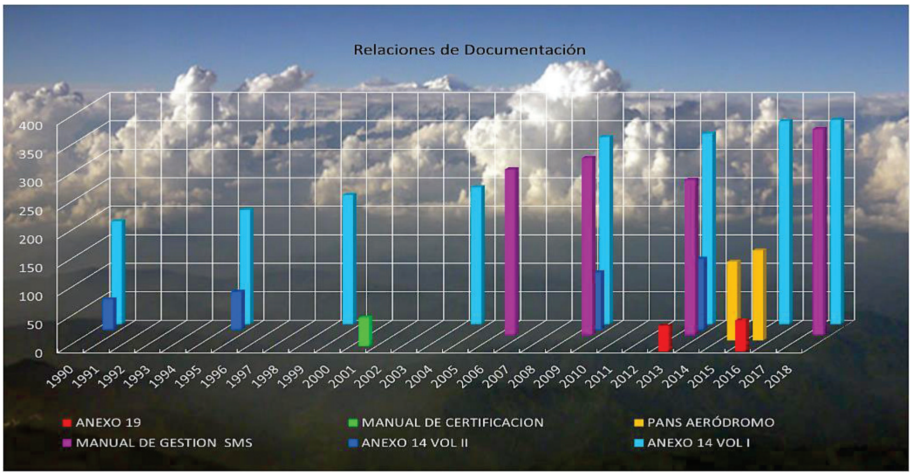


Figura 2 – Evolución del Anexo 14 respecto a documentación básica de certificación.
Fuente: Autor

Desde las primeras ediciones hasta la última, la definición del concepto de FP no ha variado, definiéndose como; *una superficie que comprende una pista y zona de parada si hubiere, destinada a reducir riesgo de daño a aeronaves que se salgan de pista o a proteger a las que la sobrevuelan*. Por ello se deduce que la misma es una superficie en sentido físico, es decir que es "*tangible*", no es una superficie imaginaria ya que uno de los objetivos es proteger a las aeronaves que se salgan de pista, vale decir que se apoyan sobre la misma, y por tanto, entendemos que es el terreno o área circundante a la pista. Esto sugiere una primera diferencia respecto de las SLOs, las cuales, sí son superficies imaginarias.

Por otra parte, las dimensiones de la FP, tanto en longitud como en anchura, están definidas por el An14. Respecto a esto, podemos decir que en las primeras ediciones de este, ambas dimensiones eran recomendaciones, salvo por la anchura para una pista de categoría de aproximación I, que estaba normada, y aún permanece igual, pero haciendo la mención "siempre que fuera posible", con lo cual, la norma podría leerse como una recomendación; en tanto que; ¿Cuándo no es posible? o dicho de otra forma; ¿Cuándo es imposible?

A partir de la tercera edición (1999) fue que la longitud de la FP comenzó a estar normada.

Las dimensiones propiamente dichas, más allá del carácter recomendado o normado, no se vieron modificadas hasta la última edición (2018) en que para pistas instrumentales (tanto de precisión como de no precisión) los 300 metros de ancho pasaron a ser 280 metros, y los 150 m de ancho pasaron a ser 140 metros, según la clave de referencia.

De la misma forma que se establecen longitud y anchura de la FP, se establece la nivelación, tanto longitudinal como transversal. Podemos observar que no ha habido modificaciones respecto a este tema, es decir que las consideraciones de nivelación de terreno alrededor de la pista siguen permaneciendo sin modificaciones con el transcurso de las ediciones del An14, así mismo, cabe mencionar que en todos los casos el carácter es recomendatorio.

Las SLOs son superficies "*imaginarias*", entorno a una pista, Figura 3, que marcan los limites hasta donde pueden proyectarse en el espacio los obstáculos, para que puedan llevarse a cabo con seguridad las operaciones de las aeronaves para las que está prevista. Observando los conceptos y definiciones de SLOs a través de las diferentes ediciones del An14, tampoco se observan cambios respecto de las mismas, salvo que, como mencionamos anteriormente en la última edición (2018) al cambiar el ancho de la FP, también se modificaron los anchos de los bordes internos de la superficie de aproximación para aproximaciones instrumentales, tanto de precisión como no precisión. Los anchos de estos bordes interiores son coincidentes con el ancho de la FP correspondiente, Tabla 1. Esto lleva a pensar que si bien la FP es una superficie tangible (terreno) tiene estrecha relación con las SLOs que son superficies imaginarias.

Tabla 1- Comparativa Longitud borde interior Superficie Aproximación.
Fuente: Anexo 14

Anexo 14 Edición 8va, 2018

Tabla 4-1. Dimensiones y pendientes de las superficies limitadoras de obstáculos — Pistas para aproximaciones

PISTAS PARA APROXIMACIONES

	CLASIFICACIÓN DE LAS PISTAS									
	Aproximación visual Número de clave				Aproximación que no sea de precisión Número de clave			Aproximación de precisión Categoría I Número de clave		Aproximación de precisión Categoría II o III Número de clave
Superficies y dimensiones[a] (1)	1 (2)	2 (3)	3 (4)	4 (5)	1,2 (6)	3 (7)	4 (8)	1,2 (9)	3,4 (10)	3,4 (11)
CÓNICA										
Pendiente	5%	5%	5%	5%	5%	5%	5%	5%	5%	5%
Altura	35 m	55 m	75 m	100 m	60 m	75 m	100 m	60 m	100 m	100 m
HORIZONTAL INTERNA										
Altura	45 m	45 m	45 m	45 m	45 m	45 m	45 m	45 m	45 m	45 m
Radio	2 000 m	2 500 m	4 000 m	4 000 m	3 500 m	4 000 m	4 000 m	3 500 m	4 000 m	4 000 m
APROXIMACIÓN INTERNA										
Anchura	—	—	—	—	—	—	—	90 m	120 m[e]	120 m[e]
Distancia desde el umbral	—	—	—	—	—	—	—	60 m	60 m	60 m
Longitud	—	—	—	—	—	—	—	900 m	900 m	900 m
Pendiente								2,5%	2%	2%
APROXIMACIÓN										
Longitud del borde interior	60 m	80 m	150 m	150 m	150 m	300 m	300 m	150 m	300 m	300 m
Distancia desde el umbral	30 m	60 m	60 m	60 m	60 m	60 m	60 m	60 m	60 m	60 m
Divergencia (a cada lado)	10%	10%	10%	10%	15%	15%	15%	15%	15%	15%

Anexo 14 Edición 7ma, 2016

Tabla 4-1. Dimensiones y pendientes de las superficies limitadoras de obstáculos — Pistas para aproximaciones

PISTAS PARA APROXIMACIONES

	CLASIFICACIÓN DE LAS PISTAS									
	Aproximación visual Número de clave				Aproximación que no sea de precisión Número de clave			Aproximación de precisión Categoría I Número de clave		Aproximación de precisión Categoría II o III Número de clave
Superficies y dimensiones[a] (1)	1 (2)	2 (3)	3 (4)	4 (5)	1,2 (6)	3 (7)	4 (8)	1,2 (9)	3,4 (10)	3,4 (11)
CÓNICA										
Pendiente	5%	5%	5%	5%	5%	5%	5%	5%	5%	5%
Altura	35 m	55 m	75 m	100 m	60 m	75 m	100 m	60 m	100 m	100 m
HORIZONTAL INTERNA										
Altura	45 m	45 m	45 m	45 m	45 m	45 m	45 m	45 m	45 m	45 m
Radio	2 000 m	2 500 m	4 000 m	4 000 m	3 500 m	4 000 m	4 000 m	3 500 m	4 000 m	4 000 m
APROXIMACIÓN INTERNA										
Anchura	—	—	—	—	—	—	—	90 m	120 m[e]	120 m[e]
Distancia desde el umbral	—	—	—	—	—	—	—	60 m	60 m	60 m
Longitud	—	—	—	—	—	—	—	900 m	900 m	900 m
Pendiente								2,5%	2%	2%
APROXIMACIÓN										
Longitud del borde interior	60 m	80 m	150 m	150 m	140 m	280 m	280 m	140 m	280m	280 m
Distancia desde el umbral	30 m	60 m	60 m	60 m	60 m	60 m	60 m	60 m	60 m	60 m
Divergencia (a cada lado)	10%	10%	10%	10%	15%	15%	15%	15%	15%	15%

El An14 expresa que teniendo en cuenta la consideración de nivelación, bajo ciertas circunstancias podría ser que la FP pueda estar por arriba, tanto del borde interior de la superficie de aproximación como del borde interior de la superficie de ascenso en despegue, pero no se pretende que se nivele la FP o eliminen objetos para que coincida con el borde interior de dichas superficies, a menos que se considere que pueden representar un peligro para las aeronaves.

No obstante lo anteriormente expresado, no se hace referencia alguna sobre cuáles son las consideraciones que habría que tener respecto del borde inferior de la superficie de transición, por lo que la consecuencia de falta de consideraciones particulares se traduce en que la superficie de transición no debería ser vulnerada por el terreno en su borde inferior.

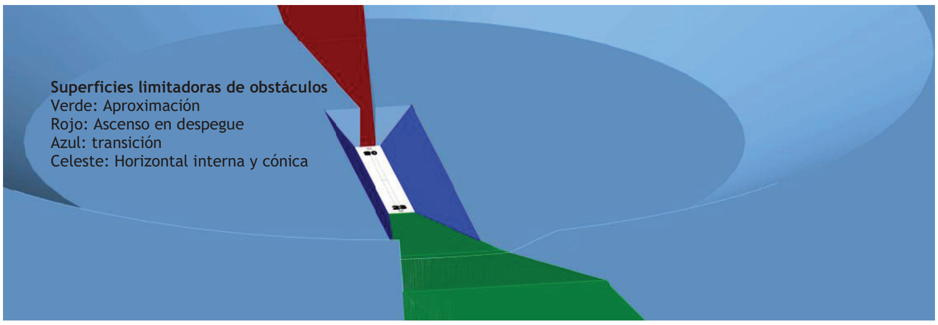


Figura 3 – Superficies limitadoras genéricas aproximación CAT I
Fuente: Autor

Por otra parte, es necesario mencionar que la franja de una pista si bien es una sola, está dividida en dos partes, que se diferencian entre otras cosas, por los criterios de nivelación. La parte más cercana a la pista, llamada en la práctica "franja nivelada" tiene criterios de nivelación más restrictivos que la parte más alejada. Incluso en la parte más alejada los criterios de limitación de nivelación son tan solo ascendentes, no existiendo condición límite para pendientes descendentes.

Si analizamos la relación entre las FP y la superficie de transición, vemos que la asociación entre ellas está dada por la definición de la propia superficie y fundamentalmente por el borde inferior de la misma, ya que el mismo se define según el AN14 como en la Figura 4:

> ***Superficie de transición***
>
> 4.1.13 *Descripción.— Superficie de transición.* Superficie compleja que se extiende a lo largo del borde de la franja y parte del borde de la superficie de aproximación, de pendiente ascendente y hacia afuera hasta la superficie horizontal interna.

Figura 4 – Descripción Superficie de Transición
Fuente: Anexo 14

Las características están dadas por la Figura 5:

> 4.1.14 *Características.—* Los límites de una superficie de transición serán:
>
> a) un borde inferior que comienza en la intersección del borde de la superficie de aproximación con la superficie horizontal interna y que se extiende siguiendo el borde de la superficie de aproximación hasta el borde interior de la superficie de aproximación y desde allí, por toda la longitud de la franja, paralelamente al eje de pista; y
>
> b) un borde superior situado en el plano de la superficie horizontal interna.
>
> 4.1.15 La elevación de un punto en el borde inferior será:
>
> a) a lo largo del borde de la superficie de aproximación — igual a la elevación de la superficie de aproximación en dicho punto; y
>
> b) a lo largo de la franja — igual a la elevación del punto más próximo sobre el eje de la pista o de su prolongación.
>
> *Nota.— Como consecuencia de b), la superficie de transición a lo largo de la franja debe ser curva si el perfil de la pista es curvo o debe ser plana si el perfil de la pista es rectilíneo. La intersección de la superficie de transición con la superficie horizontal interna debe ser también una línea curva o recta dependiendo del perfil de la pista.*
>
> 4.1.16 La pendiente de la superficie de transición se medirá en un plano vertical perpendicular al eje de la pista.

Figura 5 – Características Superficie de Transición
Fuente: Anexo 14

Esta definición y características nos muestran que, la altura del borde inferior de la superficie de transición es variable punto a punto y que es igual a la cota del eje de pista o la prolongación del mismo en el punto correspondiente más cercano.

Por otra parte la normativa nos asocia los respectivos anchos de pista según el numero clave de referencia y la anchura exterior del tren principal (OMGWS). Relacionando esto con los tipos de aproximación obtenemos la Tabla 2 donde el ancho de pista esta expresado en metros; a partir de aquí identificaremos con amarillo, verde y celeste en correspondencia con pistas de aproximaciones de precisión, no precisión y visuales respectivamente.

Tabla 2- Comparativa Longitud borde interior
Fuente: Autor

	IFR: Aproximación por instrumentos								**VFR:** VFR: Aproximación visual			
CLAVE	**IP:** Inst. de precisión				**INP:** Inst. de no precisión							
1	18	23			18	23			18	23		
2		23	30			23	30			23	30	
3			30	45			30	45			30	45
4				45				45				45

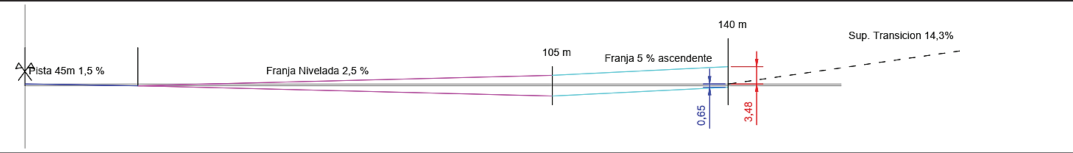
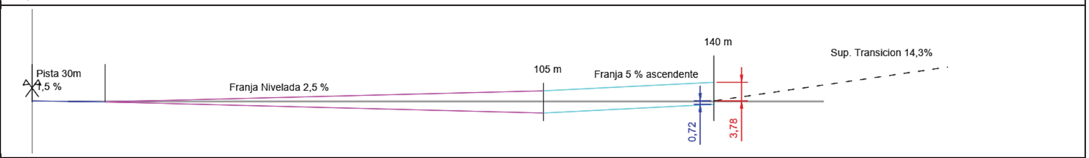
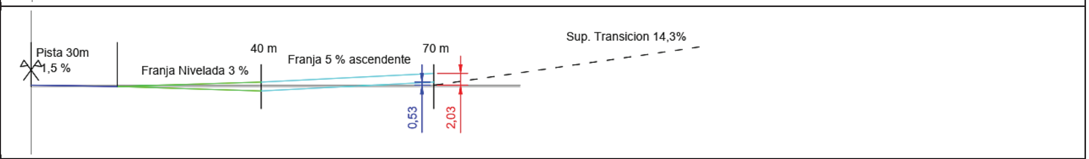
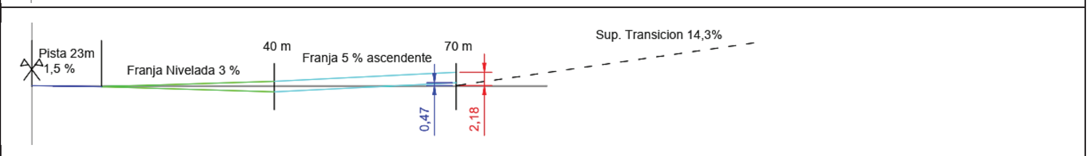
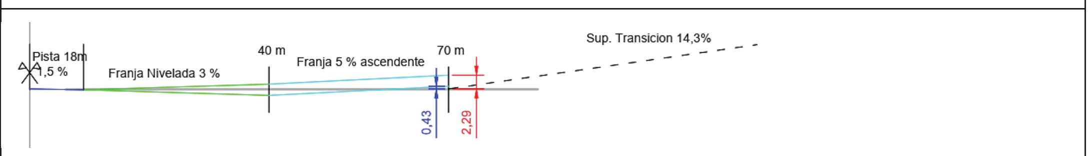
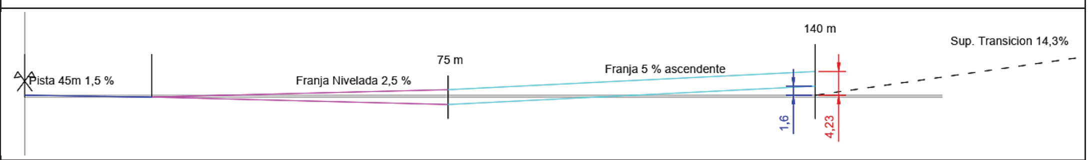
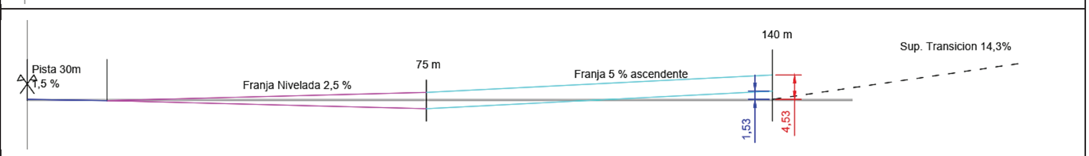
Teniendo presente lo anterior y asumiendo nivelaciones de franja admisibles máximas y mínimas simétricas respecto del eje de pista, hemos trazado los perfiles transversales para las combinaciones posibles de anchos de pista, tipos de aproximación y claves de referencia, y hemos obtenido los perfiles transversales en la franja de pista

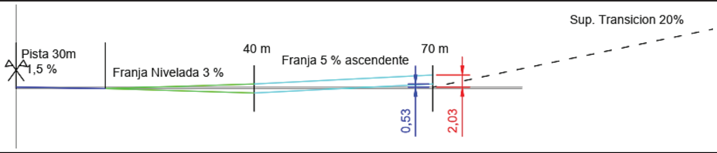
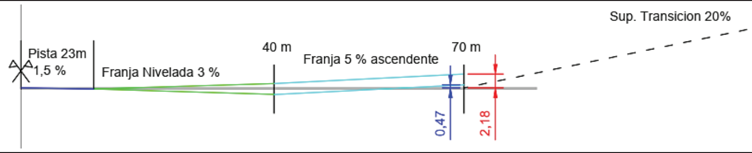
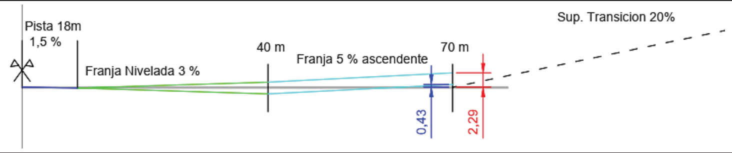
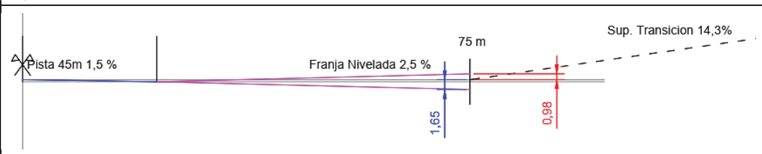
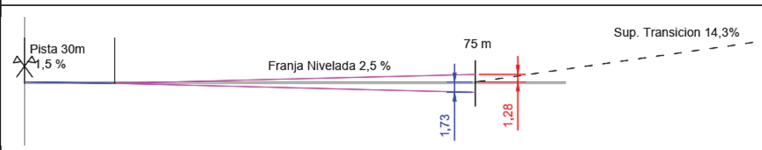
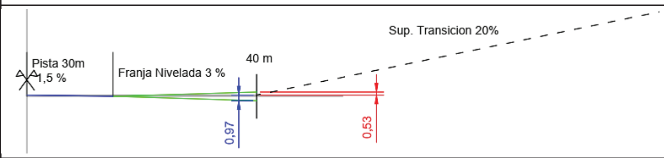
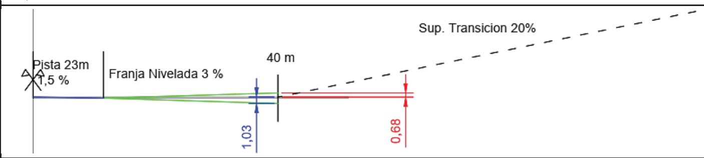
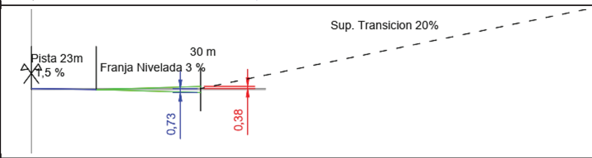
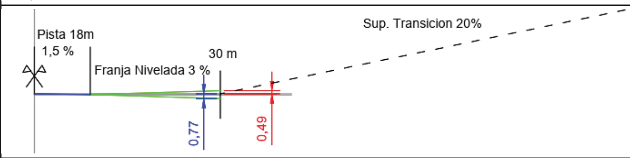
Resultados

Para simplificar los resultados obtenidos, se muestran en forma de tabla, tratando de evitar confusiones, y por simetría del perfil transversal solo se presenta un lateral de estos.

Es necesario aclarar, que en los perfiles mostrados a continuación, Tabla 3, tomando la medición de la pendiente en sentido de alejamiento de la pista, en la parte de la franja más cercana a la pista se han colocado pendientes máximas admisibles recomendadas (positivas y negativas), pero en la parte de la franja más alejada de pista solo se ha trazado la pendiente máxima positiva, ya que no existe limitación para la pendiente negativa

Tabla 3- Perfiles transversales nivelaciones Franjas de Pista
Fuente: Autor

<table>
<tr><th>Aprox.</th><th>Clave</th><th>Ancho</th><th>Perfil de pista y franja según clasificación</th></tr>
<tr><td>IP</td><td>3-4</td><td>45</td><td>
</td></tr>
<tr><td>IP</td><td>3</td><td>30</td><td>
</td></tr>
<tr><td>IP</td><td>2</td><td>30</td><td>
</td></tr>
<tr><td>IP</td><td>1-2</td><td>23</td><td>
</td></tr>
<tr><td>IP</td><td>1</td><td>18</td><td>
</td></tr>
<tr><td>INP</td><td>3-4</td><td>45</td><td>
</td></tr>
<tr><td>INP</td><td>3</td><td>30</td><td>
</td></tr>
</table>

Aprox.	Clave	Ancho	Perfil de pista y franja según clasificación
INP	2	30	
INP	1-2	23	
INP	1	18	
VFR	3-4	45	
VFR	3	30	
VFR	2	30	
VFR	2	23	
VFR	1	23	
VFR	1	18	

Los resultados de los perfiles anteriores se observan resumidos en las siguientes tablas, como diferencia de cota entre la máxima cota lograda respetando la nivelación al máximo permitido por norma y la cota del borde inferior de la superficie de transición; esto se puede ver, como la zona del círculo de la Figura 6 genérica siguiente:

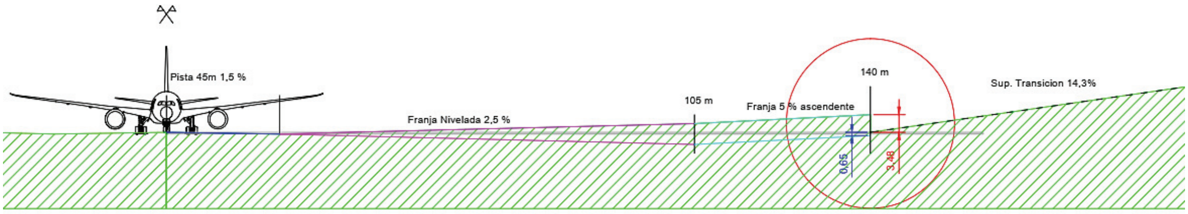


Figura 6 – Esquema genérico (Pista calve 4 aprox. Precisión)
Fuente: Autor

En la Tabla 4 se resumen los resultados de haber asumido una nivelación transversal de +2,5 % (ascendente) en la parte nivelada de la franja, y una pendiente de +5% (ascendente) en la parte más allá de la franja nivelada, ya que en esta última parte no hay límite descendente. Estos se corresponden con las cotas rojas de los gráficos de la Tabla 3.

Tabla 4- Resultados diferencias de cotas (metros)
Fuente: Autor

	IFR								VFR			
CLAVE	IP				INP							
1	2,29	2,18			2,29	2,18			0,49	0,38		
2		2,18	2,03			2,18	2,03			0,68	0,53	
3			3,78	3,48			4,53	4,23			1,28	0,98
4				3,48				4,23				0,98

En la Tabla 5 se resumen los resultados de haber asumido una nivelación transversal de -2,5 % (descendente) en la parte nivelada de la franja, y una pendiente de +5% (ascendente) en la parte más allá de la franja nivelada, ya que en esta última parte no hay límite descendente. Estos se corresponden con las cotas azules de los gráficos de la Tabla 3.

Tabla 5- Resultados diferencias de cotas (metros)
Fuente: Autor

	IFR								VFR			
CLAVE	IP				INP							
1	0,43	0,47			0,43	0,47			-0,77	-0,73		
2		0,47	0,53			0,47	0,53			-1,03	-0,97	
3			-0,72	-0,65			1,53	1,60			-1,73	-1,65
4				-0,65				1,60				-1,65

Los resultados anteriores se pueden unificar en el siguiente gráfico, Figura 7, donde el cero seria la cota de referencia en el borde de la franja para el borde interior, es decir la cota que tiene el punto del eje de pista más cercano, donde:

- La serie A, representa nivelaciones cuya parte de la franja más cercana a la pista se han colocado pendientes máximas admisibles recomendadas positiva (cotas rojas).
- La serie B, representa nivelaciones cuya parte de la franja más cercana a la pista se han colocado pendientes máximas admisibles recomendadas negativa (cotas azules).
- La codificación es, C: clave; A: ancho de pista; IFRP: aproximación instrumental de no precisión; IFRNP aproximación instrumental de precisión y VRF: aproximación visual.

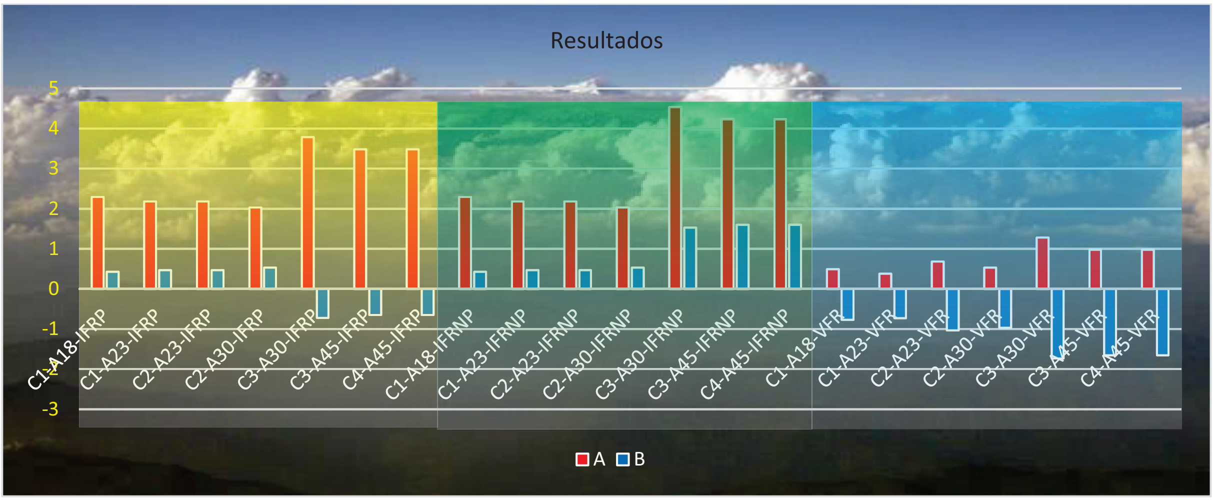


Figura 7 – Resumen de resultados
Fuente: Autor

Análisis de resultados

Respecto de los resultados anteriores podemos realizar las siguientes observaciones:

- En ninguno de los casos analizados la cota obtenida al borde de la franja es coincidente con la cota del borde inferior de la superficie de transición.
- Para las condiciones de nivelaciones de la tabla 4 (serie A) los resultados son todos positivos, esto implica que el terreno en el borde de la franja siempre está por encima del borde inferior de la superficie de transición.
- Para las condiciones de nivelaciones de la tabla 5 (serie B) los resultados son positivos y negativos, esto implica que el terreno en el borde de la franja puede estar por encima o por debajo del borde inferior de la superficie de transición.
- Para pistas IFR-INP (verde) tanto en la serie A como la serie B, los resultados son positivos, por tanto la nivelación en el borde de la franja siempre está por encima del borde inferior de la superficie de transición.
- La diferencia máxima es de 4,53 m para pistas de 30 m de ancho, clave 3 e instrumental de no precisión. Esto implica que llegado al borde de la franja, si nivelamos al máximo admisible según recomendación de AN 14, tendremos una cota de terreno de 4,53 m por encima de la cota del eje de pista en el punto correspondiente, es decir 4,53 m por encima del borde inferior de la superficie de transición.

Conclusiones

De los resultados anteriores se puede concluir que cuando:

1- Se nivela la franja de pista con valores de pendientes recomendados, pero extremos o limites, es decir los máximos admisibles en la llamada franja nivelada y en la parte de la franja más allá de la nivelada y,
2- Se respeta que el terreno en el área donde comienza la superficie de transición, ósea más allá de la franja de pista, no vulnera la superficie mencionada.

Siempre tendremos un salto o escalón del terreno en el borde de la franja para poder cumplir con la limitación de la superficie de transición. La magnitud de estos escalones será variable dependiendo del caso correspondiente, pudiendo llegar a un máximo de 4,53 m para el caso de una pista de 30 m de ancho, clave de referencia 3 e instrumental de no precisión.

Las particularidades de estas situaciones es que se dan respetando las recomendaciones establecidas por el AN 14.

En síntesis, pareciera ser que, respetando la normativa vigente llegamos a una situación que a priori no sería deseable. En este punto, es cuando volvemos a pensar en la definición de la FP que mencionaba que "*la franja es un área destinada a reducir riesgo de daño a aeronaves que se salgan de pista o a proteger a las que la sobrevuelan*". Podríamos pensar que es menos probable, que el borde de una FP sea alcanzado por una aeronave que se sale de pista que a ser sobrevolado por la misma aeronave. Este interrogante, es algo que queda pendiente para análisis en un próximo trabajo haciendo un estudio de probabilidades de alcanzar el borde de la franja de una aeronave que se salga de pista.

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Probabilistic air traffic demand forecast at São Paulo terminal

João Basílio Tarelho Szenczuk - jb_pva@hotmail.com
Instituto Tecnológico de Aeronáutica
Marcelo Xavier Guterres - m.guterres@gmail.com
Instituto Tecnológico de Aeronáutica
Mayara Condé Rocha Murça - mayara@ita.br
Instituto Tecnológico de Aeronáutica
McWillian de Oliveira - mcwillianoliveira@gmail.com
Instituto Tecnológico de Aeronáutica
Wallace Silva Sant'anna Souza - wallace2silva2souza@gmail.com
Instituto Tecnológico de Aeronáutica

Abstract
This paper presents an airport demand forecast study through Monte Carlo simulation based on historical series. Data on aircraft movements in São Paulo Terminal Maneuvering Area (TMA) between 1980 and 2017 were collected from the Brazilian air transport yearbooks and year-on-year demand variation rates were calculated. Then, the Anderson-Darling goodness of fit test was used to determine the parametric function that best fits the data. From this function, we perform the Monte Carlo simulation for a 20-year demand horizon. Confidence intervals from 10% to 90% are obtained. Finally, a comparison with results of the econometric model used by government entities is presented.

Keywords
Previsão de demanda; Aeroportos; Planejamento; Monte Carlo

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Introduction

Knowing the characteristics and the oscillation of the future demand of an activity is essential for planning and decision making at the strategic, tactical and operational levels. In the case of air transport, for example, forecasting the number of take-offs and departures enables the analysis of minimum requirements necessary to provide safe and efficient service. On the other hand, inaccurate inferences may result in loss of service quality (delays and cancellations) or unnecessary financial investments.

Given that, it is considered that the inference of the number of aircraft movements is essential for understanding airport systems, since it contributes to the assessment of operational capacity, its consequent limitations, and provides the necessary information for the development of the tactical planning of landings and departures. Thus, this knowledge allows an understanding of the magnitude and nature of the operations associated with an airport [1].

In addition to the individual aspects of each airport, each country establishes its medium and long-term aeronautical infrastructure plan that include budget forecasts for airport capacity development projects. To justify these investments, studies detailing the intensity of operations at each airport are needed. Moreover, the secondary structures of the airport system and coordination with environmental studies are also dependent on this information [2] .

Consequently, it can be said that the inference of the number of aircraft movements at a given airport is critical to the assessment of the operational capacity limit. It also serves as a parameter for future expansions. According to [3], the most preeminent methodologies used are: a) Time series methods;b) Market Share methods; c) Econometric modeling; d) Computer simulation modeling.

Time series analysis involves the construction of an equation that allows the projection of a future value based on a collection of data obtained over time. The forecast by Market Share consists in quantifying the entry of new consumers due to the implementation of new business strategies. On the other hand, the econometric modeling consists in relating a dependent variable (information to be inferred) with independent variables, through an empirical mathematical model. Finally, computational simulation models, which first examine historical information of a random variable by constructing histograms and then the adjustment of the data to a theoretical or empirical probability distribution, which serves to obtain random sampling of the phenomenon under investigation [3].

On the other hand, regarding aircraft movement in the national airport systems, Brazil has shown great concern with the regulation and preparation of the infrastructure necessary to

attend air traffic growth. In this perspective, the Ministry of Transport, Ports and Civil Aviation (MTPA) published the Demand Projections Report for Brazilian Airports for the period from 2017 to 2037. This report served as a subsidy for the elaboration of the National Aviation Plan (PAN), which is intended to guide investment policies in airport systems.

The Demand Projections Report for Brazilian Airports used classical econometric modeling. Assumed premises in the study include the division of the Country in 772 territorial units, the measurement of the influence area of a certain airport (can serve as destination for more than one territorial unit), and the sum of demand projections for the units that make up an influence area. However, regarding the validity of the results obtained, the document highlights possible limitations due to the assumed hypotheses, mainly due to the use of statistical series of future projections of variables such as: GDP, population growth and level of tourism activity. Besides that, the study did not take in consideration general aviation.

[3] points out that a given forecast model is not always capable of accurately portraying a system of uncertainties such as air traffic. To corroborate this statement, we compared the aircraft movement forecasts of the Ministry of Transport report with the actual data provided by the National Civil Aviation Agency [4], according to Table 1.

Table 1 - Comparison between the Ministry of Transport forecast and the real movement in 2017
Source: Authors

City	ICAO	Real movements	Forecasted movements	Difference between forecasted and real
Congonhas	SBSP	174136	174580	≅ -0%
Guarulhos	SBGR	249636	257255	≅ -3%
Viracopos	SBKP	104986	114638	≅ -8%

≅ sign of approximately

Table 1 shows that the demand forecast obtained by the econometric models when compared to the real values of the first year presented some degree of variation. In addition, larger oscillations are expected for subsequent years. This scenario, in terms of airport planning, may lead to investments based on lower rates of return than expected.

A complement to demand forecasting with econometric models is the Monte Carlo technique by time series developed by [5]. In this perspective, this paper presents a comparison between air traffic demand forecasts obtained by the Ministry of Transport through an econometric model and the methodology proposed by [5]. For that, the case study explores the three main airports of the São Paulo Terminal Maneuvering Area (TMA): Congonhas (SBSP), Guarulhos (SBGR) and Viracopos (SBKP).

Literature Review

According to [6], Monte Carlo Simulation is a stochastic method that estimates the expected value of a random variable by means of random samplings of the probability density function of the random variable under examination. It is usually used in physical and mathematical simulations of systems. Its use is particularly suitable when computing the exact result of a deterministic algorithm is not reasonable.

However, regarding the use of Monte Carlo Simulation to predict demand the literature is relatively scarce. In this sense, an important article is that of [5]. In this study, the authors develop probabilistic demand forecasts through Monte Carlo Simulation for the 50 main commercial airports of the United States. Also, they compare their results with the forecast developed by the FAA Office of Aviation Policy and Plans (APO). For that, parametric distributions of historical growth rates were produced to represent future airport uncertainties.

Another relevant study was developed by [7], that used the Monte Carlo technique via Markov Chains to estimate the intervals between aircraft arrivals at an airport. Monte Carlo simulation was also the method used to estimate the aircraft movement at airports which data collection was hampered by the absence of control towers, as highlighted in [1]. This research uses algorithms developed in R through the JAGS (Just Another Gibbs Sampler) library to obtain higher quality results in relation to conventional statistical methods.

Among the literature that best exploits the use of Monte Carlo simulations, the road sector stands out. [8], [9] and [10] evaluate vehicle queues, [11] proposes the optimization of urban routes for the faster flow of taxis, and [12] estimate the demand for electric vehicles based on traffic and optimized routes.

Monte Carlo simulation have also been used, at an advanced stage, in studies of the industrial sector. [13] study the economic and technical feasibility of electrical systems in a factory. [14] evaluate the monetary flow in commercial establishments, and [15] estimates the future demand for bottled products.

Methodology

The model of Bhadra e Schaufele

It should be noted that the main objective of this paper is to make a comparison between the econometric forecast of aircraft movement of the Ministry of Transport with the estimates calculated by the methodology outlined in [6]. Since there is a temporal lapse between [6] and the present investigation, a validation of their results is presented in Table 2, with the actual aircraft movements made available by the competent bodies of the U.S.

[6] presented the results of two different predictions of aircraft movement, one of them being developed by the competent federal agency (APO) with a forecast around the median. The other was proposed by the authors, which main characteristic was the delimitation of the statistical intervals in percentiles of 20%, 40%, 60% and 80%.

With this information and actual aircraft movement, Table 2 was elaborated. It presents the comparative results of each forecast with the percentage changes in relation to the real value. Finally, a color code was used to determine which of the methods obtained the best results (green - Monte Carlo; yellow - results with statistically insignificant differences between the two models; red - APO) for a sample of 19 of the 50 evaluated airports.

Table 2 – Comparison between the results of the Monte Carlo method and the APO forecast of 19 commercial airports of the United States for the year 2015.
Source: Authors

Airport	APO forecast	Monte Carlo forecast	Real movement	Difference APO vs. real (%)	Difference Monte Carlo vs. real (%)	Color code
ATL	1149439	1015730	882497	-0,3	-0,15	
BOS	537940	387388	378013	-0,42	-0,02	
BWI	401127	291455	246460	-0,63	-0,18	
CLE	315121	207238	117773	-1,68	-0,76	
CLT	599431	556645	543944	-0,1	-0,02	
CVG	509511	627497	133225	-2,82	-3,71	
DCA	300004	311658	297095	-0,01	-0,05	
DEN	581580	372733	547648	-0,06	0,32	
DFW	890742	999654	681261	-0,31	-0,47	
DTW	671847	576446	379376	-0,77	-0,52	
EWR	558884	275113	416947	-0,34	0,34	
FLL	459797	262979	278005	-0,65	0,05	
HNL	393922	251640	312934	-0,26	0,2	
IAD	647107	443971	294807	-1,2	-0,51	
IAH	731840	637785	502844	-0,46	-0,27	
JFK	508325	267083	446644	-0,14	0,4	
LAS	861482	606885	524878	-0,64	-0,16	
LAX	838892	639374	654493	-0,28	0,02	
MDW	341501	359640	253519	-0,35	-0,42	

As shown in Table 2 demand forecasts obtained through the Monte Carlo simulation were closer to real movements. It should be noted that the Monte Carlo results located in the 20%

percentiles were closer to reality, which shows a reduction in the growth rate of aircraft movements in relation to the historical series.

Moreover, [6] describe that the proposed methodology provides several positive aspects to demand prediction modeling, especially because it uses parametric functions that can statistically describe the input data with a good level of significance.

Therefore, as the validation result was favorable, the methodology was considered satisfactory to be used in this research, but here oriented to the analysis of an entire TMA.

Data

There is no specific data source for the number of take-offs and landings in São Paulo TMA. To address this problem, we aggregate data sources from the three main airports, corresponding to about 98% of the commercial flights in the region:

- Aeroporto de Guarulhos – SBGR/GRU;
- Aeroporto de Congonhas – SBSP/CGH;
- Aeroporto de Viracopos – SBKP/VCP.

The number of aircraft movements, considering regular and non-regular commercial aviation, was collected from INFRAERO's yearbooks from 1980 to 2002 and from the National Civil Aviation Agency [4] from 2004 to 2018. To avoid atypical variations arising from the transition between different databases, we opted for the exclusion of the sample for the year 2003. In other words, the database accounts for a historical series referring to 35 years.

According to the results of the first statistical experiments, the random variable (number of aircraft movements) in its natural state did not present acceptable adhesion rates for the parametric functions tested. As an alternative to this variable, we consider the percentage of variation relative to the previous year, as presented in Figure 1.

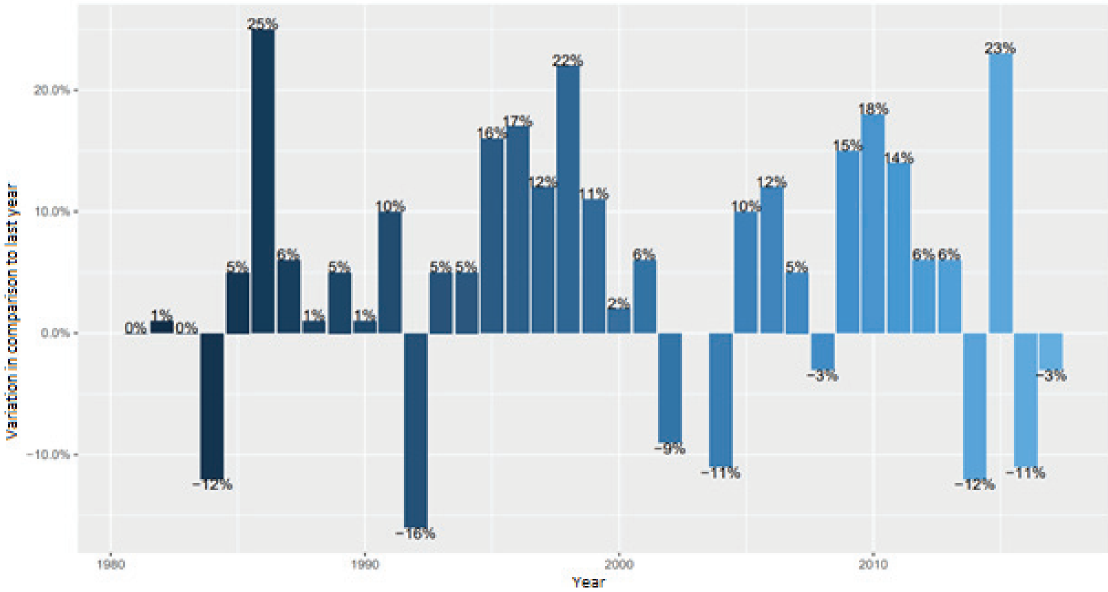

Figure 1 - Annual variation of commercial aviation traffic in São Paulo
Source: Authors

A frequency distribution histogram of the historic year-over-year traffic variation rate is presented in Figure 2. Goodness-of-fit (GoF) tests were then employed to determine which parametric distribution better represents the data.

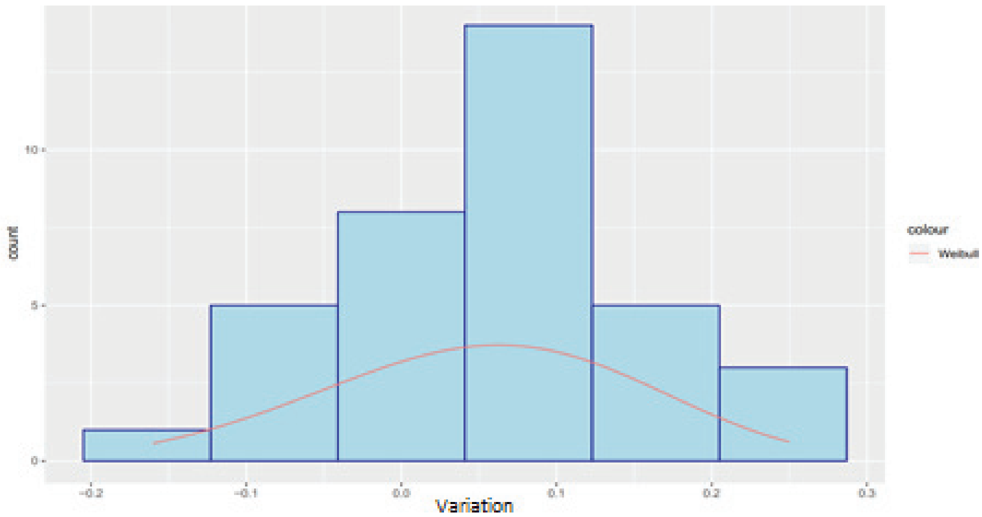

Figure 2 - Frequency distribution histogram of the historic year-over-year traffic variation rate
Source: Authors

In general, GoF tests compare the observed frequencies with the theoretical frequencies of the functions for which the data is tested for. [6] indicates that the Anderson-Darling (A-D) test is the most suitable for this application since it measures the difference between distributions with focus in the tails rather than the central part. Results with ρ-values lower than 1.5 are characterized with good adherence to the original sample.

Thus, to employ the methodology presented in [6] we use the Crystal Ball software, by Oracle, for both GoF tests and the Monte Carlo simulation process. After the A-D test, it was found that a Weibull function is the one that best fits the data with A-D statistical result of 0.30. This distribution has parameters η (scale), ß (form) and y (location). Its probability density function $f\ (t)$ is given by Equation 1:

$$f(t) = \frac{\beta}{\eta}\left(\frac{t-y}{\eta}\right)^{\beta-1} e^{-\left[\frac{t-y}{\eta}\right]} \tag{1}$$

where: f(t) ≥ 0; t ≥ y; ß > 0; η > 0; e -∞ < y < ∞. Equation 2 represents the cumulative distribution function $f\ (t)$:

$$f(t) = 1 - e^{-\left(\frac{x}{\lambda}\right)^{k}} \tag{2}$$

where: x ≥ 0, f(t, k, λ) = 0 for x < 0.

Regarding the Monte Carlo simulation, pseudorandom number generators were used for each forecast year. The annual rates of change were then transformed into a forecast of total annual traffic (TAT) (commercial aviation) in t + 1, according to Equation 3.

$$TAT_{\ t+1} = (1 + \text{annual variation}_{\ t+1}) \text{ X } TAT_{\ t} \tag{3}$$

Finally, with the results of the Monte Carlo simulation a distribution is generated for each forecast year in order to provide the probability bands.

Monte Carlo simulation and results

The São Paulo TMA handled in 2017 a total of 454,262 commercial aviation aircrafts. This number was used to start the first year of forecast, 2018, with 10000 simulations interactions in Crystal Ball. This process is repeated for each year until 2038.

To avoid repetition, the distributions resulting from the total annual traffic (TAT) of only three years are reported: 2018, 2027 and 2037, according to Figures 3 to 5, respectively. An early interpretation points out that a maximum extreme value distribution best captures forecasts for the first two years, 2018 and 2019. While a lognormal best describes the following years.

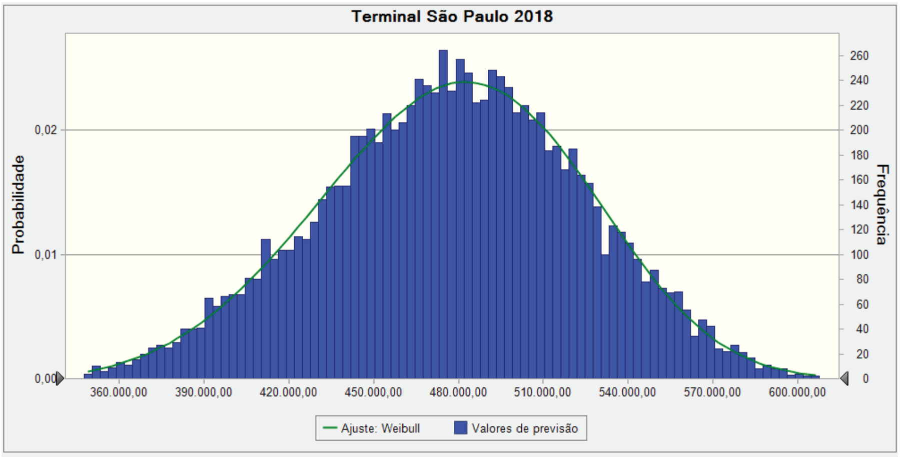

Figure 3 - Distribution resulting from the Monte Carlo simulation for the year 2018.
Source: Authors

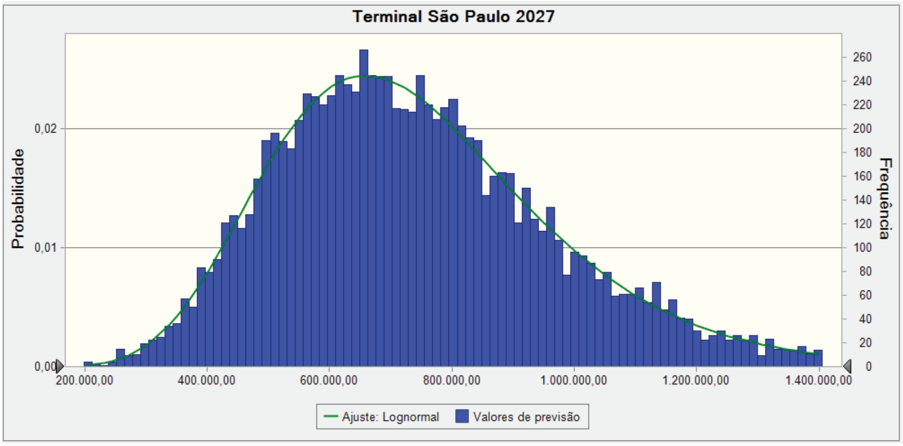

Figure 4 - Distribution resulting from the Monte Carlo simulation for the year 2027.
Source: Authors

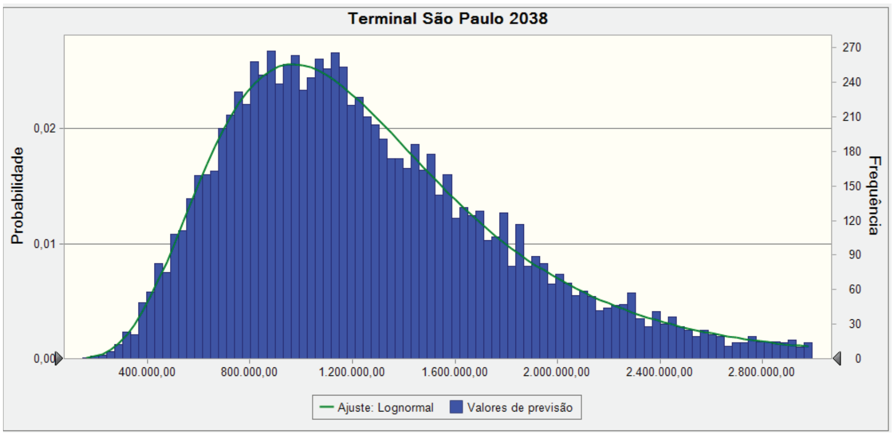

Figure 5 - Distribution resulting from the Monte Carlo simulation for the year 2038.
Source: Authors

It is important to note that the method does not provide a single estimate for annual demand, but rather a probability distribution. Finally, when aggregating the annual demand forecast

data, we obtained Figure 6, which presents the probability distribution for all forecast years, centered at the median for the statistical intervals of 10%, 25%, 50 % and 90% forecast.

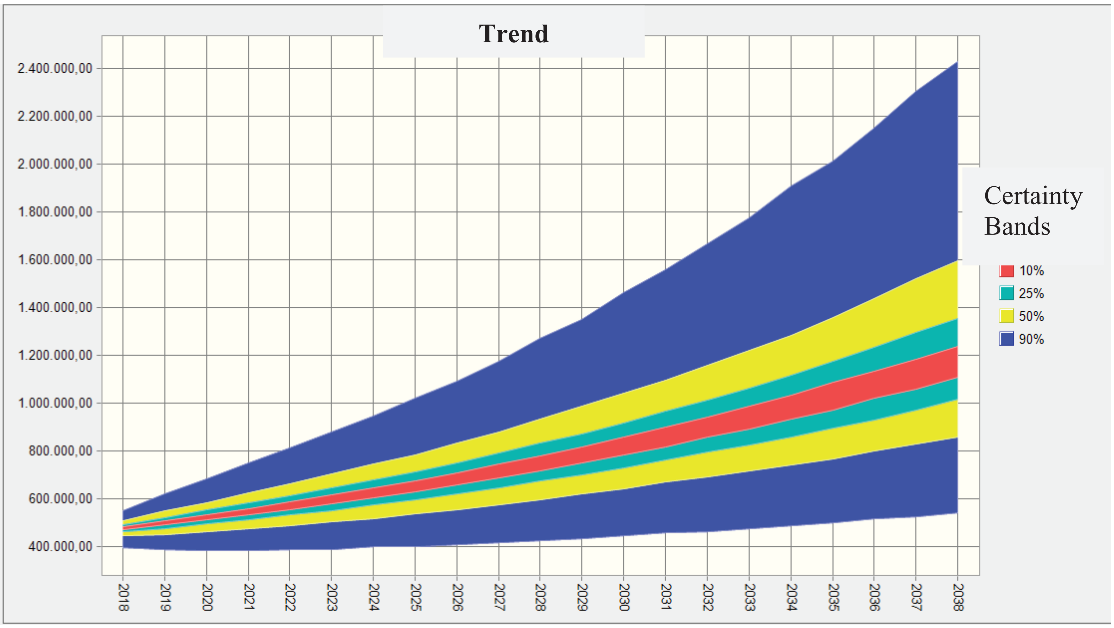

Figure 6 - Probability bands of predictions with Monte Carlo simulation for the terminal area of São Paulo.
Source: Authors

Figure 7 shows the linear development of predictions over the years. As the Monte Carlo forecast allows to group the forecasts into different confidence intervals, it was grouped in the quartiles of 20% to 80% compared to the MTPA model.

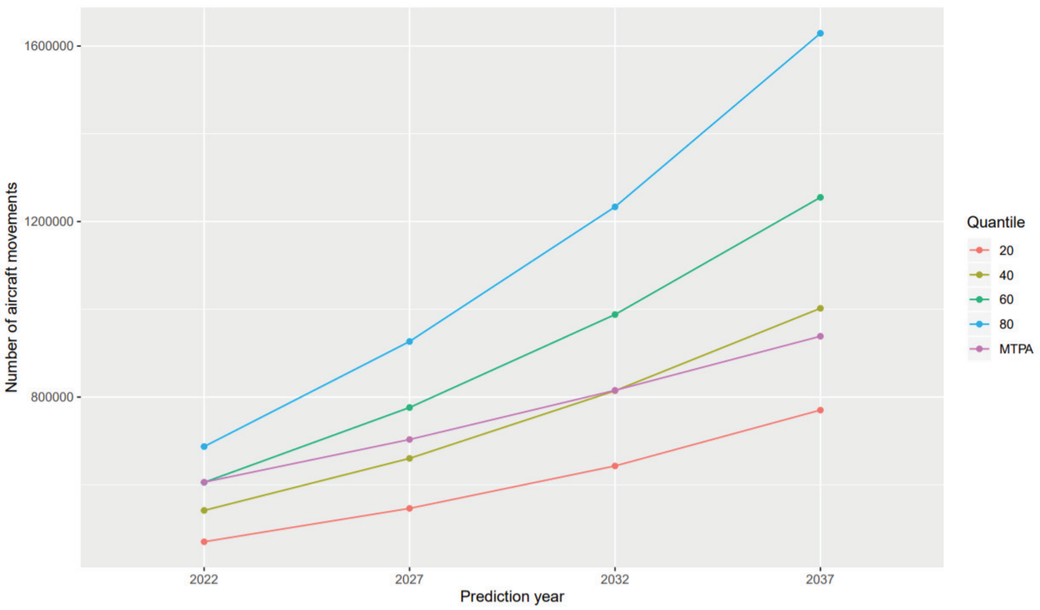

Figura 7 – Probabilistic forecast bands (%) and comparison with MTPA point forecast.
Source: Authors

To complement the information in Figure 7, Table 3 presents the comparison between the absolute values of both demand forecasts (Monte Carlo and MTPA) for the years 2022, 2027, 2032 and 2037.

Table 3 - Comparison between the prediction ranges of Monte Carlo simulation and the Ministry of Transport for the years 2022 to 2037.
Source: Authors

Forecast year	MTPA	Up to 20%	Difference (20%)	Up to 40%	Difference (40%)	Up to 60%	Difference (60%)	Up to 80%	Difference (80%)
2022	605.977	470.277	-22%	541.585	-11%	605.522	0%	687.214	13%
2027	703.292	546.209	-22%	660.259	-6%	776.188	10%	926.740	32%
2032	815.334	642.998	-21%	814.334	0%	987.971	21%	1.233.546	51%
2037	938.612	770.327	-18%	1.002.262	7%	1.255.196	34%	1.629.158	74%

In relation to the results obtained by Bhadra and Schaufele (2007) and by the present authors, the individual analysis by airport and the whole TMA were similar in comparison to the econometric models of both countries, the United States and Brazil. Another factor of interest is the perception that both forecasting methods present complementary results since the econometric methodology considers several variables that are not addressed in the historical series, while the Monte Carlo model allows greater variability of statistical intervals.

In general, the results obtained in the econometric model were within the statistical range of quartiles 40 to 60 of the Monte Carlo model. Another factor of analysis is the fact that the relative difference between the smallest and largest prediction quartiles is approximately 100%. This uncertainty contributes to optimistic forecasts that do not always come to reality.

Conclusion

Predicting traffic at airports is an essential activity for planning investments in infrastructure. However, it is historically proven that there is no model for perfectly accurate demand forecast in air transport. Therefore, it is possible to use a combination of several models to achieve more probable results. In this sense, the present work presented a probabilistic method of forecasting demand, in which the historical series of annual variation in commercial aviation traffic volume in the main Brazilian TMA (São Paulo) was adjusted to a parametric distribution.

This distribution was then used to run Monte Carlo simulations that forecast the demand for aircraft movements over a 20-year horizon. In this way, the results obtained by the Monte Carlo analysis can be compared with those presented by the competent Brazilian agency (Ministry of Transport, Ports and Civil Aviation). The advantage of the methodology used is

the possibility of observing the associated probabilities for each expected traffic range and, thus, determining the required minimum capacity and investment efforts.

It is important to point out that this paper presents some limitations. First, the sample of annual traffic variation for fitting a parametric distribution is relatively small, with 36 observations. The program used (Crystal Ball) is closed source software, which makes it impossible to confirm the internal programming logic used, as well as a description of the parameters considered.

In addition, there is no certainty that these data will have significance in the future variation of traffic since there are several factors of uncertainty that can affect the demand in commercial aviation. Among these, we can highlight economic growth or recession, population income, construction of new competing airports and the prohibition or limitation of the operational capacity of airports by regulatory bodies.

It is recommended for future work the use of open codes for the execution of the Monte Carlo simulations and the increase in the number of data components of the historical series. Another exploratory possibility would be the use of Monte Carlo analysis linked to other variables that influence air transport, such as per capita income and domestic market of the region in which the airport (s) are located.

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Air Transportation Sustainability Strategies: Technological, Operational, Economic, Social and Environmental.

Decision-making Processes Economic Strategies

Distributed ledger technology opportunities in the aeronautical sector: application to airport runways rehabilitation

Angel Paris Loreiro - angel.paris@upm.es
Universidad Politecnica de Madrid -Dpto. Sistemas Aeroespaciales, Transporte Aéreo y Aeropuertos (SATAA)
Joaquin Ordieres - j.ordieres@upm.es
Universidad Politecnica de Madrid
Leticia de Marcos - ldmarcos@aena.es
AENA
Antonia Pacios Alvarez - antonia.pacios@upm.es
Universidad Politecnica de Madrid

Abstract

The main objective of this work is to evaluate the improvement provided by Distributed Ledger Technology (DLT) implementation for decision making processes in the management of airport runways rehabilitation. They are complex construction projects due to the interconnections of different construction/service companies and the tied schedule to work with.

A review of DLT case studies in the aeronautical sector and more specifically in the area of smart construction introduces the case study of runway rehabilitation. It includes the management perspective, including agents, activities, interrelationships, etc., looking to identify solutions adapted to these needs.

The result of this work is a proposal for a distributed registry management model with integration of existing technologies in the market, which facilitates decision making and access to agents, according to privileges and verified updated information. A scalable proposal, that allows to adapt the integration of applications from the different companies, which enable the automation of processes, including tracking of performance.

The contribution of this publication is, based on a well documented case study, to be able to identify decisions that can be transformed into automated processes and implement them in the integrated DLT model, to allow different actors to access over different periods of time and to benefit from current and secure records.

Keywords

Gestión la construcción; construcción inteligente; red de sensores; Gestión distribuida de registros

Distributed ledger technology opportunities in the aeronautical sector: application to airport runways rehabilitation

INTRODUCTION

Due to the increasing number of passengers travelling, airports and smaller regional aerodromes have experienced a consequent increase in runway usage, accelerating the need for major maintenance. Maintenance at airports includes set of activities with continuous innovation to ensure safety, provide quality construction, and avoid excessive air traffic delays.

AENA is the first airport manager with more than 280 million of passengers (all the Spanish airports and Luton). Only in the past five years close to 15 pavement reparation on runway were performed. For an airport manager, maintenance of runways requires a significant amount of work that needs to be made in a short period, because of airport construction activities cause severe disruptions to regular airport operations. Such amount of work involves different providers and contractors, with strict regulated criteria to be met, which configures a complex system.

One of the characteristics of this complex system is the high number of interfaces and agents being involved; for each runway construction project the network of collaborations are set together and dismantled by the end of the project. The number of specialized node in such network (the number of companies being involved) is large, and the exchange of information is more frequent and relevant than before. To face failures or breakdowns in information exchange mean being exposed to relevant risks.

Construction phasing plans should specifically identify recommended work periods, inspections, service areas and routes for construction vehicles. With a very tied schedule, the laboratory acceptance testing should be performed at the specified intervals during each work period. Field samples and the results of tests must be assessed before the next work period begins, which may require nighttime testing laboratory, avoiding additional delays in construction activities. Therefore, motivation for detailed field monitoring and rapid acceptance testing is recommended due to the need to reopen the pavement with the minimum disturbance.

In aeronautical sector, pavement evaluation is an activity linked to a Repair and Maintenance Program (RMP) and Pavement Management Program (PMP). Deterioration of pavement is caused by environmental and structural causes, due to weathering, aging and repeated traffic loading. Understanding the defects and causes helps in selecting the extension of the repair. An integration of all the “life” data is needed to assist in the decision making process.

Surface quality of the pavement is well defined by control parameters. Over time, a monitoring system of airport’s response to traffic will require evaluation of many parameters, some quantitative (physical properties) and some qualitative (subjective characteristics). High performance measuring devices are used in order to minimize the number of vehicles and personnel involved in the surveys [1].

Most of data acquisition are obtained from pavement field survey; along with continuous registered data, field notes, pictures and sketches should all be imputed into the PMP. Precise pavement composition of each unit, historic traffics type, historic availability of non destructive test (NDT). With the advantage of getting all RM activities digitalized, historic deterioration rates and knowledge generation could be used for futures work. The improvement for assessing pavement conditions is an essential first step; model for rating the surface condition will help to use funds most efficiently identifying the appropriate rehabilitation project [2].

BIM alone, and now combined with DLT, is changing the construction system by promoting collaboration throughout the value chain, and enables accurate, well-informed decisions to be made through the lifecycle, as well as it brings the opportunity for integration of all those flows of digital information that can be related to geometric elements placed in such BIM model.

Construction companies (including Spanish players like Ferrovial, INECO, ACCIONA, ACS, etc.), have already experience on implementation of 4D BIM. During construction processes it can help as well with the control of road layout, structures, drainage systems by getting fast information on geometry, constructability, management and validation of temporary activities as for example temporary traffic deviations. It is unneglectable the impact that such new way of work will have in the management of such projects, with augmented accountability because of the automatic flow of data.

STATE OF THE ART

Digitalization for construction companies provides a new branches in the decision-making structures on the building site. For example, up to now, construction companies have sourced building materials from manufacturers of their choice, in line with specifications drawn by designers. It will be possible however that owner and designers will also decide to select manufactures, based on their profile and previous work, from a builder suppliers' database accessible to all actors enrolled in the construction project.

Building Information Modelling (BIM) promises to improve communication, to increase productivities, to increase quality and to reduce errors and cost. As far as it can be used for the rendering, management, design, simulation, measurement, construction, precast, and maintenance operations, it covers all life cycle for buildings and civil work. For public buildings and civil work, it is mandatory to work under this standard. For example in Spain, since December 2018 it is mandatory for all public buildings, and by July 2019 for all public infrastructures.

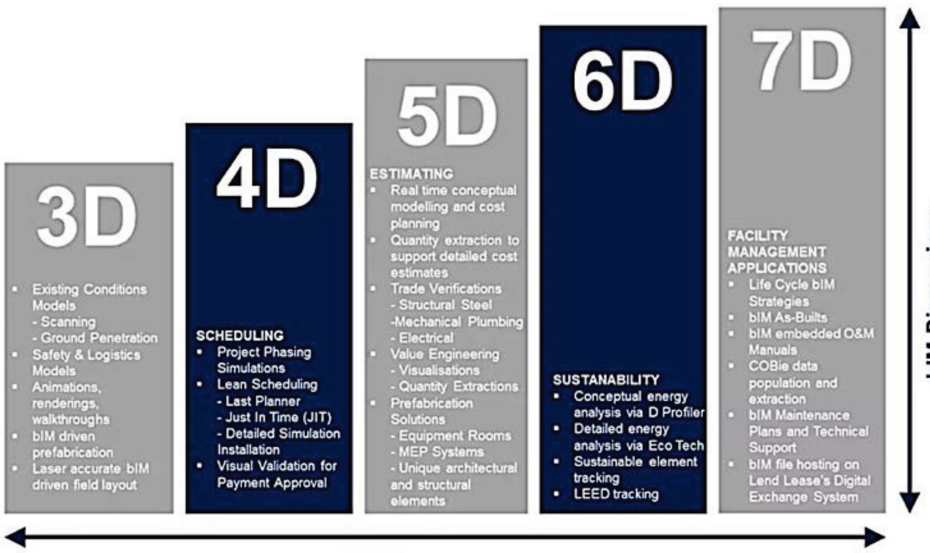


Figure 1- Agreed set of BIM Dimensions
Source: Adapted from Charef et al. [3]

There are different levels of BIM model development according to the detail included in a model element. Depending on the level of development BIM supports all life cycle of the buildings due to the management of graphic information and non-graphic information as cost, environmental parameters, technical product information data, maintenance services, to be included in pre-design, schematic, design, design development, construction documents, construction stage, as build. This helps the project team specify information in a BIM with a higher level of clarity and reliability as it contains geometry and information to support operations and maintenance activities including workflow, inventory, maintenance, production capacity, safety, etc.

The digital data embodied in the BIM model is shared between the project stakeholders from the various disciplines. After giving an overview of the BIM 3D Model, data used for planning (4D) and costing (5D). Most of professionals agree upon placing Sustainability on the 6D and they are using 7D to allocate Facility Management (see Figure 1).

As for facility management, for example, BIM either alone, or with other digital technology applications become more and more present (see Table 1).

Table 1 - Number of research focus on digital technology applications in facility management
Source: Adapted from Wong [4]

	2006/2007	2008/2009	2010/2011	2012/2013	2014/2015	2016/2017
BIM	1	6	16	26	18	6
GIS with BIM	--	--	1	1	3	1
Point cloud/laser scanning	--	--	1	1	--	1
IoT (RFID and sensors)	--	1	1	3	3	1
BIM + Point cloud		--	--	--	--	--
Sensor systems	2	--	--	--	--	--
BIM + RFID	--	--	1	--	--	--
Bar code + RFID	--	--	--	--	1	--
BIM + photogrammetry + laser scanning/point cloud	--	--	--	--	--	1
BIM + Point cloud	--	--	--	1	2	1
Augmented reality + photogrammetry	--	--	--	--	1	--

What it becomes also true is that, the higher dimension is adopted, the larger number of IFC entities will be implied in the BIM model and, as they are exported as text files, the size of the models will increase dramatically. To address this issue, Krijnen, & Beetz, [5] have proposed to use the open standard HDF5, as it will significantly reduce the required size.

Focus on automated system to measure remotely with enough accuracy the runway surface condition parameters (on the scale of the area of operation) not may results were found. Most of the works has been related to research on linear infrastructures. Since no automated system exist to assess properties requiring visual inspection, some new research systems from other related physical characteristics may be explored. Matei et al. [6] proposed a system based on image processing method for visual inspection and, more recent research, to estimate de surface drainage. Elunai et al. [7] propose a similar method to estimate the surface texture coarseness distribution from its edge profiles.

The decision support system related to technically and economically sustainable management strategies requires an Airport Pavement Management System. Di Mascio et al. [8] proposes two management levels: network level and project level. This paper gives an extensive information regarding automated procedures to get reliable information on the structural and functional performances of the paved surfaces. However, the paper does not address how to manage this data to better interconnect with the agents' decision to be made.

CASE STUDY: RUNWAY 18R-36L OF BARAJAS AIRPORT

Airfield pavement basic functions are to provide adequate bearing capacity, good rolling qualities and good surface friction characteristics. Ease of maintenance, durability or sustainability are other requirements having increased relevance through time.

Since the decision of resurface or rehabilitate should not been taken lightly, sufficient data to inform the decision-making process, from a number of sources, well in advance, should be obtained. These data can include those specific from the runway pavement conditions, as well as others, for example traffic forecast, weather forecast, budget, consultation with stakeholders among others.

Case presentation

Barajas airport runway 18R-36L was built in 1998 and it had not been renovated until 2015. It has a length of 4109 m and a width of 60 m (plus 7.5 m on each side). Currently has a capacity of 87 operations/hour and it is the one that transoceanic flights use without payload penalty.

For a month work, mid-April to mid-May, reparation of runway pavement was planned. Simultaneously other construction works were programmed:

- Moving the Deicing Plant
- New Instrumented Landing System for runway 18R
- New Electricity Transforming Centers

Table 2 - Resources for con site construction
Source: Authors

Asphalt plants with a capacity of 250 t/h	(3)	Bathtub truck	(18)
Concrete Pumps	(2)	Tipper trucks	(50)
Milling machines with an effective width of 2 m	(14)	Bituminizing trucks	(2)
Pavers of 11 m width, and a efficiency of 150 t/h	(6)		
Rollers	(8)		
Sweeping and self-loading machines	(12)		
Sweeping machines	(2)		
Painting machines	(4)		
Beaconing equipment	(8)		
Lighting equipment	(50)		

Equipment available on site during construction time is listed in Table 2. The equipment needed to accomplish these construction works gives some information of the complex interaction between activities and the importance of a Pavement Management Plan (PMP). All together were more than 1500 accredited people from 50 different companies, 500 simultaneous workers on site, and 200 vehicles driving along the construction site.

Regarding the quality control of the product, the following parameters from NDT data were obtained:

- Boeing Bump Index_(BBI) for evenness evaluation determined by Laser profile method (see Figure 2). Skilled operators are required for collection and data processing. The analysis of the graphical results allowed identification of the precritical and critical sections.
- Pavement Condition Index (PCI) for Pavement Distress Evaluation, determined by visual inspection.
- Pavement Classification Number (PCN) for structural evaluation, determined by Falling Weight Deflectometer (see Figure 3).
- Skid Resistance Airport Surface (MUM) for Pavement Friction Evaluation, determined by de Mu-meter (see Figure 4).

- Surface Texture Index (STI) for Surface Texture, determined by NASA Grease Patch Method. It does not have a associated standard. Is a discontinuous data acquisition, covers a small area, slow ,laborious,…

Figures 2 to 4 show examples of mapping data being included in the reports.

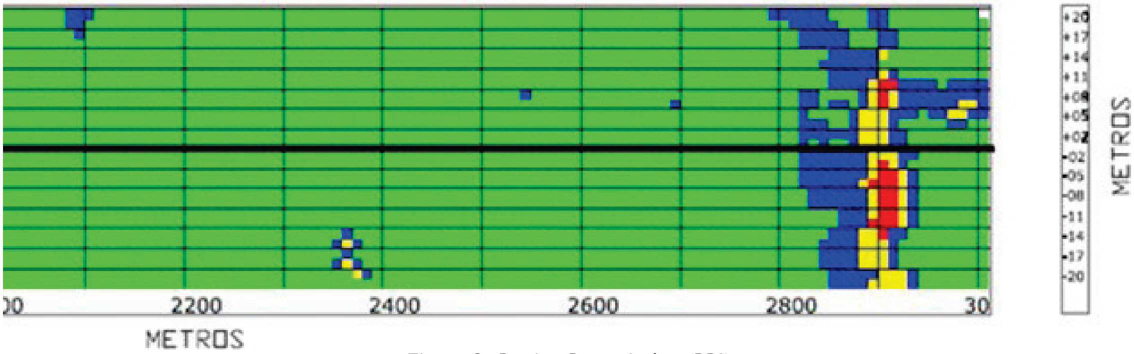


Figure 2. Boeing Bump Index (BBI)
Source: Authors

Figure 3. Pavement Classification Number (PCN)
Source: Authors

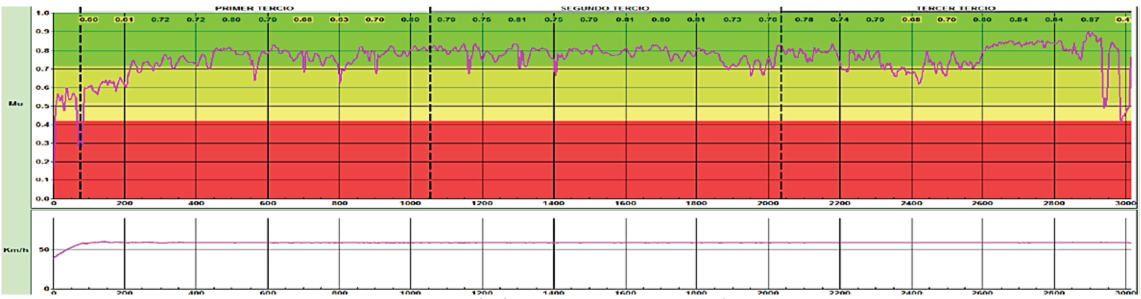


Figure 4. Skid resistance airport surface
Source: Authors

Given all the obtained results, the need for a structural and functional requalification of different areas of results. Pavement actuation covers seven areas with different length, width, and depth so it can be optimized according to the level of degradation (see Figure 5 and Table 3). A total of 4000 T of Portland Cement Concrete (PCC) pavement were demolish and reconstructed; 167000 T of Hot Mix Asphalt (HMA) pavement were regenerated.

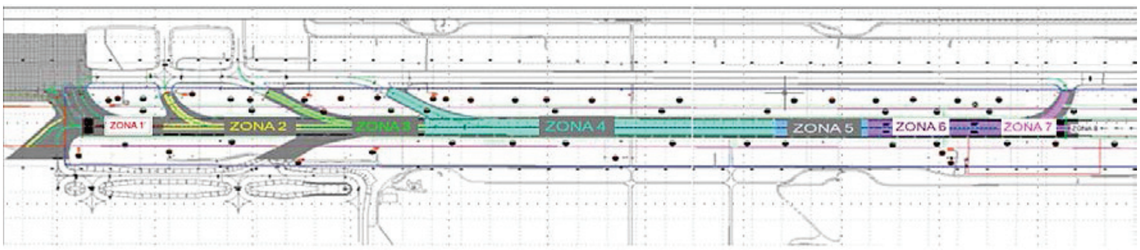


Figure 5. Actuation areas
Source: Authors

Table 3. Areas of pavement reparations
Source: Authors

AREA	FOM KP TO KP (m)	LENGTH (m)	WIDTH (m)	DEPTH (cm)
ZONE 1	0-278	278	15	130
ZONE 2	278-753	475	20	11
ZONE 3	753-1178	425	20	26
ZONE 4	1178-2378	1200	60	40
ZONE 5	2378-2693	315	60	26
ZONE 6	2693-3143	450	60	47
ZONE 7	3143-3403	260	20	40

Reports are a result of software, most of the cases not open but proprietary, with no compatibility attributes. However, control parameters need to be taken into account and integrated.

Maintenance and Repair Plan in the Pavement Project Management

Given the high operational impact of the needed works, the opportunity to concentrate them in a single period is important. The works were conducted within three phases (see Figure 6).

PHASE 0. IMPLEMENTATION. Under fully operational runway, all operations necessary for the preparation of the construction sites, the procurement and storage of materials, avoiding contamination between them, access fitting, take place. A complete history/records pavement inventory obtained from visual survey and field data acquisition from Topographic (LIDAR data processing relies on specialized tools and operators on Digital Topographic Models) and Geotechnical Data (Core testing and Seismic Refraction Profiling) is collected.

PHASE 1. CONSTRUCTION WORKS
Total closure of the airport runway for one natural month working on surface restoration, or structural restoration according to needs identified in phase 0. Hourly construction program for 24 h/day was approved (see Figure 6). Measurements for night shift work is needed. According to the zone the activities of mill and overlay of hot mix asphalt, surface dressing, retexturing by milling off the surface, should be performed. For concrete pavement, concrete slab demolition, rod perforation, and concrete placing have to be done.

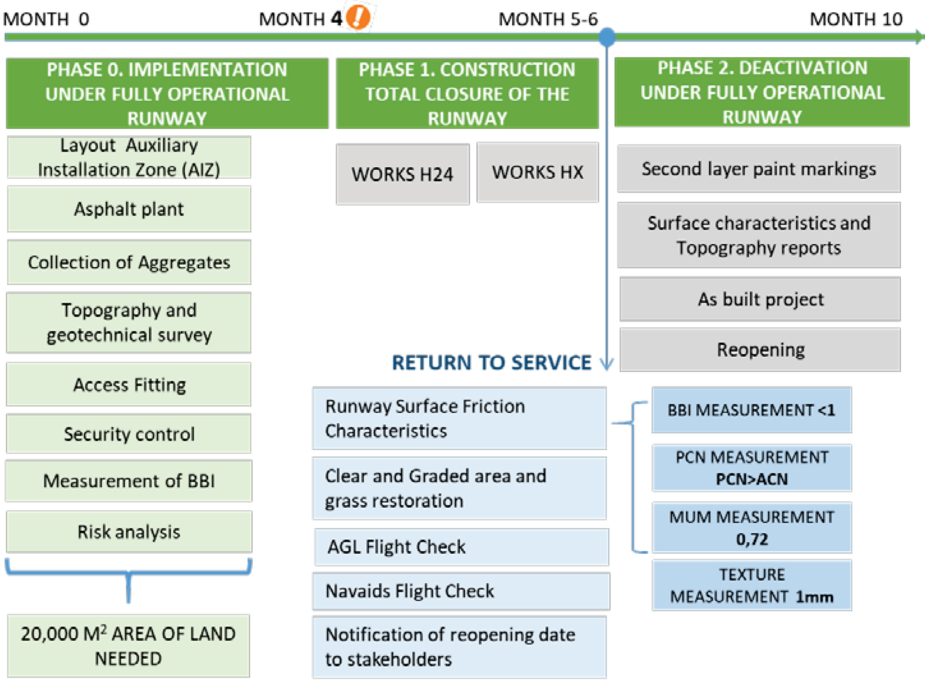


Figure 6. Construction phases
Source: Authors

Figure 7. Construction Plant Break Down
Source: Authors

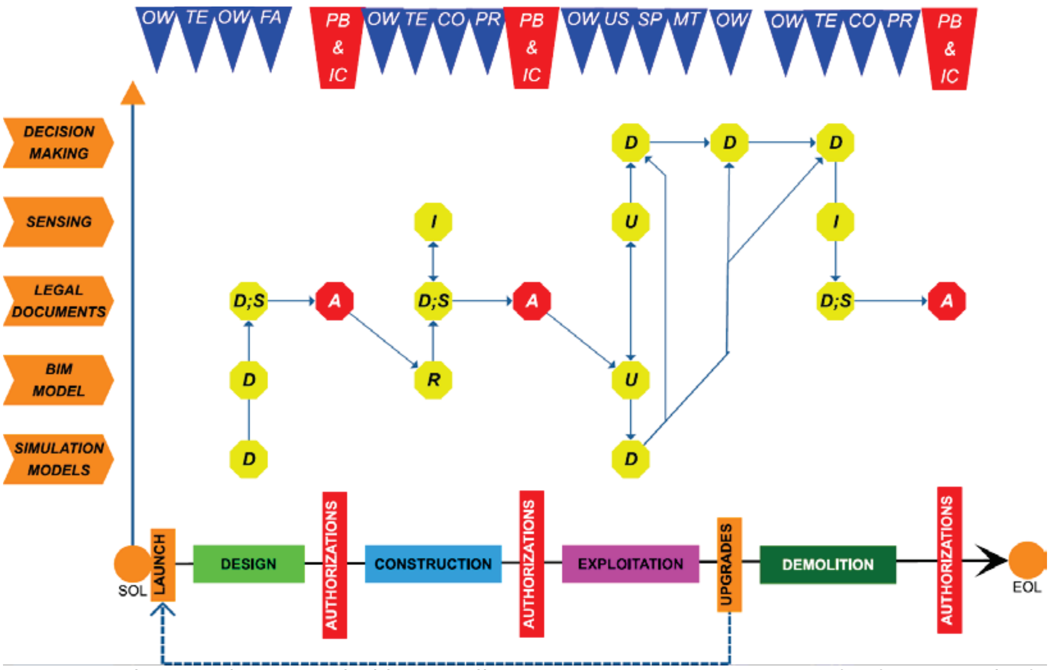
Previous to reopen a second topographic survey an fields test should be run to get integrated information of surface pavement quality (PCI, BBI, MUM, PCN).

PHASE 2. DEACTIVATION WORKS
All provisional works are demolished, and the original conditions restored, for a fully operational runway (see Figure 7).

FRAMEWORK PROPOSAL

What is also clear is that just up to the dimension 7D, all aspects are related to the construction of the building/infrastructure, but none is related to the remaining dimensions of the life cycle. Indeed, during the construction phase itself, as there are different type of related documents, it becomes fairly unrealistic to imagine that all of them will be stored inside the BIM model. Instead our proposal is to have a dynamic, federated and potentially encrypted constellation of objects all of them related through a DLT database, able to track who was accessing any of those objects.

In order to provide a comprehensive perspective, in general terms, both for the process and for the involved agents, the Figure 8 is provided, where the principal agents involved per phase, as well as the different digital products required. Therefore, during the design phase, and based on the vision and requirements provided by the owner and, probably by using different simulation models (energy consumption, structural design, etc.), a solution is finally developed, through the BIM model as well as all the technical documentation required to ask for the authorization for the solution from the proper public bodies, which should include the adequate insurance coverage. For the construction phase, maybe financial help will be required, where the business model but also the BIM one will be required to be presented. If the solution gets the approval, the construction phase starts, which involves the BIM usage to drive the technical implementation of the construction.



Notation: D=Develop, S=Submit, R=Rebuild, I=Install, U=Use, A=Approve. SOL=Start of Life, EOL=End of Life; OW=Owner, TE=Technical Staff, FA=Financing Agents, PB=Public Bodies, IC=Insurance Companies, CO=Constructors, US=Users, PR=Providers of Good & Services, SP=Service Providers; MT=Maintenance People, US=Users

Figure 8 - Reference framework connecting product phases along the X axis with type of digital elements along the Y axis and the agents on top.
Source: Authors

Such framework is based on the agent's interaction depicted in Figure 9, which is also provided as matter of reference.

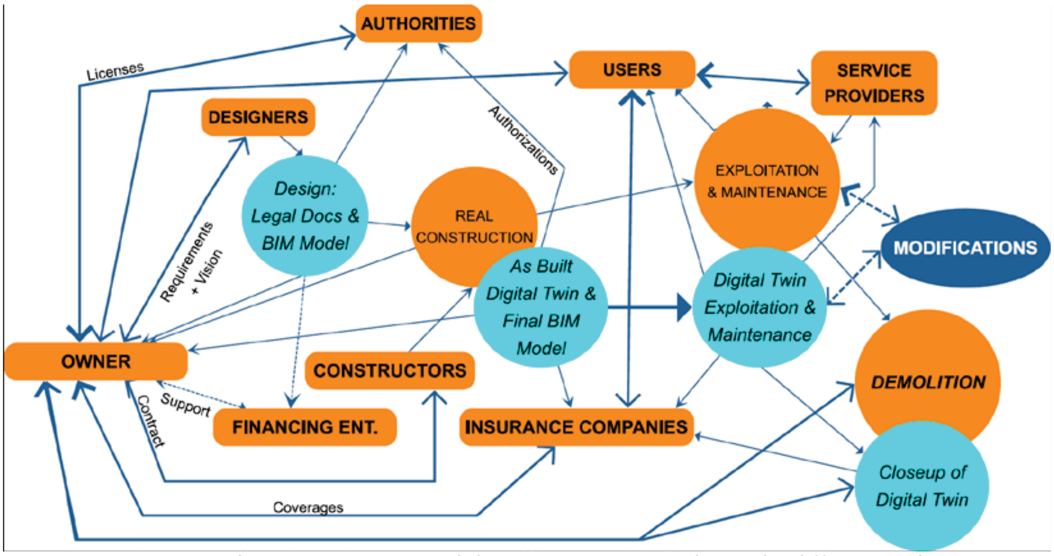


Figure 9 - Interactions between agents around the construction, considering the different evolving states. Source: Authors

When the solution described above gets the approval, the construction phase starts, which involves the BIM usage to drive the technical implementation of the construction but also the Supply Chain Management as well as the selected sensing level decided for the usage of the product (buildings or infrastructure). When the upgraded BIM model, according to the decision taken during the construction phase, as well as all the required as-built documentation become ready, the authorization for services and exploitation happen. After its approval, the exploitation phase starts, which means that different agents, like the users appear, including potentially the ownership transfer process. However, because of the existing upgraded BIM model, and the live information provided by the installed sensors in accordance to the BIM model, different decision makers can utilize different tools, including simulation models to contribute to a better usage of the product. The usage can be complemented with maintenance, operational decisions, etc. Such operations can include at some point in time to start revamping of different elements or installations. Such events have been considered in the life cycle as a loop to the design step, covering obviously only the decided items. Finally, at the end, when approach the end of its life the decision making process will require the preparation of the legal documents, including the plan for dismantling it.

From the proposed framework it becomes clear that different agents will require different access levels to different digital elements. Indeed, it appears as evident that it will happen a continuous data production from different sensors that could benefit to different agents during their own decision making processes.

Therefore, in order to configure an actionable proposal the framework requires a complementary proposal of potential implementation for such combination of digital storage for very different elements, including digital models, as well as for live data, in such a way that enough guaranties for decentralized, privacy, trustworthiness, fare-less and support for the required dynamic behavior.

As different agents require different level of access in different periods of time, the proposed framework, as the general description of the interaction among those actors needs to be

matched to an operational strategy able to facilitate such access. Therefore, either the owners of the construction product or its users will probably need get access to the legal authorization but, to grant traceability, probably other information like the constructive project or the models used into the design process or modification processes are also collected. From this perspective, different type of objects need to be stored, and different type of agents need to get access to different components.

To provide a convenient and flexible operational strategy enabling to handle relevant information, this paper proposes to store encrypted objects in a proper containing structure able to deal with such complexity level. Those different type of objects like BIM models (original, as built, upgraded, etc.), FEM models, documents, excel files, Pdf documents, etc., can be placed under a logic hierarchical structure. To support such containing structure, this paper proposes the adoption of the Experimental Directory Structure (Exdir protocol), that can be translated into the HDF5 format [9] [5].

The (Exdir), an open specification for data storage in experimental pipelines, amends drawbacks associated with HDF5 while retaining its advantages. Exdir, on the other hand, uses file system directories to represent the hierarchy, with metadata stored in human-readable YAML files, datasets stored in binary NumPy files, and raw data stored directly in subdirectories. On top od that, Exdir is not a file format in itself, but a specification for organizing files in a directory structure. Exdir uses the same abstractions as HDF5 and is compatible with the HDF5, which enables the usage of their open source tools.

When longitudinal information through time is considered, it can be stored either on the same Exdir container or in different ones depending on the responsible author in charge. It is easy to understand that any refurbishment to be made needs to take care of the original design, i.e. to consume the existing information in the Exdir container, but it needs to deliver the new documents describing the proposal and the changes finally made. Such new documents can be placed in the same Exdir container, when the author is the same than the first project or under a new one when they are different.

One of the critical aspects to provide convenient access to the information is to have a distributed database providing support to data access for different agents, with the convenient privacy levels. It is proposed to adopt the IOTA protocol, which was designed to be lightweight and serving for secure data communication between IoT devices. It differentiates itself from traditional blockchain-based distributed ledger (DLT) protocols by addressing two major pain points: latency and fees. IOTA does not utilize the concept of blocks and miners. Instead, all transactions that want to be added to IOTA's distributed ledger, known as the tangle, must validate two unconfirmed transactions on the ledger by solving a low-cost computational proof of work [10].

To keep the owner aware of the different containers, their location (URL with the storage of Exdir container), as well as the potentially different encryption keywords to access the individual components, it is proposed to be configured as transactions, encrypted, and being headed to the owner's IoTA wallet and finally sent to them through the tangle. Therefore, they always can have a centralized access to the information, through time. When convenient, the owner can either have direct access to the elements into the Exdir structure to disseminate with any relevant agent or just to inform him where the appropriate Exdir container is located, as well as the unencrypting keyword for accessing the specific document.

When someone with the proper access rights to the information needs to upgrade the information, the same approach will be implemented, and a new transaction covering the Exdir object for the updated information will be published and the corresponding encrypted transaction will be headed to the owner. If a transfer of property happen, the former owner needs just to send one transaction to the new one, by giving him the URL and keywords for each of the Exdir containers related to the construction object.

The second relevant aspect is to enable the collection and or usage for data being produced dynamically for the construction object during its life. In order to complement and properly provide support to the dynamic behavior of sensors, a digital structure of objects is needed. This is evident as the location of sensors, their characteristics and other relevant information is supported by the BIM model.

Fortunately, the same protocol can be used to handle data streaming from different sensors as well as from service providers of different commodities, as far as they want to implement such option. In this case, full traceability about what and when the usage of such services are provided, in addition to the cumulative figures on monthly bases, by using the Masked Authenticated Messaging (MAM). IOTA offers the MAM extension, acting as a second layer data communication protocol making it possible that sensors can broadcast encrypted, authenticated data streams being transmitted through the tangle as zero-value transactions. Such architecture can enable to introduce different monetizing approaches as potential agents interested in the data streams can subscribe to them, if the decryption keys have been given, in addition to the interested subscribers, which can send back to those smart sensors messages or instructions when convenient.

CONCLUSSIONS

Case study has contributed to identify the limitations for a proper digital transformation of the Management in Construction procedures. In addition, it has proposed a comprehensive framework enabling the information collection related to the runway construction all along its life cycle, taking into account the different agents' perspective.

The main contribution of the paper is that it provides, throughout the framework and its operational strategy, a common approach able to serve different agents in different time periods, and that is able to integrate different types of information like documents and models, but also being produced with very different technologies, like CAD/CAE engines, sensors, certification authorities, etc. The limitation for this research is that just some of the elements have been tested in the real environment, and no full pilot is available as it requires different agreements between agents at different levels. Therefore, the proposed framework is based partially on existing experiences and it is a very nice context to develop further research.

The future research will address such practical applications in order to assess the advantages and limitations of the proposed approach.

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Recovery policies to mitigate airline disruptions: case study of a European airline

Lucas Montenegro - lucas.montenegro@tecnico.ulisboa.pt
Instituto Superior Técnico, Universidade de Lisboa
Vasco Reis - vasco.reis@tecnico.ulisboa.pt
Instituto Superior Técnico, Universidade de Lisboa
Rui C. Oliveira - rui.oliv@tecnico.ulisboa.pt
Instituto Superior Técnico, Universidade de Lisboa
Antonio J. M. Castro - ajmc@fu.up.pt
LIACC, Universidade Porto

Abstract
This study is aimed at studying the causes of airline delays, as well as the different recovery solutions for the three most important dimensions within an airline: aircraft, crew and passengers.
A software previously developed for automating the recovery process of irregular operations is used to interpret analytical data from a case study of a medium-sized European national airline. A set of KPIs will be established to compare the different recovery solutions. The most efficient integrated recovery actions will be suggested by comparing the costs that have an impact in these solutions, with the introduction of passenger goodwill.
By comparing the different costs and factors that have an impact on the integrated recovery actions, this study expects to identify solutions that can minimize the costs associated with delays while maintaining customer satisfaction. The latter may be reached by introducing an indirect cost factor - passenger goodwill – whilst maintaining or reducing the weight of other direct costs in the utility function.
The novelty of this study is the application of an integrated approach to identify solutions for airline disruptions. Thus, the three most important dimensions are considered, also including the passenger goodwill, which are quality operational costs that represent the effect of punctuality on customer satisfaction. Furthermore, the software to be used comprises a multi-agent system through an automated negotiation process to reach the best solution according to the airline’s interest.

Keywords
Airline Disruption Management; Integrated Approach; Quality Costs

Recovery policies to mitigate airline disruptions: case study of a European airline

1. Introduction

Over 4 billion people currently travel by air throughout the globe, with IATA [1] forecasting an increase to over 7 billion passengers transported annually by 2034 - more than twice the number of passengers currently flying [2]. Air travel is considered the fastest and most reliable mode of transport available, having become increasingly cheaper and more accessible to the wider public. However, the efficiency of its operations relies on various external factors and, with more passengers and planes in the air, it is more bound to be affected by unexpected events, described as irregular operations. Amadeus points out that only 77% of all flights operated in Europe, North America and Asia arrived on time in 2012 [3]. Thus, these delays widely affect airports, passengers, aircraft and crew, representing major costs for all stakeholders involved.

Irregular operations (IROP) or airline disruptions are considered any situation that alters the original schedule, leading to flight delays and/or cancellations. The impact of such disruptions and their consequent delays is tremendous. Accordingly, a study carried out by the Air Transport Association concludes that delays cost both customers and airlines roughly U$65 billion in 2000 [4]. This figure may vary according to the scale of the airline's network, size and region where it operates, though consensus states that it may have an impact of approximately 8% on the airline's annual revenue [2]. Some authors estimate that better recovery solutions during irregular operations may help reduce costs in at least 20%, vital to both large and small airlines [5].

In order to prevent losses in profit, passenger satisfaction and the impact on operations, carriers should have a system that can pro-actively prevent disruptions, rapidly identifying the irregular event and its source, creating a suitable recovery plan. Unsolved disruptive operations can cause a cascading effect on other flights, having a great impact on the airline's network, leading to further delays and cancellations. Most air carriers try to anticipate stochastic events by creating some flexibility in their schedules, such as introducing time buffers, which can be used in recovering from unexpected events and consequent delays [6].

Disruptive flights can originate from various sources, typically as a result of a local event that may spread throughout the airline's operations. According to the American Aviation Authority (FAA) [7], weather accounted for over 69% of all significant delays (over 30 minutes) in the US in 2016, being the greatest cause of airline irregular operations (IROPs) worldwide and commonly unpredictable [3]. Thus, managing the impact of those on an air carrier's network may come as a major challenge. Various authors have explored the different ways which such delays and cancellations can be managed and mitigated, developing different algorithms to solve the issue on the perspective of the three most common dimensions englobing air transportation, with the recovery actions taken mainly depending on the dimension (crew, passenger, aircraft, ground handling, among others) to be considered.

With this in mind, this paper is aimed at studying the causes of airline delays, as well as the different recovery solutions for the three most important dimensions within an airline: aircraft, crew and passengers. A software previously developed for automating the recovery process of irregular operations (MASDIMA [8]) is used to interpret the analytical data of a medium-sized European airline. This traditional airline operates over 3,000 weekly flights to over 80 destinations worldwide.

Using this airline as a case study, a set of flight data comprising a period of 60 days will be used to compare the recovery actions taken by the human Operations Control Centre (OCC) controllers with the recovery solutions proposed by the software. For this purpose, a set of weighting coefficients will be estimated using Excel Solver so that the solutions proposed by the automated system can be similar to the actions taken by the human operators.

Therefore, a set of metrics are established to evaluate the quality of these recovery solutions, i.e., the ones that generate most efficient integrated recovery actions. This analysis will be carried out by comparing the costs that have an impact in these solutions, as well as quantifying the utility parameter of each solution and partial-solution. By comparing the different costs and factors that have an impact on the integrated recovery actions, it is expected to identify solutions that can minimize the costs associated with delays. An additional factor will be used to analyze this impact: soft costs, i.e., the effect of punctuality on customer satisfaction.

The novelty of this study is the application of an integrated approach to evaluate and compare alternative solutions for airline disruptions, including the passenger's perspective on airline disruption. Furthermore, the software to be used comprises a multi-agent system through an automated negotiation process to reach the best solution according to the airline's interest.

This paper is divided as follows. In **Section 2** an overview of Airline Disruptions is, as well as a brief discussion of the typical costs involved in Disruption Management and the main recovery actions taken. Finally, a brief literature review is carried out on the main recovery methods developed throughout the literature to tackle airline disruptions. In **Section 3**, the Case Study is presented, with details of the Research Methods used. **Section 4** includes Results and Discussions. Finally, **Section 5** draws the final Conclusions and opportunities for Future Works.

2. Airline Disruptions: an overview

When considering an adequate course of action to solve a disruptive airline operation, carriers need to coordinate the various resources involved, with aircraft, crew and passengers being the three most important resources to be considered in an airline's operation, besides other resources, such as handling, baggage, catering, etc.

The process of solving these problems is defined by Kohl *et al.* (2004) [6] as *Disruption Management*: the process of monitoring and scheduling resources close to the day of operations. Even though aircraft, crew and passengers are the most important aspects to be dealt with in the case of a disruption, other resources, such as ground staff, catering and gate operations, should also be considered, though more flexibly than the others, as they are less costly. The Disruption Management problem is considered a three-stage process, consisting of monitoring, event detection and resolution of problems [9], with disruptions being dealt at both an airline and an airport level [10].

Airline Operations Control Centres (OCCs) are responsible for managing operational disruptions, overseeing daily operations, as well as co-ordinating recovery actions among the different units within an airline (crewing, ticketing, maintenance, etc.) by optimally allocating limited operational resources, while minimising extra costs due to disruptions with the desired trade-off between the goal of operational recovery and commercial interests [11]. Thus, all airlines rely on their OCCs to manage their resources, proactively taking measures that can minimise the impact on operations or prevent additional costs to the company, constantly monitoring flights to minimise the impact of occasional delays. As reported by Clarke (1995) [12], airline operations are usually handled in tactical and strategic phases, with strategic operations dealing with schedule planning and resource allocation to the various areas of the operation.

Several authors argue that the final operational decisions rely on OCC supervisors or controllers, the only operational group within the OCC with the authority to approve or reject actions that may resolve operational irregularities [12]–[14]. These supervisors tend to base their decisions on personal judgements and past-experiences, the so-called rule-of-thumb, with each airline Operations Control Centre adopting a different set of solutions and rules that best cater their needs.

Passengers have different perspectives of what impact delays have on their journeys, which may compromise their willingness to do to future business with the airline. Amadeus [16] defines this customer perspective on delays as *soft costs*. Soft costs, quality costs or even *passenger goodwill*, represent the effect of punctuality on customer satisfaction. Estimating these costs is a complex task, as it involves several factors, varying according to the passenger's profile and purpose of travel [17]. These authors developed a system that is capable of estimating these quality costs in the recovery problem, taking into account the importance that delays have on passengers, creating an agent that considers passenger profiles. According to Amadeus [16], the customer point of view is not often considered in IROPs, though they may represent a significant part of the overall costs in such events.

A study suggested a formula to calculate these quality costs, which considers how much each passenger values a minute of delay, considering the different passenger profiles [8]. Thus, in the formulation proposed, *quality costs can be represented by the relation between the number of passenger profiles in a flight and the delay cost for each passenger with those profiles from their point of view*. Three different passenger profiles can be considered: business (those travelling in business or first class), pleasure (travel in economy class) and illness (ill doctor on-board, accompanied by a doctor or nurse).

According to Clausen *et al.* (2001) [18], the biggest airlines tend to solve the disruption management process in a sequential form, firstly dealing with aircraft, then crew, ground operations and finally passengers. Thus, each resource is analysed separately, with a general solution that covers all resources being later established. However, Bisaillon *et al.* (2011) [4] argue that this sequential treatment of recovery problems may not ensure the best recovery solutions, despite the simplifications in decision making. Furthermore, it may impose an implicit hierarchy and level of importance to the different dimensions of resources from an airline. This implicit hierarchy is to be avoided at times, as resources should be treated with equal level of importance, despite the different costs related to each resource. Thus, integrated recovery approaches are considered preferable.

The choice of a recovery plan to be considered is highly important to an airline, as disruptions represent an enormous source of financial losses. The average cost of delaying a full aircraft was estimated in a report by EUROCONTROL [19] as being of 100 euros per minute. Thus, in disruption management, one of the main objectives is to minimise costs. These costs can be broken-down as aircraft, crew and passenger costs.

A delayed aircraft can lead to great financial losses, as aircraft, especially narrow-bodies, tend to be scheduled to operate a great number of daily flights, with a single delayed flight culminating in several other disrupted flights. As narrow-body aircraft are usually deployed on short-haul flights, they tend to have a stronger impact on an airline's operations, as they are expected to perform several rotations a day. In turn, wide-bodies, which usually operate long-haul flights, have a greater margin to recover from delays between rotations.

The same happens to crew, who can easily miss their following operating flight in the case of a delay, or even be taken ill, preventing them from operating their assigned flight. As for passengers, a disrupted flight can also lead to a missed connecting flight or lost baggage, with airlines having the responsibility of rebooking them onto other flights, on a different airline at times, as well as providing minimum assistance. In addition, as previously discussed, quality costs should also be taken into account, as dissatisfied passengers are less likely to fly with the airline again.

Therefore, an integrated recovery solution should be a priority for carriers, as it can more easily respond to the three main resources involved: aircraft, crew and passengers. However, airlines tend to neglect solutions focused on passengers in disruption management, not considering opinions from customers, nor measuring the impact of delays on passenger satisfaction. Passengers tend to value transparent information regarding delays, with a passenger-tailored solution leading to greater loyalty to the airline, in line with the concept of soft costs previously introduced.

In a bolder recovery solution, some researchers highlight the increasing importance given to intermodal transportation as an alternative to disruption specially for short flights, integrating air, rail and road transportation [10]. This solution has gradually been adopted by some European airlines, as multimodality is a promising alternative to reach higher efficiency levels with lower costs. This argument can be corroborated with a study in which it was proved that it is possible to lower the impact on disrupted passengers by improving intermodal transportation [20]. In sum, a different array of solutions can be created to recover airlines and their flights from IROPs. The best alternative to be adopted will vary according to the airline's needs, considering the resource at its highest priority. This decision is usually based on rules-of-thumb, i.e., on previous knowledge and experience from the OCC operator, and on the airline's recovery policy.

Various authors have focused on developing and studying a wide range of methods for recovery from irregular airline operations, designing systems capable of recovering the various resources involved in the airline industry. Some authors stress the need of developing software agents that can carry out repetitive recovery tasks instead of the human controllers in the Operation Control Centre (OCC), reducing margin of errors and enhancing the recovery solutions [14]. When human operators deal with a large volume of data and variables simultaneously, they are bound to neglect some crucial information that would be relevant to reach the optimal solution. However, two studies claim that human controllers should mostly be involved in the main stages of disruption management, as automation provides limited decision-making support at such stages [6], [21]. Thus, human experts are capable of dealing with novelty events during disruptions as well as being responsible for the final decision. Nevertheless, Clausen *et al.* (2010) [22] argue that automated systems are able to generate more proactive solutions to mitigate and minimise delays, with operations research playing an important role in this dynamic disruption management environment. These authors also point out that most recovery models are solved similarly to the corresponding planning and scheduling problems carried out for aircraft and crew.

Three main recovery scopes are commonly identified in the literature: aircraft recovery, crew recovery and integrated recovery. The latter integrates the first two resources (aircraft and crew) with the passenger dimension, generating solutions that take into account the passenger's perspective and pondering between the best recovery alternative for each resource or all three resources combined. However, most studies have mostly focused on aircraft recovery, as aircraft is considered a limited resource and despite the legal duty requirements for crew, the crew resource can be repositioned more easily with standby and deadhead crewmembers [6]. Furthermore, there are less aircraft than crewmembers and the rules for aircraft scheduling are usually simpler. As for the crew recovery problems, most formulations are based under the theory that the flight schedule is recovered before the actual crew re-scheduling, based on a hierarchical recovery structure. Some authors noted that a majority of the studies analysed employ Operational Research (OR) methods, relying mostly on integer programming solutions methods, with a considerable number of models applying metaheuristics to solve the recovery problems [14]. However, in one work it is argued that these OR techniques require precise mathematical models, though they may not be entirely efficient [23]. Thus, heuristic approaches can be considered more useful in these types of problems, producing near-optimal solutions in shorter periods of time.

Castro (2013) [8] developed a multi-agent system for the integrated approach of aircraft, passengers and crew, denominated MASDIMA. MASDIMA can be described as a new concept of Disruption Management, considering several restrictions to minimise delays and costs. The author used real flight data from September 2009 from a European airline to test the different behaviours taken by human operators, comparing with a Q-Negotiation approach developed and the Traditional Sequential Approach. In order to act as a human-independent system, three different sub-organisations, representing the aircraft, crew and passenger dimensions, were created in MASDIMA. These sub-organisations of agents act as managers, in replacement of a human team, being capable of coordinating the different activities within the roles of each dimension and to cooperate with the other managers.

Every sub-problem solved by each manager generates a partial solution. The quality of each partial solution is then measure by a utility parameter. This utility is calculated for each sub-problem, from a value ranging between 0 and 1.0, with 1.0 being considered the optimal solution. The utility function is a combination of delay and cost parameters for each dimension involved, as well as coefficients that characterise the relative importance of each dimension in the overall solution. Thus, the overall solution, i.e., the supervisor utility, considers all three dimensions simultaneously, with their respective levels of importance.

This supervisor utility can be calculated according to Equation 1.

$$u_{sup} = 1 - \left\{\alpha_1 \left(\beta_1 \left(\frac{ad}{max(ad)}\right) + \beta_2 \left(\frac{ac}{max(ac)}\right)\right) + \alpha_2 \left(\beta_3 \left(\frac{cd}{max(cd)}\right) + \beta_4 \left(\frac{cc}{max(cc)}\right)\right) + \alpha_3 \left(\beta_5 \left(\frac{pd}{max(pd)}\right) + \beta_6 \left(\frac{pc}{max(pc)}\right)\right)\right\} \quad (1)$$

With $\sum_{i=1}^{3} \alpha_i$ and $\sum_{j=1}^{6} \beta_j$

Where $\alpha_1, \alpha_2, \alpha_3$ represent the importance of each dimension – aircraft, crew and passengers, respectively – in the problem. β_j represent the importance of each attribute in the problem, with β_1, β_3 and β_3 representing the importance of the delay attribute in each sub-problem for the aircraft, crew and passenger dimensions, respectively. In turn, β_2, β_4 and β_6 expresses the importance of the cost component in each sub-problem for the aircraft, crew and passenger dimensions, respectively. Thus, it is important to highlight, that the supervisor agent represents the integrated goals of the OCC, with a global view of the problem, considering the three dimensions when choosing the best recovery action.

As for the values of max(ad), max(ac), max(cd), max(cc), max(pd) and max(pc), which represent the maximum values of each attribute within the partial-solution of each dimension, they are previously defined so that the score function can generate values between [0,1].

In sum, the Multi-agent System (MAS) developed aims to reach a distributed and decentralised general approach for an integrated and dynamic disruption management, with multiple interacting intelligent agents solving disruption problems in parallel, with equal levels of importance.

3. Case Study

A medium-sized traditional European airline is used as a case study to compare the solutions proposed by MASDIMA with the recovery actions taken by human controllers in the OCC. The airline in study operates over 3,000 weekly flights to over 80 destinations worldwide, with a fleet of over 100 airplanes: more than 80 aircraft from the Airbus family (being 27 wide-body aircraft used in long-haul flights) and other 20 regional aircraft. The airline also employs over 7,000 people, being the national airline of the country where it operates.

A set of flight data, comprising a period of 60 days, is used to compare the solutions proposed by MASDIMA with the ones adopted in reality, as well as to estimate the set of weighting coefficients from the utility function, so that the solutions proposed by MASDIMA would represent the actions taken by the human operators. In order to compare the quality of these solution and actions, a set of metrics (performance indicators) are established.

To estimate the coefficients from the supervisor utility function (Equation 1), the set of flight data will be analysed by the Method of Least Squares using Microsoft Excel Solver. With Excel Solver, it is possible to find an optimal value for a previously defined objective function. By selecting a group of adjustable cells, Solver will change the value of the changeable parameters in order to optimise the value of the objective function. Within the software, GRG (Generalised Reduced Gradient) solver is an efficient search tool to be used in non-linear optimisation problems, being characterised as a deterministic method, due to the use of non-random sampling [24]. In addition, this solver method needs a set of initial values in order to estimate the parameters.

Therefore, the data from the table including real flights (i.e., what happened in reality, as a result of the decisions either taken by the human operators in the OCC or by MASDIMA) will be used to compare the solutions proposed by MASDIMA (*solution_flights* table) and the flights identified as impacted (i.e., flights that were considered disrupted, either because of delay or any other disruptive event). In order to estimate the coefficients, the squared difference between the utility of real flights and the utility solution flights will be calculated for each event and considered as the squared error. Thus, the sum of these squared differences (to be minimised) will be used as the objective function in this study, with the coefficients from the supervisor utility function considered as adjustable parameters. For this purpose, Excel Solver will be used to minimise the sum of the squared differences (SSD), assuming non-negative parameters, as the coefficients must range between [0,1]. In addition, some constraints will be added to the analysis, to limit the value of some parameters, comparing the effect of these constraints in the results of the coefficients found. Furthermore, Central differences will be the options for derivatives used, as these generate greater accuracy in nonlinear problems, as pointed out by [25].

By using the least squares method, it is possible to find the set of parameters that best describes the experimental data by assuming a certain relation between the variables, as well as by minimising the sum of the squared errors. In the field of air transportation, the least squares technique was used to estimate the effect of delay propagation through an airline schedule [26]. More specifically, Microsoft Excel Solver was used to analyse experimental data by least square fitting in the fields of pharmacology, with one study [27] estimating the coefficients of an equation for describing simple enzyme kinetics and another for hydrologic modelling [24].

In order to compare the quality of the solutions proposed by MASDIMA and the actions taken by the human controllers in the OCC, a set of metrics or performance indicators were used. Four different scenarios will be compared: *impact flights* (flights that were originally identified as disrupted for any reason), *solution flights without goodwill* (recovery solutions proposed by MASDIMA without considering quality solutions, i.e. *passenger* goodwill), *solution flights with goodwill* (recovery solutions proposed by MASDIMA considering quality costs) and *real flights* (what happened in reality, with recovery actions either implemented by human controllers from the OCC or implemented based on the solutions proposed by MASDIMA). In most indicators, the *impact flights* table will serve as comparison basis to measure the level of recovery or improvement from the initial delays and costs predicted for each disruptive event.

Considering the different table structure of flight data provided by MASDIMA, a comparison between the *schedule_flights, impact_flights, solution_flights* and *real_flights* tables will be made. A direct comparison between *schedule_flights* and *real_flights* can provide information on the performance of the OCC with no interference from MASDIMA. In turn, a comparison between *solution_flights* and

real_flights can determine the potential of MASDIMA when compared with the OCC. Finally, a comparison between *impact_flights* and *real_flights* can determine the potential, from either the OCC or MASDIMA, in recovering flights identified as disrupted. Thus, the scenarios considered for analysis will be as follows:

- *Scenario 1 - impact_flights s_gw vs. real_flights* (without considering quality costs, i.e. passenger goodwill);
- *Scenario 2 - impact_flights c_gw vs. real_flights* (considering quality costs);
- *Scenario 3 - solution_flights s_gw vs. real_flights*;
- *Scenario 4 - solution_flights c_gw vs. real_flights*.

The data provided by MASDIMA were provided in SQL format. For the data considered, the aircraft manager within MASDIMA can propose two possible recovery actions in *solution_flights*: KEEP (do-nothing, i.e., no recovery action to be taken to recover the disruption) or EXCHANGE (exchange the aircraft with a different one that is available). In turn, the crew manager can propose the following recovery actions: KEEP (do-nothing) or OTHER (which can represent any other recovery action). As for the passenger manager, the following actions can be proposed: KEEP (do-nothing) or REACCOMMODATE (re-accommodate to another flight). It is important to highlight that MASDIMA offers other more specific recovery actions, though the airline in study only chose to have these implemented. For the actual recovery actions (*real_flights* table), one additional recovery description was created: MISSED, in the passenger dimension, when the passengers missed their connection flight.

Subsequently, it was determined which actions were performed in reality and, more specifically, if it was an action employed by the OCC controller or an action suggested by MASDIMA. It was considered that the action employed was proposed by MASDIMA if, what happened in reality, was exactly the same as what was proposed by the software, although the OCC controller did not necessarily take the proposal from the software into consideration.

To calculate the utility scores of the supervisor, some initial values of coefficients were used. These initial values are a result of a series of experiments carried out with MASDIMA in the airline in study, considering feedback from the human OCC controllers.

For each scenario, a set of constraints were created, in order to vary the value of the coefficients to find the optimal solution. In addition, some criteria were established in order to determine which results could be considered the optimal solution, as well as to exclude other results that generated coefficients that did not represent reality, despite being mathematically feasible.

Table 1 shows the constraints employed for each scenario analysed, where *Alpha_sum* and *Beta_sum* represent the sum of the alpha and beta coefficients from the supervisor utility function (Equation 1).

Table 1: Constraints employed for each analysis scenario.
Source: Authors

Constraint 1	Alpha_sum = 1 ; Beta_sum=1
Constraint 2	Alpha_sum =1 ; Beta_sum = 1; alpha_ac >=0.1; alpha_cw>=0.1; alpha_px>=0.1
Constraint 3	Alpha_sum =1 ; Beta_sum = 1; All alpha >=0.1; All beta >= 0.01
Constraint 4	Alpha_sum =1 ; Beta_sum = 1; alpha_ac >=0.1; alpha_cw>=0.1; alpha_px>=0.1; beta_ac_SUM >=0.1; beta_cw_SUM>=0.1;beta_px_SUM>=0.1
Constraint 5	Alpha_sum =1 ; Beta_sum = 1; beta_ac_SUM >=0.1; beta_cw_SUM>=0.1;beta_px_SUM>=0.1
Constraint 6	Alpha_sum = 1 ; Beta_sum=1

NOTE: Alpha, beta = coefficients of the utility function (Equation 1).

Besides these constraints, a series of iterations were carried out for each constraint imposed, within each analysis scenario. It is important to add that some iterations were not performed for some of the constraints employed. Table 2 shows the iterations considered.

Table 2: Iterations considered for each constraint imposed and for every analysis scenario.
Source: Authors

Original Value	Initial Values used.
Iteration 1	From the initial values, vary all coefficients.
Alpha	From the initial values, vary only Alpha coefficients, with Beta remaining fixed at the initial values.
Alpha 2	From the values generated in the Alpha iteration, vary all coefficients.
Beta	From the initial values, vary only Beta coefficients, with Alpha remaining fixed at the initial values.
1.00E-01	From the initial values, vary all coefficients with a reduced precision of 10^{-1}.
Alpha_cw_px	From the initial values, vary all coefficients, except alpha_cw and alpha_px.
Alpha_ac	From the values generated in the Alpha_cw_px iteration, vary all coefficients, with alpha_ac remaining fixed at the initial value.
Alpha_ac'	From the initial values, vary all coefficients, with alpha_ac remaining fixed at the initial value.

4. Results and Discussion

Data from 110 routes (78 short-haul and 32 long-haul routes) were considered. Of the 60 days analysed, 41.2% of the scheduled passenger flights were identified as disrupted for any reason, with over 40% representing a 15 minutes delay.

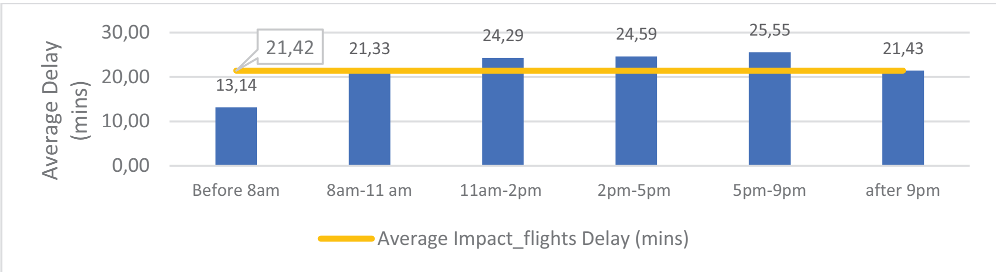

Figure 1: Average Delay of flights from impact_flights Table per Period of Day.
Source: Authors

Figure 1 presents the average delay per period of day. By observing these results, it is noted that the greatest delays on average occurred during the afternoon and evening (2pm-5pm and 5pm-9pm), with these greater delays being airport-related. On the other hand, the early morning period led to smallest delays, with delays of 13 mins on average. The maximum delay observed for the period in study was of approximately 25 hours (1,489 mins) on a long-haul flight due to aircraft or crew rotation problems (ROT). Furthermore, it can be noticed that, both in the approach considering quality costs (*solution_flights cgw*) and without considering quality costs (*solution_flights sgw*), MASDIMA generated recovery solutions with approximately the same delay as in the *real_flights* table, after intervention from either the OCC controller or MASDIMA.

The fact that the actual flights, covering the recovery actions from the OCC and MASDIMA, generated slightly lower delays may be due to the fact that MASDIMA mostly considers block times, i.e., the time between departure from the gate at the departure airport and arrival at the gate at the arrival, instead of that flight times when calculating the possible solutions to the flights. This is because the airline in study not always provides the information of the actual flight plan to the software, with MASDIMA consequently using this block times, which are usually greater than the actual flight times from the flight plan.

When considering the average cost recovery ratios, it could be observed that the solutions generated by MASDIMA, on average, led to better total costs, crew costs, passenger costs and quality costs recovery ratios, i.e., positive values, when compared to the figures from real flights in most of the periods of day. The difference in passenger cost recovery ratios between the solutions generated by MASDIMA in both scenarios (*c_gw* and *s_gw*) and the real flights is clearly noticeable, with MASDIMA generating recoveries of over 50%, while some real flights even generating greater passenger costs than initially detected, i.e., negative recovery ratios. However, the real flights resulted in slightly better aircraft cost recovery ratios than the solutions, as presented in Figure 2. This can be explained not only by the use of block times by MASDIMA, but also by the way it considers fuel consumption, a major cost-driver of aircraft costs. Due to the way in which this information is provided to MASDIMA by the airline, the fuel consumption calculated in the solutions is based on an average consumption per minute of block-time, not considering a real-time cost calculation with data from the flight plan, nor considering the different refuelling costs per airport. This estimation by MASDIMA also results in greater aircraft costs. On the other hand, it may be argued that OCC controllers can indeed generate better recovery solutions, based on previous experience and knowledge of the airline's culture and of which recovery actions are more appropriate in certain routes. Nonetheless, the recovery solutions from MASDIMA still lead to better total cost recovery ratios.

When observing the crew cost recovery ratios (Figure 3), it is evident that MASDIMA was mostly unable to generate recovery solutions that could reduce crew costs $(\overline{CC_{rcv}} = 0)$, with negative recovery ratios, i.e., greater costs, seen in the real flights. This inability to generate recovery actions that can lower the costs of disrupted crew members in all scenarios considered can possibly be explained by the great complexity involving the recovery of disrupted crew members, due to labour legislations on the limits of duty hours and rest.

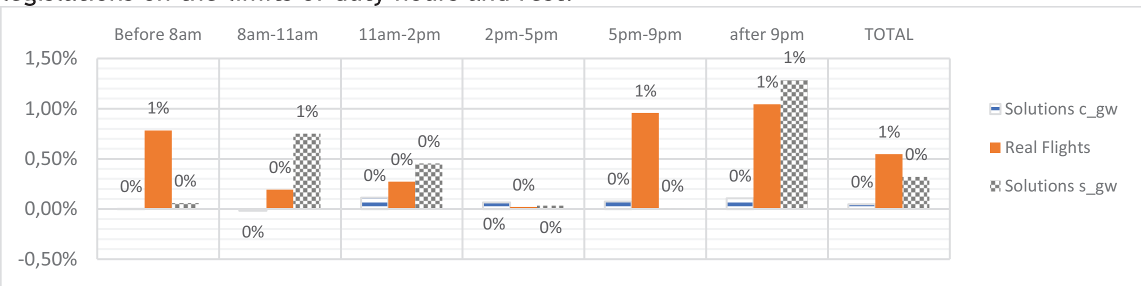

Figure 2: Average Aircraft Cost Recovery Ratio $(\overline{AC_{rcv}})$ of the three approaches.
Source: Authors

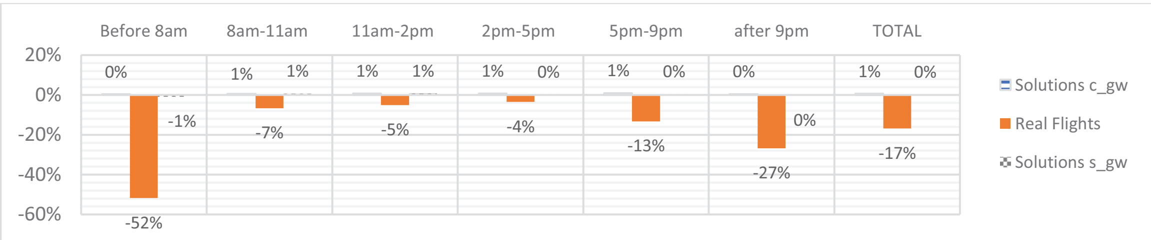

Figure 3: Average Crew Cost Recovery Ratio $(\overline{CC_{rcv}})$ of the three different approaches.
Source: Authors

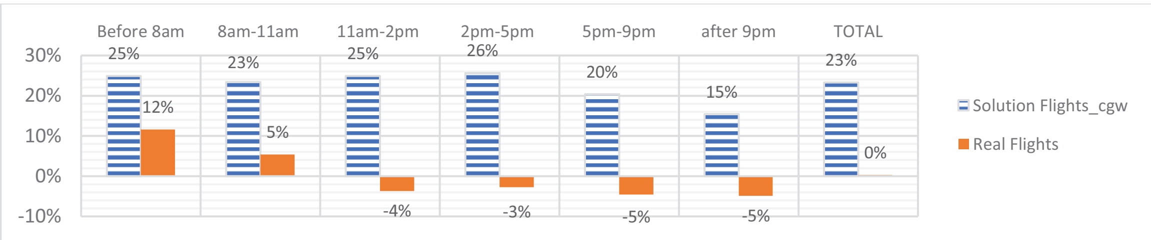

Figure 4: Average Quality Cost Recovery Ratio $(\overline{GW_{rcv}})$ of the solution_cgw and real_flights.
Source: Authors

The effect of considering quality costs is clearly evidenced in Figure 4, with the software generating much better recovery ratios than those of real flights. This can corroborate the idea that OCC controllers and, more specifically, most airlines do not entirely consider the passenger's perception of delays in Disruption Management. Furthermore, it is observed that by introducing this factor, the software was still able to generate recovery solutions with similar crew costs than calculated in the approach without considering these quality costs. Thus, it can be argued that the introduction of the *passenger goodwill* parameter does not affect crew costs. However, a slight increase in aircraft costs is noticed in this approach, probably as some actions that might prevent passengers from missing their connections will result in an increase of flight costs.

It was concluded that the actions taken by the OCC, i.e., those different to what was proposed by MASDIMA, in at least one of the dimensions accounted for 5,190 (36%) and 4,736 (33%) of the flights in the *solution_flights sgw* and *solution_flights cgw* approaches, respectively. It is worth noting that more flights were recovered by the OCC in the scenario without considering quality costs, when compared to the scenario with quality costs, which is in line with the conclusions made from the other results.

Several iterations were carried out for each constraint imposed and for every scenario considered, with the results of these weighting coefficients being presented in Tables 3-5, with the cells marked in grey representing the coefficients that remained fixed for in the constraint scenario. From these coefficients, some iterations were considered optimal or close to optimal. However, despite some results exhibiting mathematically optimal results, with an SSD equal to zero, the weighting coefficients from these iterations would sometimes lead to unfeasible weighting coefficient solutions of the utility scores. Consequently, some results were not considered as optimal solutions, in spite of leading to complete minimum values of SSD.

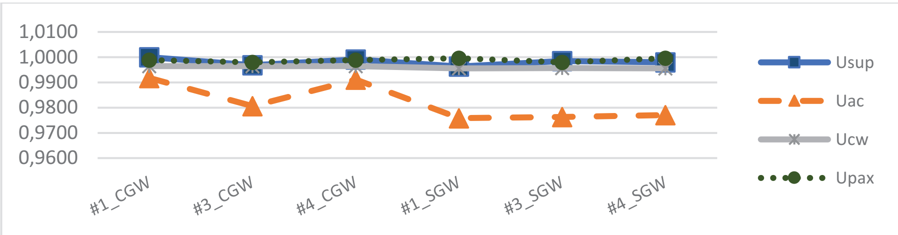

Figure 5: Average Utility Scores (real_flights) for the optimal solutions of Scenarios 1 and 2, where $\bar{U}_{sup}$, $\bar{U}_{ac}$, $\bar{U}_{cw}$ and $\bar{U}_{px}$ represent the supervisor, aircraft manager, crew manager and passenger manager utility scores, respectively.
Source: Authors

Table 3: Results from the optimal weighting coefficient solutions from Scenarios 1 and 2.
Source: Authors

	Constraint									
	#1_SGW	#3_SGW		#4_SGW	#1_CGW		#3_CGW	#4_CGW		
Coefficient	Beta	Iteration 1	Beta 2	Beta 2	Iteration 1	Beta 2	Beta	Beta 2	1.00E-01
beta_delay_ac	0.000	0.056	0.014	0.049	0.791	0.000	0.010	0.000	0.558
beta_delay_cw	0.075	0.010	0.129	0.025	0.000	0.000	0.010	0.000	0.000
beta_delay_px	0.000	0.018	0.010	0.000	0.000	0.000	0.010	0.000	0.000
beta_cost_ac	0.401	0.538	0.559	0.751	0.192	0.413	0.365	0.402	0.173
beta_cost_cw	0.213	0.010	0.278	0.075	0.000	0.587	0.568	0.498	0.154
beta_cost_px	0.312	0.368	0.010	0.100	0.018	0.000	0.037	0.100	0.115
alpha_ac	0.334	0.100	0.100	0.100	0.000	0.000	0.334	0.334	0.068
alpha_cw	0.333	0.800	0.100	0.439	1.000	0.000	0.333	0.333	0.710
alpha_px	0.333	0.100	0.800	0.461	0.000	1.000	0.333	0.333	0.222
SSD	8.94E-04	1.17E-04	1.23E-04	2.35E-04	0.00E+00	0.00E+00	1.21E-03	1.25E-03	9.23E-04

Table 4: Results from the optimal weighting coefficient solutions from Scenario 3.
Source: Authors

	Constraint				
	#1_SGW	#2_SGW	#4_SGW	#5_SGW	#6_SGW
Coefficient	1.00E-01	Beta 2	Alpha 2	Beta 2	Alpha_ac'
beta_delay_ac	0.318	0.190	0.241	0.000	0.000
beta_delay_cw	0.000	0.023	0.009	0.047	0.000
beta_delay_px	0.000	0.000	0.003	0.010	0.746
beta_cost_ac	0.548	0.522	0.559	0.800	0.000
beta_cost_cw	0.038	0.263	0.091	0.053	0.000
beta_cost_px	0.096	0.002	0.097	0.090	0.254
alpha_ac	0.000	0.100	0.100	0.010	0.334
alpha_cw	0.527	0.100	0.364	0.487	0.666
alpha_px	0.473	0.800	0.536	0.503	0.000
SSD	3.74E-04	1.94E-04	0.000	1.11E-04	0.00E+00

Table 5: Results from the optimal weighting coefficient solutions from Scenario 4.
Source: Authors

	Constraint								
	#1_CGW		#2_CGW		#3_CGW	#4_CGW		#5_CGW	#6_CGW
Coefficient	Alpha	Beta 2	Beta	1.00E-01	Alpha 2	Beta	Beta 2	Beta 2	Alpha_cw_px
beta_delay_ac	0.333	0.000	0.000	0.516	0.134	0.000	0.000	0.008	0.333
beta_delay_cw	0.133	0.000	0.000	0.000	0.010	0.000	0.000	0.000	0.133
beta_delay_px	0.201	0.000	0.000	0.000	0.010	0.000	0.000	0.000	0.201
beta_cost_ac	0.111	0.183	0.360	0.217	0.150	0.350	0.100	0.092	0.111
beta_cost_cw	0.111	0.817	0.589	0.156	0.010	0.550	0.800	0.800	0.111
beta_cost_px	0.111	0.000	0.051	0.111	0.685	0.100	0.100	0.100	0.111
alpha_ac	0.000	0.000	0.334	0.119	0.010	0.334	0.774	0.833	0.334
alpha_cw	1.000	0.000	0.333	0.781	0.980	0.333	0.100	0.000	0.666
alpha_px	0.000	1.000	0.333	0.100	0.010	0.333	0.126	0.167	0.000
SSD	2.84E-03	0.00E+00	1.13E-03	1.05E-03	1.77E-07	1.16E-03	3.06E-04	1.94E-04	1.63E-05

Based on the results from the iterations carried out with Excel Solver, it can be noticed that the supervisor utility score of the real flights was increased on average by 0.06% in Scenarios 2 and 4, by 0.12% in Scenario 3 and reduced by 0.03% in Scenario 1 with the new weighting coefficients calculated, from initial values of $\overline{U}_{sup}$= 0.9981 in the approaches without considering quality costs and $\overline{U}_{sup} = 0.9985$ when considering quality costs. The average utility scores of scenarios 1 and 2 are presented in Figure 5, where $\overline{U}_{sup}$, $\overline{U}_{ac}$, $\overline{U}_{cw}$ and $\overline{U}_{px}$ represent the supervisor, aircraft manager, crew manager and passenger manager utility scores, respectively.

Regarding the local utility scores, in the aircraft dimension, the initial utility score in the *real_flights* Table was of $\overline{U}_{ac\_sgw}$= 0.9946 in the scenarios with no passenger goodwill and $\overline{U}_{ac\_cgw}$= 0.991 in the scenarios considering passenger goodwill. With the new coefficients generated, the aircraft manager utility score decreased on average 1.40% and 0.12% in Scenarios 1 and 2, while remaining on average the same in Scenario 4 and decreasing by 1.10% in Scenario 3. In turn, in the crew dimension, the initial values of the real flights were of $\overline{U}_{cw\_sgw}$ = 0.9972 and $\overline{U}_{cw\_cgw}$ = 0.99 in the approaches without and with quality costs, respectively. In this dimension, the manager utility score increased in all Scenarios studies, rising by up to 0.80% on average in Scenario 1. Finally, in the passenger manager's perspective, which exhibited initial utility scores in the *real_flights* table of $\overline{U}_{px\_sgw}$ = 0.9974 and $\overline{U}_{pc\_cgw}$ = 0.9962, the coefficients produced mostly led to an upsurge of this utility score, rising by up to 0.18% in Scenarios 2 and 4, when considering passenger quality costs.

Although an improvement in the supervisor utility score may seem negligible, when considering the airline's revenue of approximately 3 billion euros in 2017, this increase in $\overline{U}_{sup}$ may result in annual savings of millions of euros. However, it cannot be concluded that these results, from recovery actions taken by the OCC controllers, would necessarily generate better recovery solutions than those suggested by MASDIMA, given the approximations aforementioned.

When considering the optimal weighting coefficient solutions, *alpha_ac* decreased on average by 35% in Scenarios 1 and 2, and by 63% in Scenarios 3 and 4. On the other hand, *alpha_cw* increased on average by 77% in Scenarios 1 and 2, and by 105% in Scenarios 3 and 4. In turn, *alpha_px* decreased on average by 42% in all Scenarios. This trend shows a clear preference to the crew dimension in the global and integrated solution, while clearly neglecting the passenger and crew dimensions. Nevertheless, these results may not entirely be in line with what is found in the literature, in which most authors argue that a greater preference is given to the aircraft dimension. Although these results may not entirely reflect the reality of the OCC, the mathematical explanation to the inclination in preference to the crew dimension, over the aircraft and passenger dimensions, can be explained by the high crew costs seen.

While most of the weighting coefficients do not represent the reality of the Operations Control Centre, some iterations could generate weighting coefficients that would corroborate the results found in the literature, in which greater preference is given to the aircraft dimension while almost neglecting the passenger dimension. This can be evidenced in Scenario 4, for constraints 4 and 5, which resulted in values of *alpha_ac* of 0.774 and 0.833, respectively, with values of *alpha_cw* and *alpha_px* between 0 and 0.167. For both constraints, greater importance was given for the local coefficients of costs (*beta_cost*), with the delay being considered locally irrelevant, leading to low or null values of *beta_delay* coefficients. This greater importance to costs rather than delays can be explained by the extremely high costs associated to aircraft, as well as by the fact that most of the disruptions analysed generated small delays. Although these solutions could more closely represent the reality of the OCC, they generated values of supervisor utility of 0.9982, with negligible variation from the initial scenarios and, thus, not improving the overall solution. This non-improvement of the overall solution is in line with the greater preference given by OCC controllers to one resource dimension, while giving less importance to the passenger and crew dimensions.

Regarding the values of *global fairness (GF)* from the optimal weighting coefficient solutions generated show that, despite improving the supervisor utility scores on average, the coefficients resulted in less fair solutions. In the scenarios without quality costs considered, the global fairness increased by 400% in Scenario 1 and by 1.4% in Scenario 3, while increasing by 152% and 43% in Scenarios 2 and 4, respectively. This growth in global fairness corroborates the conclusions made from the overall results of the alpha coefficients, in which a clear preference is given to one dimension within the airline. Finally, it is important to point out that, considering the reduced time period of flight data, some of the findings and conclusions drawn from the results of these comparisons may not represent the reality of the airline for its all-year-round flight operations.

5. Conclusions

In this paper, the problem and concept of Airline Irregular Operations (IROP) is discussed. Disruptions or IROPs can be a great cause of financial to losses to airlines, which have enormous costs associated to their operations. Having carried out the experiments and comparing the experiments in Excel Solver, comparing Scenarios with or without quality costs, it was found that the solutions led to a greater importance of the crew dimension, in terms of the global recovery solution employed by the Operations Control Centre (OCC). This finding was linked to the possible lack of synchronisation of certain information between the airline's OCC system and MASDIMA.

Despite finding mathematically feasible results, with certain weighting coefficients leading to total minimisation of the sum of the squared differences (SDD = 0), most results may not entirely represent the reality of the OCC, or even be feasible. According to general consensus in the industry and in the literature, OCC operators tend to give greater importance to the aircraft dimension.

Considering that the analyses of Scenarios 1 and 2 can determine the potential, from either the OCC or MASDIMA, in recovering flights identified as disrupted, it can be concluded that after employing recovery actions on the disrupted flights, the total costs associated to these disruptions increased, with a slight improvement to the initial delay. Regarding the analyses of Scenarios 3 and 4, which can determine the potential of MASDIMA when compared with the OCC, it can be noticed that MASDIMA could recover approximately 10% of the total costs from the initial disruptions, also with a slight improvement to the initial delays. As it is not possible to clearly identify which of the recovery actions were in fact taken by the software and which were taken by the human controllers, it is not entirely possible to state that MASDIMA had a better performance than the OCC. However, when only considering the comparison between the solutions generated by the software and the results of the real flights, it is clear that the recovery solutions, with and without quality costs, generated only by MASDIMA were able to greatly reduce costs when compared to the recovery actions taken by either the OCC or MASDIMA in reality.

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Queue behavioural patterns for passengers at airport terminals: a Machine Learning approach

Álvaro Rodríguez-Sanz - alvaro.rodriguez.sanz@upm.es
Universidad Politécnica de Madrid (UPM)
Alberto Fernández de Marcos - a.fernandezdemarcos@alumnos.upm.es
Universidad Politécnica de Madrid (UPM)
Javier Pérez Castán - javier.perez.castan@upm.es
Universidad Politécnica de Madrid (UPM)
Fernando Gómez Comendador - fernando.gcomendador@upm.es
Universidad Politécnica de Madrid (UPM)
Angel Paris Loreiro - angel.paris@upm.es
Universidad Politécnica de Madrid (UPM)

Abstract

Passengers go through different handling processes inside airport terminal buildings. The quality of these processes is usually measured by the time spent to take the required actions and the comfort level experienced by passengers. We present an analysis of behavioural patterns in queues at check-in desks and security controls. The passengers' flow is simulated to obtain the and queue lengths at one busy European airport between 2014 and 2016, supported by real flight data. Simulation is designed as a store-and forward cell-based system, whose parameters have been tuned and validated with empirical capacity studies within the airport. Random Forest algorithms are then implemented to develop different models for each parameter prediction, after a data analysis stage based on statistical and visualization methods. Feature analysis techniques between dependent variables and the target output (queue length) determine which are the fundamental elements to explain queue behaviour and to predict target variables. We provide a method to forecast behavioural patterns at check-in desks and security controls, so suitable response policies can be implemented. Queue behavioural patterns are captured by Machine Learning models, which can be used to offer improved passenger services, or can be considered in a dynamic approach for terminal services design (as the entire progress of terminal handling depends on the stochastic behavior of passengers). This could be a key tool for managing passengers demand.

Feature analysis techniques between dependent variables and the target outputs (average time spent at queue and queue length) determine which are the fundamental elements to explain queue behaviour and to predict target variables. We provide a method to forecast behavioural patterns at check-in desks and security controls, so suitable response policies can be implemented.

Keywords

Airport processes; Simulation; Random Forest; Waiting time

Queue behavioural patterns for passengers at airport terminals: a Machine Learning approach

Introduction

Passengers go through different handling processes inside an airport terminal building in order to board the aircraft. The quality of this processes is usually measured by the time spent to take the required actions and the comfort level of passengers [1]. Both international organizations, such as Airport Council International (ACI), and airport operators, perform surveys and control reports on the quality of the services [2]. According to ACI, check-in process, security control and passport control are the most critical services for the passenger experience inside the airport [3].
Air traffic demand has been rising over the years, which could lead to an issue when capacity exceeds demand [4], [5]. Moreover, growing security constraints and delays significantly consume system capacity [6].
Although much work has been carried out to improve the service offered at airport terminals in recent years, there are key aspects where new technologies could help. Machine Learning (ML) is being applied by different stakeholders of air transport. Airline operators are investing in optimizing their operations systems, from real time crew scheduling to flight delay prediction [7]–[10]. Aircraft manufacturers have been investing in augmented reality and predictive maintenance [11]. Regarding airport operators, some work can be accomplished to offer a more personalized and client-based service within the terminal [12]. Our study seeks to experiment the predictive potential of passenger behaviour in the airport.
This paper presents two Random Forest models designed to predict queues' length in the check-in desks and security control area in Palma de Mallorca airport. We present the influence of dependent variables and the evaluation of results for each model.
The remaining part of the paper is organized as follows. The Background section reviews the literature related to the problem and contextualizes the topic and its approach. The Methodology chapter introduces the framework used to simulate passengers flows in the airport and the ML techniques applied to build the predictive model. The Results part presents the statistical analysis, feature importance on queue length and evaluation metrics of the model computed on the test dataset. The last section concludes the paper.

Background

Operational research is widely used to support decisions in planning and operating aviation activities [13]. When analysing the requirements for check-in and security operations, the most challenging issue is to consider the different elements that influence the performance of those time dependent and stochastic systems [14]. Particularly, key elements are the arrival of passengers and their queuing behaviour [15].
The arrival rate of the passengers of a single flight depends on the scheduled departure time and on the flight itself [14]. The distribution of the arrival rate over time (also called passenger earliness of arrival profile) depends for example, on the destination, on the flight category (business or charter), or on the time of the day [16]. The arrival process has a dynamic and stochastic nature. In our study (see Methodology section) we will model passenger arrival rates (daily profiles) by adjusting the input passenger flow into the departure hall to a Weibull probability distribution.
Several approaches for the performance approximation of time-dependent queueing systems have been proposed in the literature [17], [18]. Usually, ordinary differential equations can be solved [19] or the randomization approach could be applied [20] for Markovian systems. However, both approaches are not suitable for queues with generally distributed arrival and

service processes. Similarly, fluid approximations [21] and infinite server approximations [18] are not able to handle generally distributed service and interarrival times. Fluid approximations are often called cumulative diagrams in airport literature. Tošić [22] analysed different queueing models for airport terminals and used cumulative diagrams to model the check-in facilities. Janić [23] modelled the check-in process using cumulative diagrams, too. Barros and Tomber [16] analysed the passenger and baggage screening with cumulative diagrams. Brunetta et al. [24] argued that stationary stochastic queueing models could not be applied because of the importance of the dynamic effects and therefore applied cumulative diagrams to analyse different processing facilities. In general, approximations with stationary approaches are often used to approximate the performance of time-dependent service systems, see for example the Stationary Independent Period by Period (SIPP) approach [25] and the Stationary Backlog Carryover (SBC) approach [17].
This paper introduces a novel approach to predict passenger behaviour: simulation is designed as a store-and forward cell-based system, whose parameters have been tuned and validated with empirical capacity studies within the airport. Random Forest algorithms are then implemented to develop different models for each parameter prediction. Queue behavioural patterns can be used to offer improved passenger services or can be considered in a dynamic approach for terminal services design. This could be a key tool for managing passengers demand.

Methodology

Data Acquisition

The data preparation phase covered all activities required to assemble the final dataset from the initial raw operational data provided by the airport, including locating and refining erroneous measurements. The initial step is related to the identification of the available data sources and data requirements for solving the problem.
In order to predict the number of passengers at each time unit in each of the service's queues, a complete dataset of more than a single year (containing the number of passengers per time unit and a set of explanatory features) was built.
Candidate features to model both queue length and waiting time are divided in three categories.

- *Flight data*. It contains a history of flights which were performed in Palma de Mallorca airport between years 2014 and 2016, both included.
  For every flight, this dataset included the following information: scheduled and actual departure hour, total number of passengers boarded, aircraft related information (model, callsign, registration number), route and flight segment, which can be Schengen, non-Schengen or inter-island.
  Figure 1 shows the annual departure passenger volume, which illustrates a constant proportion of the three types of flight, in a proportion of 75%-22%-3%, respectively.
  This will be considered in the design of the model, since the boarding gates hall will be designed as a single cell although there is a hall for every type of flight.
- *Time features*. These variables are needed to capture the time dependency of queues behaviour.
- *Unusual event features*. Special dates or events, such as regional or national holidays, crowded events (sports, music...) can produce important differences in airport performance.

The target features, queue length and waiting time, are not available through real observations. Thus, a simulation of passenger behaviour inside the airport terminal has been implemented.

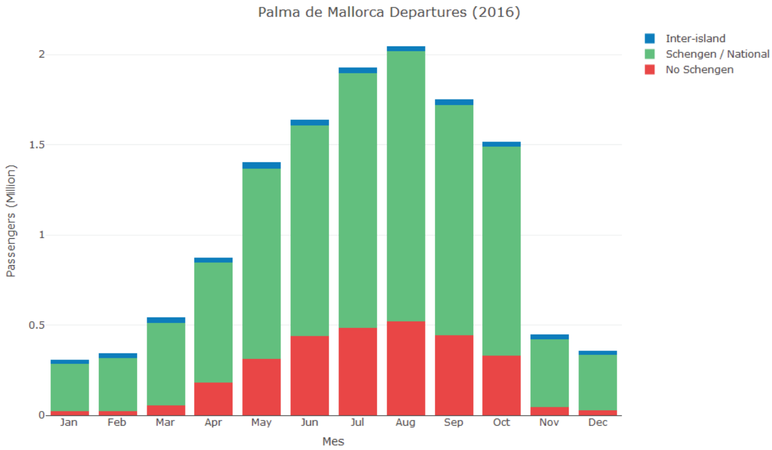

Figure 1: Departure passengers' volume (millions) in Palma de Mallorca airport. Year 2016.

Simulation

Nowadays, several systems simulation tools and techniques are available for this purpose. SimEvents, from MATLAB, or SIMIO are complete, user-friendly interfaces for achieving robust simulation results.
More simple, yet robust methods were developed for simulating passengers dynamics within airport terminals, as the two methods presented in [26]: a store-and-forward cell model, which achieve results accurate enough for a macroscopic study of passengers queues, and a Petri network model, computationally more expensive but which offers lower scale results.
Since the objective of the present work was the simulation but obtaining general metrics of the passenger flow, the store-and-forward model was chosen.
The store-and-forward model is a difference equation-based model, in which the cell state is updated every sample time, T. Each cell is defined by an input queue, as the number of passengers waiting for the service, and the functional unit, which models the actions performed in the current cell. (1) and (2) show the cell state at a given time $k+1$.

$$\bar{x}_i(k+1) = x_i(k) + T\sum_j B^*(j,i,k)u_j(k) - T\sum_j B^*(i,j',k)u_i(k) \tag{1}$$
$$x_i(k+1) = \max(\min(Q_i, \bar{x}_i(k+1)), 0) \tag{2}$$

where $x_i(k)$ is the number of passengers at time k in cell i, and $B(j,i,k)$ is the probability of a passenger moving from cell j to cell i at time k.

In the case of contiguous cells reaching its maximum capacity (Q),

$$B'(i,j) = \begin{cases} 0 \ if \ B(i,j) = 0 \lor x_j \geq Q_j \\ \quad B(i,j) \ otherwise \end{cases} \tag{3}$$
$$\bar{B}(i) = \sum_j B'(i,j) \tag{4}$$
$$B^*(i,j) = \begin{cases} \dfrac{B'(i,j)}{\bar{B}(i)} \ if \ \bar{B}(i) > 0 \\ \quad 0 \ otherwise \end{cases} \tag{5}$$

passengers from the current cell cannot move forward to the next cell, so that the branching rate from i to j, $B'(i,j)$, becomes 0. Besides, branching rate from cell i to the remaining following cells is recomputed so that total probability of going from cell i to any of the following cells is 1.

Finally, the processing speed of cell i at time k, $u_i(k)$

$$\bar{u}_i(k) = f(x_i(k), p_{i1}, \dots, p_{im}, d_{i1}, \dots, d_{in}) \quad (6)$$

$$u_i(k) = \begin{cases} 0 \text{ } if \text{ } \forall j: B(i,j) \neq 0, x_j \geq Q_j \\ \bar{u}_i(k) otherwise \end{cases} \quad (7)$$

depends on two variables: constant parameters, p, which remain the same during the simulation, such as the average speed of security control, and decision variables, d, which can modify the passenger flow and that are typically chosen by the airport operator. Check-in and security number of open desks among others are an example.

Equation (2) limits the total number of passengers at the cell between 0 and the cell capacity, Q_i. For a more detailed explanation, [26] might be checked.

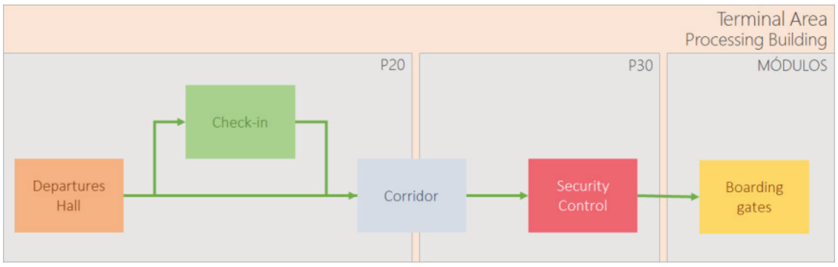

Figure 2: Passenger flow diagram through Palma de Mallorca airport terminal.

In order to simulate the passenger flow through the terminal, several differentiated cells must be defined in order to capture every service's characteristics within the terminal. The complete flow diagram of the model is presented in Figure 2 and a more detailed schema is presented in Figure 3, so that the methodology can be easily understood.

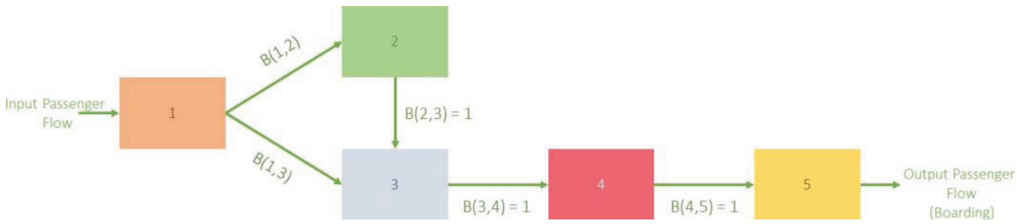

Figure 3: Passenger flow store-and-forward cells model through Palma de Mallorca airport terminal.

Departures Hall. The departure hall is the access cell into the terminal. It acts as a passenger transit area. Thus, its processing speed depends on the number of passengers present at moment k as follows in (8), where p_{11} is the minimum flow speed, p_{12} is the maximum speed and p_{13} is the free-flow limit, the number of passengers from which processing speed stops being p_{12} and begins to decrease.

$$\bar{u}_1 = p_{11} + \left[1 - \frac{\max(x_1(k) - p_{13}, 0)}{Q_1 - p_{13}}\right](p_{12} - p_{11}) \quad (8)$$

$$u_1(k) = \begin{cases} 0 \text{ } if \text{ } x_2(k) \geq Q_2 \lor x_3(k) \geq Q_3 \\ \bar{u}_1(k) \text{ } otherwise \end{cases} \quad (9)$$

Regarding its branching rates, $B(1,2)$ is the probability of a passenger moving from the departure hall to the check-in area and $B(1,3)$ the probability of a passenger going directly to the security control. Aena (the Spanish airport operator) reported in [27] that 87% of passengers personally check-in in the traditional desks at the airport, while the 13% remaining does it via internet or use the self-check-in desks at the terminal. Hence, $B(1,2) = 0.87$ and $B(1,3) = 0.13$.
The input passenger flow into the departure hall is determined by the arrival rate of departure passengers. A probabilistic method is presented in [28]. The Weibull distribution, whose density

function is given by (10) can model the arrival rate of passengers to the terminal, with parameters empirically obtained depending on the type of flight, No Schengen or Schengen. Parameters chosen are shown in Table 1.

Table 1: Weibull distribution parameters for arrival passengers

Parameter	No Schengen	Schengen-National
λ	60 min	90 min
k	6.2	
Δt	-150 min	

$$P(x) = \frac{k}{\lambda}\left(\frac{x - \Delta t}{\lambda}\right)^{k-1} e^{-\left(\frac{x-\Delta t}{\lambda}\right)^{k}} \quad (10)$$

Check-in desks. The processing speed of the check-in cell is computed by (11) which depends on p_{21}, the processing speed of an individual desk, and d_{21}, the number of open desks. This parameter depends on time and operator's decisions. An empirical method for determining it is designed. Two desks will be opened 90 minutes before of gates' opening time and will remain open for 45 minutes for each scheduled flight.

$$u_2(k) = \begin{cases} 0 \; if \; x_3(k) \geq Q_3 \\ \min\left(\frac{x_2(k)}{T}, p_{21}d_{21}\right) otherwise \end{cases} \quad (11)$$

Corridor. This cell has been included to model the effect of delay of a person moving from the departure hall or the check-in area to the security control (dwell time). Its dynamics are modelled as in the departure hall. Parameters are minimum speed, p_{31}, maximum speed p_{32} and free-flow limit p_{33}.

$$\bar{u}_3 = p_{31} + \left[1 - \frac{\max(x_3(k) - p_{33}, 0)}{Q_3 - p_{33}}\right](p_{32} - p_{31}) \quad (12)$$

Security Control. This cell behaves similarly to the check-in desks cell. Parameters are the individual processing speed of a security desk, p_{41} and the number of open desks at time k, d_{41}. In order to determine d_{41} passengers flow data has been analyzed.

$$u_4(k) = \begin{cases} 0 \; if \; x_5(k) \geq Q_5 \\ \min\left(\frac{x_4(k)}{T}, p_{41}d_{41}\right) otherwise \end{cases} \quad (13)$$

Passenger flow behaves uniformly along the year, showing a clear daily pattern. Three transit spikes occur during the day, one from 8 am to 1 pm, one in the afternoon, from 3 to 5 pm and another in the evening, from 8 to 12 pm. Hence, security desks will be opened proportionally to the number of passengers entering to the terminal, up to 10 desks when 40 passengers arrive per minute and a minimum of 2 continuously desks open. This number will be smoothed by the hourly mean of opened desks in order to avoid sudden, unreal changes.

Boarding gates. This is the exit cell of the terminal

$$x_5(k-1) = x_5(k) + TB^*(4{,}5)u_4(k) - Tv_{OUT}(k) \quad (14)$$

where $v_{out}(k)$ is the total number of passengers boarding at time k. As presented in [29], the boarding process can be approximated to a linear process that begins 45 minutes before departure time and ends 25 minutes before according to ACI's reports.

In Table 2 we show the values of the parameters that were chosen for the simulation and are based on Palma de Mallorca Demand-Capacity study [27]. Although the simulation time step, T, is 1 minute, final results are averaged every 30 minutes because of the simulation method's accuracy level.

Table 2: Simulation parameters for the store-and-forward model

Cell	1	2	3	4	5
Q	$Q_1 = 8000$	$Q_2 = 3100$	$Q_3 = 1800$	$Q_4 = 900$	$Q_5 = 16800$
p	$p_{11} = 70$ $p_{12} = 80$ $p_{13} = 7900$	$p_{21} = 60\ sec$	$p_{31} = 70$ $p_{32} = 80$ $p_{33} = 1700$	$p_{41} = 15\ sec$	
d		$d_{21}(k)$		$d_{41}(k)$	
B	$B(1,2) = 0.87$ $B(1,3) = 0.13$	$B(2,3) = 1$	$B(3,4) = 1$	$B(4,5) = 1$	

Data processing

In this stage, data from the different sources that were presented before is now gathered into a single dataset. Every sample correspond to a snapshot of terminal situation every 30 minutes. The simulation results offer two variables: queue length at check-in desks, QUEUE_CHECK_IN and queue length at the security control, QUEUE_SECURITY.
Flight data is rearranged so that 24 KPIs (Key Performance Indicators) are built to capture the behaviour patterns of passengers both in check-in desks and security control. The time window selected to compute each KPI depends on the target. For check-in modelling a 90 minutes time window is used, while 45 minutes is applied to security control features. The features' descriptions are the following:

- *INSULAR_CI(_SEC)*. Number of inter-island flights scheduled within the next 90 (45) minutes.
- *SCHENGEN_CI(_SEC)*. Number of Schengen flights scheduled within the next 90 (45) minutes.
- *INTERNATIONAL_CI(_SEC)*. Number of international flights scheduled within the next 90 (45) minutes.
- *INSULAR_CI(_SEC)_AVG*. Mean number of seats of inter-island flights scheduled within the next 90 (45) minutes.
- *INSULAR_CI(_SEC)_MAX*. Maximum number of seats of inter-island flights scheduled within the next 90 (45) minutes.
- *INSULAR_CI(_SEC)_MIN*. Minimum number of seats of inter-island flights scheduled within the next 90 (45) minutes.
- *SCHENGEN_CI(_SEC)_AVG*. Mean number of seats of Schengen flights scheduled within the next 90 (45) minutes.
- *SCHENGEN_CI(_SEC)_MAX*. Maximum number of seats of Schengen flights scheduled within the next 90 (45) minutes.
- *SCHENGEN_CI(_SEC)_MIN*. Minimum number of seats of Schengen flights scheduled within the next 90 (45) minutes.
- *INTERNATIONAL_CI(_SEC)_AVG*. Mean number of seats of international flights scheduled within the next 90 (45) minutes.
- *INTERNATIONAL_CI(_SEC)_MAX*. Maximum number of seats of international flights scheduled within the next 90 (45) minutes.
- *INTERNATIONAL_CI(_SEC)_MIN*. Minimum number of seats of international flights scheduled within the next 90 (45) minutes.

Regarding the temporal variables, three features have been computed:

- *DAY_WEEK*. Day of the week (0-6).
- *MONTH*. Month of the year (0-11).
- *HOUR*. Hour of the day (0-23).
- *ESPECIAL*. Flag variable which indicates whether current date corresponds to holidays or any special event (0-1).

A total of 16 features are included in the final dataset for each of the targets.

Modelling

Modelling the length of a service queue is a regression, supervised problem, since the known target can take any integer value from zero to the capacity of the service. The Random Forest technique, first introduced by Leo Breiman in [30], has been widely studied and used for regression problems in Machine Learning. The main reasons why it has been selected for this model are:

- Overfitting reduction. If the trees that compose the forest are decorrelated, variance of the model will tend to 0 as the number of decision trees (DT) increases.
- Variable flexibility. Random Forests, based on decision trees, are suitable to model categorical and numerical predictors. Besides, data normalization is not needed, since each feature is independently processed by each node of the tree.
- Parallelization. Training time can be reduced by building independent trees simultaneously.
- Explicability. Random Forest, as a bagging ensemble model, offers a feature importance measure obtained using the out-of-the-bag (OOB) samples.

In order to evaluate the model, data has been split into three sets, a training set which contains 70% of the samples, a validation set with a 10% of samples, both randomly chosen, and a test set containing the remaining samples (20%).
Random Forest hyperparameters used for this study are number of DTs and the number of features considered on each split. They have been tuned using the validation set, and choosing the set of parameters that achieved the best evaluation metrics.

Evaluation

Three metrics have been used in order to assess the model performance, mean squared error $MSE = \frac{1}{n}\sum_{i=1}^{n}\left(Y_i - \hat{Y}_i\right)^2$, mean absolute error $MAE = \frac{1}{n}\sum_{i=1}^{n}|y_i - x_i|^2 = \frac{1}{n}\sum_{i=1}^{n}|e_i|$, which offers a general view of the model's power and $R^2 = 1 - \frac{SS_{res}}{SS_{tot}}$, where $SS_{tot} = \sum_i (y_i - \bar{y}_i)^2$ and $SS_{res} = \sum_i (y_i - f_i)^2 = \sum_i e_i^2$, which provides a measure of how well observed outcomes are replicated by the model.
It is worth mentioning that these measures are computed on the test set, in order to provide a measure of the generalization of the model.

Results

Results are presented in two sections. First, security control analysis is carried out and modelling insights are introduced. The second section presents the same content for check-in desks.

Queue lengths at security control model

A descriptive and statistical analysis is presented in order to remove the outliers' effect on the model and determine statistically significant features to predict queue length.

Month. One-way ANOVA test is applied to compare the means of several groups on the dependent variable and check whether the means are different or not. In other words, queue length is compared for different months and states to find out if a month presents different mean queue length or if there are no differences in queue length during the year. $p - value < 2 \cdot 10^{-16}$, which is significantly lower than the significance level $\alpha = 0.05$. This indicates that at least one month present a different queue length mean than the others.
In conjunction to ANOVA, Tukey's range test is used to compare all possible pairs of means of the dependent variable between all the groups, and to identify any difference between two means that is greater than the expected standard error [31].

Month pairs from January to March, November and December present a p-value greater than $\alpha = 0.05$, which means that queue length mean is similar during those months. Hence, they have been grouped in a single category called Low Seasonality, which presented statistically significant differences with the rest of months.

Day of week. Same methodology as for month variable is applied to the day of the week. ANOVA test indicates that at least one day of the week presents a significant difference in queue length mean. $(p - value < 2 \cdot 10^{-16})$. Tukey HSD test is then applied.

Hour. The hour is an important variable to determine queue length, since most of the flights are cumulated in first hours in the morning and in the evening. $p - value$ ($< 2 \cdot 10^{-16}$) of ANOVA tests also suggests that at least one of the hours present different mean of queue length. Tukey HSD test invites to group hours from 21 to 3 in a same group that has been called Night Hours.

Focusing on outlier detection, Figure 4 and Figure 5 collect all queue length values divided in hour, day of the week and month. They suggest that some points which a priori can be taken as outliers correspond to high seasonal months, from June to September.

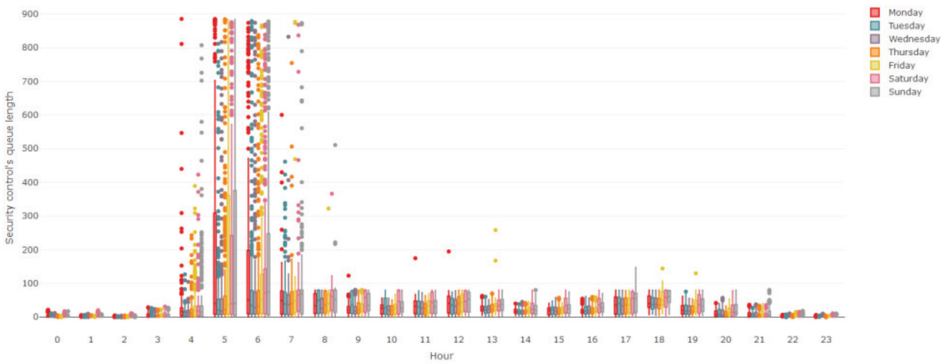

Figure 4: Security control's queue length by hour and day of the week. Potential outliers are represented by scatter plot.

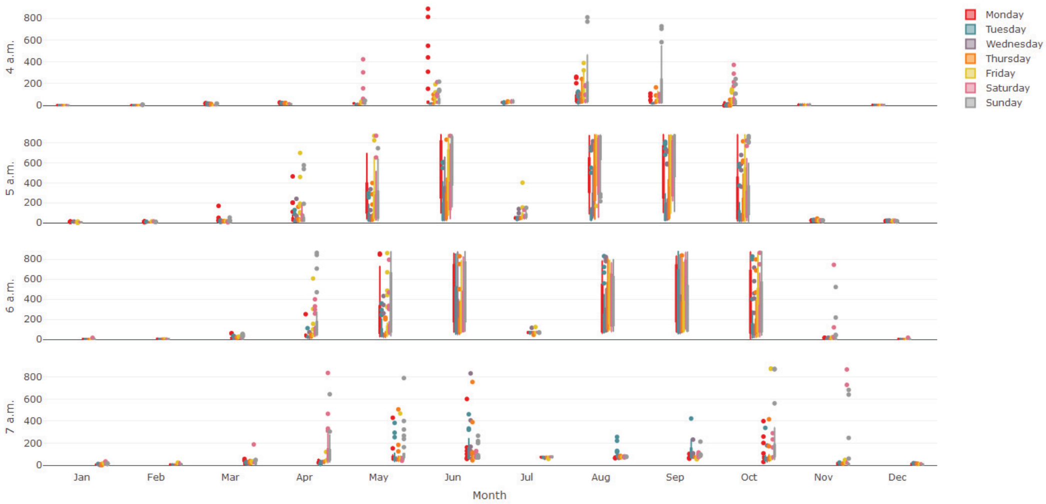

Figure 5: Security control's queue length by month and day of the week at each hour from 4 am to 7 am. Potential outliers are represented by scatter plot at each pair of hour-day.

Scheduled passengers and flights. A new feature, scheduled averaged passengers, has been introduced as a linear combination of those referring to the number of seats per flight and number of flights scheduled within the next hours. The variable "Scheduled averaged passengers" can be obtained as follows.

$$Scheduled\ avg\ passengers = (INSULAR \cdot INSULAR\_AVG) + (SCHENGEN \cdot SCHENGEN\_AVG) + (INTERNATIONAL \cdot INTERNATIONAL\_AVG) \quad (15)$$

For this numerical, continuous variable Pearson correlation test will be carried out to test the relation between the queue length and the scheduled averaged passengers. Queue length values greater than 100 passengers correspond to busy hours as can be seen in Figure 6.

Figure 6: On the right figure, relationship between number of scheduled averaged passengers within the 45 next minutes and security control's queue length (correlation coefficient=0.442, p-value $< 2 \cdot 10^{-16}$). The left figure shows a detail for queue lengths lower than 100 passengers (correlation coefficient = 0.97, p-value $< 2 \cdot 10^{-16}$).

Feature Importance

Before training Random Forest algorithm, a first approach to variable influence on the model will be analysed using the feature importance measure provided by the algorithm. Figure 7 shows the high influence of hour (HORA), scheduled averaged passengers (SCH_PAX_SEC), seasonality (TEMPORADA) and the low influence of maximum, minimum and average number of seats per flight type, especially for inter-island and international flights.
Following this analysis, features chosen to train the model are scheduled averaged passengers (SCH_PAX_SEC), hour (HORA), seasonality (TEMPORADA), day of the week (DAY_WEEK) and holiday or special event flag (ESPECIAL).

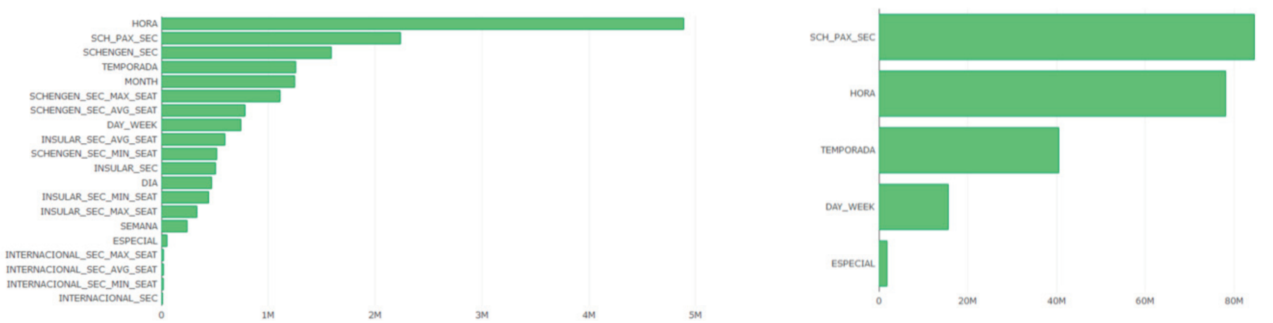

Figure 7: On the left, preliminary study of features influence on the security control's queue length. Units reflect the purity evaluated by the Random Forests algorithm. On the right, features included in the final security control's queue length model. Units reflect the purity evaluated by the Random Forests algorithm.

Training and evaluation

Validation evaluation metrics used to select best model hyperparameters are shown in Table 3. It is worth mentioning that the error does not decrease for a number of DTs much greater than 1000 neither for a large number of variables considered at each split. In fact, as the number of variables considered increases, DTs are likely to be more correlated so that model performance gets worse.

Table 3: Hyperparameter tuning of queue length at security control model. Validation set is used to compute loss function and select model with best performance

Nb. of DTs	Nb. of variables considered at each split	MSE	MAE [passengers]	R^2
500	1	2830	15	0.5964
	2	1657	10	0.7626
	3	1468	9	0.7547
	4	1788	10	0.749
1000	1	2840	15	0.5949
	2	1673	9.6	0.7613
	3	1461	8.67	0.7557
1500	1	2836	15	0.5954
	2	1667	9.6	0.7621
2000	1	2798	14.5	0.6
	2	1673	9.6	0.761

Hyperparameters chosen are 1000 DTs and 3 variables considered since it presents the lowest validation MSE. Evaluation performance is shown in Figure 7.

Nb. of DTs	Nb. of variables considered at split	MSE	MAE	R^2
1000	3	1823	9.9	0.753

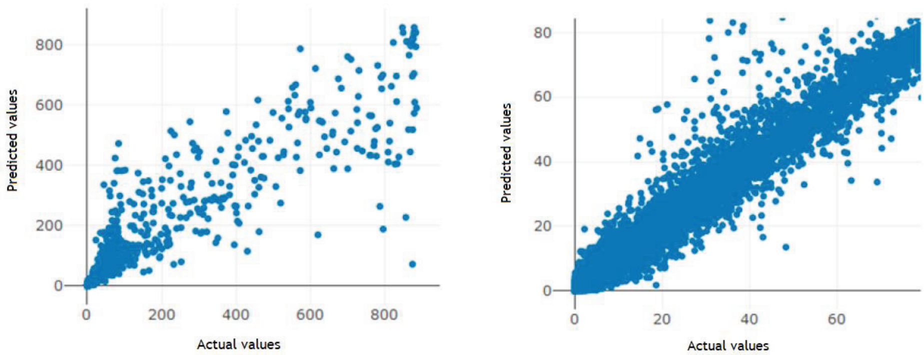

Figure 8: On the left, security control's queue length model performance on evaluation set. Actual values are plotted against predicted values. On the right, a detail of the left figure for queue length values lower than 80 passengers.

Queue length at check-in desks model

Same methodology and structure will be followed to present results in the queue length at check-in model.

Statistical analysis for every categorical variable, applying ANOVA test, indicates that at least one category of each of the variables (month, day of the week, hour and special) present differences on the mean of the queue length at check-in area, since all p-values are less than $2 \cdot 10^{-16}$.

Month. Tukey HSD test invites to gather months of low seasonality (January to March, November and December) and summer-end months (September and August).
Day of week. p-values of Tukey HSD test allow days of the week to be divided into two groups, weekdays (Wednesday and Thursday) and pre-post weekend (Monday, Tuesday and Wednesday) and finally, Saturday and Sunday remain separated.
Hour. Queue length in check-in desks present a similar distribution to the one in the security control, but in this case, Tukey HSD test did not allow to directly group some of the hours.
Scheduled passengers and flights. Scheduled averaged passengers has been built with the check-in passengers variables. Correlation coefficients with queue length at check-in desks is 0.252 (p-value $< 2 \cdot 10^{-16}$) for all data. Coefficient for queue length values lower than 100 passengers is 0.884 (p-value $< 2 \cdot 10^{-16}$).

Feature Importance

The preliminary feature selection based on RF's importance measure shows that scheduled averaged passengers (SCH_PAX_CI), hour (HORA), day of the week (DAY_WEEK), month (MONTH) and seasonality (TEMPORADA) have a high influence on the model. Seasonality and month capture the same information but from different levels of aggregation. Thus, except for seasonality, every mentioned variable is included in the model training (Figure 9).

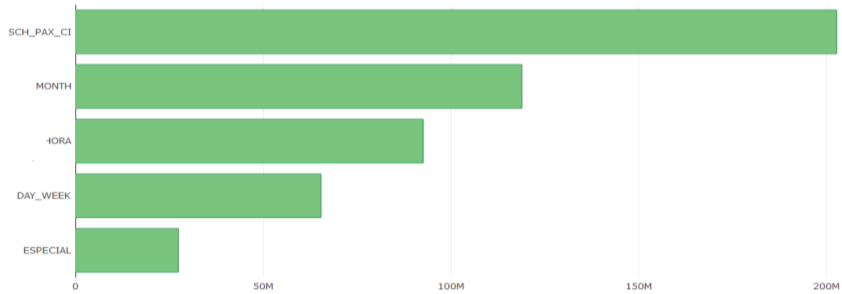

Figure 9: Features included in the final check-in desks' queue length model. Units reflect the purity evaluated by the Random Forests algorithm.

Training and evaluation

In order to tune model hyperparameters, validation phase is performed to select hyperparameters which achieve best accuracy. These values, as can be observed in Table 4 are 500 DTs and 2 variables to be considered at each split.

Table 4: Hyperparameter tuning of queue length at check-in desks model. Validation set is used to compute loss function and select the model with best performance.

Nb. of DTs	Nb. of variables considered at each split	MSE	MAE [passengers]	R^2
500	1	23108	33.5	0.184
	2	16233	27	0.26
1000	1	23110	33.5	0.184
	2	21782	29.7	0.23
1500	1	22950	33.36	0.19
	2	21644	29.7	0.235

Finally, the evaluation of the model is presented in Figure 10.

Nb. of DTs	Nb. of variables considered at split	MSE	MAE	R^2
500	2	16322	27	0.264

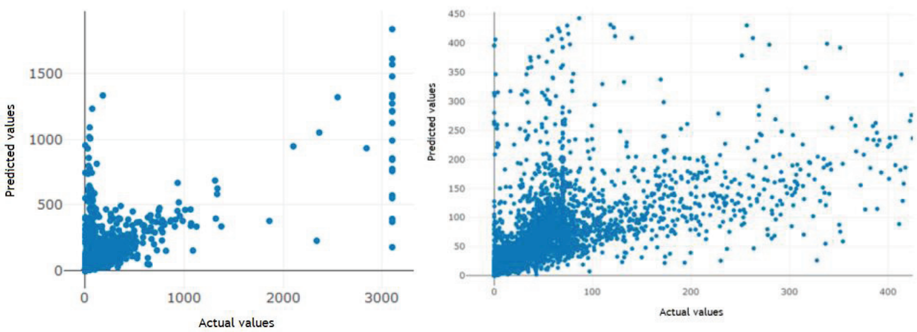

Figure 10: On the left, check-in desks' queue length model performance on evaluation set is presented. Actual values are plotted against predicted ones. On the right, a detail for queue length values lower than 450 passengers.

Conclusion

Random Forest algorithms have been used to model queue length at the check-in desks and at the security control in Palma de Mallorca airport. These algorithms have captured the influence of hour, month and day of the week, whether the date is a special event at the calendar or not (holidays beginning or end, long-weekends, Easter or New Year's Eve). Moreover, they are able to predict scheduled averaged passengers in the next 45 (for security control) or 90 minutes (for check-in) in both queues' dynamics. A brief report of the results is presented in Table 5.
These models show that data of passenger flow in the terminal can be used to predict demand on terminal services, which might help airport operator's decisions on number of opened services (security and check-in desks). Moreover, this tool could be used as an input for an optimization algorithm of workers scheduling, achieving better economic and customer service performance.

Table 5: Summary of models' performance on evaluation set. Accuracy has been computed dividing *MAE* by the mean value of the model's target.

	Queue length at check-in desks	Queue length at security control
MAE	27 passengers	10 passengers
Accuracy	66%	69%

This work proves that predict passengers' behaviour inside airport terminals can be accomplished with reasonable accuracy. It is worth recalling that this work is supported on simulated data due to the lack of public collected data. In order to adapt to the new era of services, where Artificial Intelligence is showing its huge impact, any source of stored data can lead to an improve in the economy of customers and airports. Using real data instead of simulated data will lead to more accurate, specific models for any airport with available data. Nowadays, any consistent data source can result in a market advantage for the operator.

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Spanish airports performance and efficiency benchmark. A PESA-AGB study

Pablo Martinez Ferrer - pablito_martinez_ferrer@hotmail.com
University of Beira Interior, Covilhã, Portugal
Maria E. Baltazar - mmila@ubi.pt
University of Beira Interior, Covilhã, Portugal; CERIS, IST University of Lisbon, Lisbon, Portugal
Jorge Silva - jmrs@ubi.pt
University of Beira Interior, Covilhã, Portugal; CERIS, IST University of Lisbon, Lisbon, Portugal

Abstract
This study uses a MCDA tool to analyse and improve Spanish airports performance and efficiency. Thus, a holistic study using MACBETH (with PESA-AGB) is used. This study has never been applied before in Spanish airports.
Firstly, a literature review related to this study keywords is conducted, as well as about benchmarking concept applied specifically to airports. Secondly, several methodologies in used to benchmark airports are reviewed and compared. Thirdly, airport performance and efficiency issues are addressed and described. Finally, the MCDA-MACBETH (with PESA-AGB) tool is applied to 4 Spanish airports.
Spanish airports belonging to AENA transported 263,753,406 passengers in 2018 with an increase compared to 2017 of 5.8%. General data enables to conclude that Spanish air transportation system is growing annually and hence there is the need to improve airports performance and efficiency, also to maintain the high levels of quality to address the growing demand.
Spanish air transportation system is growing annually and is it upmost important to maintain high levels of quality to address such demand. Through this study, performance and efficiency improvements are seek within several airport key areas such as Safety and Security, Quality Service, Productivity and Effectiveness, Financial and Environment. As far as known, this study has never been applied before in Spanish airports.

Keywords
Spanish Airports; Airport Performance; MCDA - MACBETH; Benchmarking

Spanish airports performance and efficiency benchmark. A PESA-AGB study

Introduction

Throughout history, Spain has not been a country that has been noted for its aeronautical advances. However, the use of aircraft within the air transportation of passengers and cargo has been present in the twentieth and twenty-first century. It is possible to observe a change from the decade of the nineties, where various processes were developed such as the liberalisation of air transportation, globalisation, or the emergence of low-cost airlines, which changed several things in the Spanish airport system. Currently, Spanish airports belonging to AENA transported 263,753,406 passengers in 2018 [1] with an increase compared to 2017 of 5.8%. In 2017, traffic was 249,218,316 people transported, and the increase related with 2016 was 8.2%, while 2016 pointed to 230,231,359 people and an increase of 11.0% over 2015 [2]. This data enables to conclude that Spanish air transportation is growing annually and, therefore, the need to improve and assess airports' efficiency and performance is essential to maintain high levels of quality to address the demand. If we do not improve efficiency and performance, there will be a point where airports will be congested, so two options can be performed: expand airport facilities, or improve their efficiency and performance. The last option is much more economical and maximises the airport infrastructure. Thus, this will increase stakeholders' satisfaction and will reduce airport costs. In Spain, the management of airports is centralised; that is, they operate as independent profit centres but are under the control of a central authority, AENA. This study focusses on large airports leaving small (less than 1 million passengers per year) behind as they are not considered profitable.

The motivation of this work is to use an MCDA tool that will suggest how to improve performance and efficiency of Spanish airports, and thus a holistic study using a mathematical tool such as MACBETH (Measuring Attractiveness by a Categorical Based Evaluation Technique) is used to do so. For this purpose, this was the Multi-Criteria Decision Analyses (MCDA) methodology chosen using the PESA-AGB (Performance Efficiency Support Analysis – Airport Global Benchmarking) model. Four airports were chosen: Adolfo Suárez Madrid-Barajas (MAD), Josep Tarradellas Barcelona-El Prat (BCN), Sevilla (SVQ) and Valencia (VLC).

Through this study, we seek to achieve improvements in many key areas of the airport, such as core, safety and security, quality service, productivity and effectiveness, financial and environment, where specific measures can be taken to reduce costs and thus improving satisfaction. Moreover, therefore, to achieve a global evaluation of the infrastructure. The study will be performed throughout two benchmarking studies.

Methodology

Four airports have been chosen in Spanish territory: Adolfo Suárez Madrid-Barajas, Josep Tarradellas Barcelona-El Prat, Valencia and Sevilla. From these airports, we will obtain data from 6 key performance areas (KPA): Core, Safety and Security, Quality, Productivity/Cost Effectiveness, Financial/Commercial, and Environmental. These six areas are those of Airport Council International (ACI), and they have 42 key performance indicators (KPI), associate. For this study, we gathered for each airport data for each KPA and the related KPI for the last five years (2014, 2015, 2016, 2017 and 2018). Once we have completed our database, we must allocate all these data to MACBETH. Afterwards, it is necessary to assess the weights of each KPA/KPI according to an expert data survey. In the weights regarding the airports, a meeting will be held to give the correct weights to the airports in this study. Once all the weights and data have been gathered, it is necessary to analyse and draw conclusions from the outputs of the model and understand what will be the efficiency and performance proposals for the improvement of Spanish airports, and this will be achieved by carrying out internal and external Benchmarking studies. Figure 1 depicts the sequence of the methodological process.

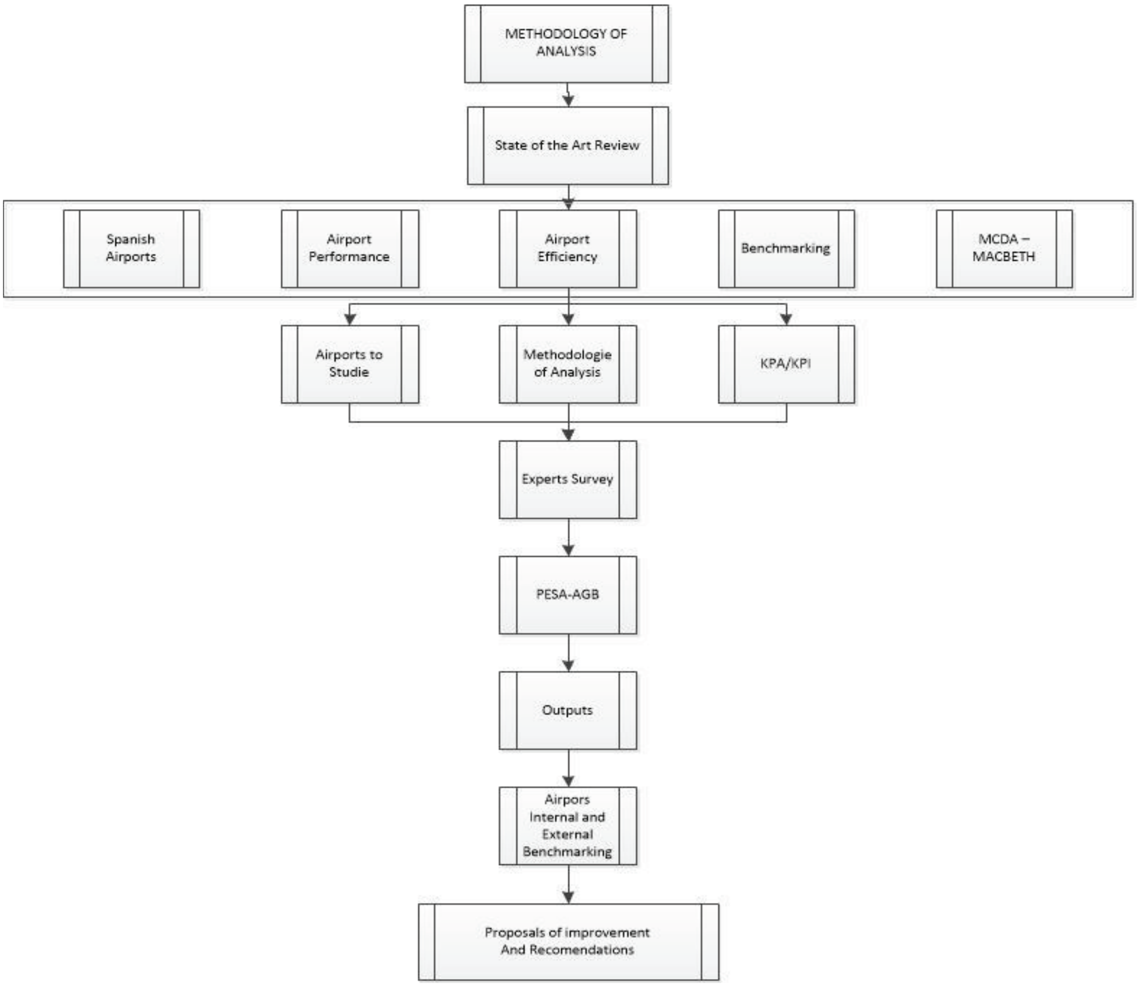


Figure 1 - Analysis Process Methodology
Source: [3]

Measuring Attractiveness by a Categorical Based Evaluation Technique (MACBETH)

MACBETH (Measuring Attractiveness by a Categorical Based Evaluation Technique) is an approach designed to build a quantitative model of values, developed in a way that enables facilitators to avoid forcing decision-makers to produce direct numerical representations of their preferences. MACBETH employs a non-numerical interactive questioning procedure that compares two stimuli at a time, requesting only a qualitative judgment about their difference of attractiveness [4]. When the judgments of the evaluator are established, their consistency is verified; nevertheless, many corrections may be necessary to avoid unconscious errors [5]. Thus, the main difference between MACBETH and any other type of MCDA method is that MACBETH only needs quantitative judgments, where different criteria and weights are set. A scale of values with ranges must be assigned to each alternative. MACBETH allows assigning ranges to each alternative directly or in pairs by comparing elements according to their relative attractiveness. Given two alternatives, the decision to make is much more attractive [6]. We can divide the process into three distinct phases [7]:

1. Structuring:
    a. Criteria: Values under concern and identifying the criteria;
    b. Options: To be evaluated, as well as their performances.
2. Evaluating:
    a. Scoring: Each option's attractiveness concerning each criterion;
    b. Weighting: Weighting the criteria.
3. Recommending:
    a. Analysing Results: Overall attractiveness and exploring the model results;
    b. Sensitivity Analyses: Sensitivity and robustness of the model's results considering several types of data uncertainty.

Before developing a model, it is necessary to have a global vision of the subject under analysis. After, we may create a MACBETH value tree. The value tree has nodes that correspond to KPA and KPI to be considered. The next step is to obtain data for each indicator. After, it is necessary to decide how attractive each indicator is, based on a previously defined scale. For each node, some decisions must be made individually so that in the end the model is consistent. However, it will be possible to vary them later to give robustness to the system.

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

PESA-AGB model is conceived based on PESA-GB (Performance and Efficiency Support Analysis for Global Benchmarking) model [8]. PESA-AGB was built to assess airport performance and efficiency using pre-defined KPAs and KPIs. This model is based on the MACBETH mathematical foundations supported on the work of Bana e Costa et al. [5].

It is structured in a six steps arrangement (Figure 2): Structuring (Step 1); Survey (Step 2); Meeting (Step 3); Evaluation (Step 4); Classification (Step 5); and Outputs (Step 6). Although the sequence of the task is as shown, it is possible to redefine or adjust any task at any time.

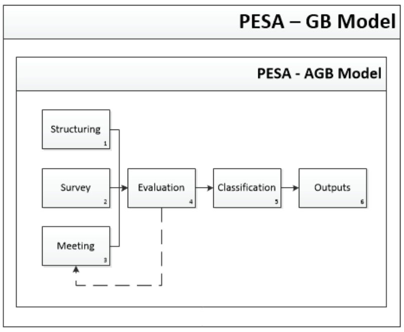


Figure 2 - PESA-AGB Model Tasks
Source: [9]

MACBETH mathematical foundations allow the development with a PESA-AGB model incorporating forty-two key performance indicators for a global analysis of airport performance and efficiency, and it is the model that will be used to the 4 Spanish airports case studies.

Case Studies

Case I - MACBETH Self-Benchmarking

Before starting, we must clarify that in the studies of Case I, we will do Self-Benchmarking, that is, a study of 1 airport in particular during 5 years where we will analyse their KPIs and their KPAs, as depicted in Figure 3.

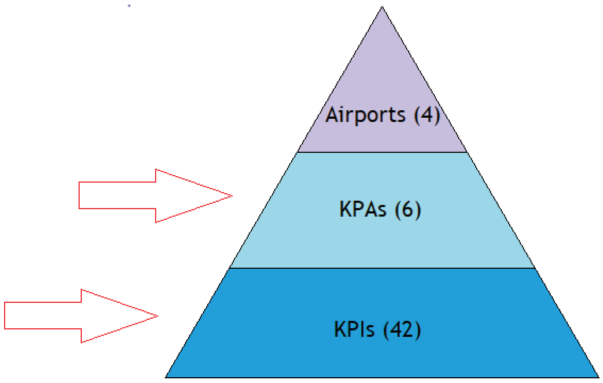


Figure 3 – Triangle of KPIs, KPAs, and Airports
Source: Authors

We are emphasizing this because the opinion of the specialists is applied in these two areas (KPI and KPA) by means of matrices of judgments and by means of weights. Thus, we started the process. Once we have all data, we start with MACBETH. First, we create a decision tree, with the airport as the main node. There are 6 more nodes (KPA) from this main node. All the nodes named so far are non-criteria ones. We can see how it looks in Figure 4.

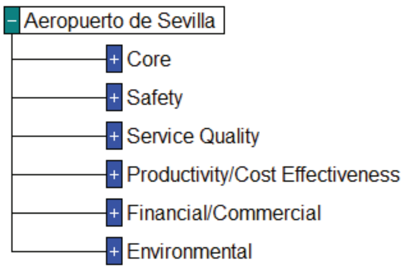


Figure 4 – MACBETH KPAs
Source: Authors

Next, we proceed to the creation of the KPI nodes as depicted in Figure 5. In this Figure, we may see only the KPIs of KPAs Core, and Safety and Security because it is just an example. In this example, there are 4 missing KPAs with their respective KPIs (42 in total). Regarding Safety, the ACI calls this KPA Safety and Security but in reality, it is only Safety because no airport provides data on Security. For specialists, this is the KPA that has a more expressive weight.

Figure 5 - MACBETH KPIs
Source: Authors

The KPI nodes are criterion ones and belong to the quantitative level as depicted in Figure 66.

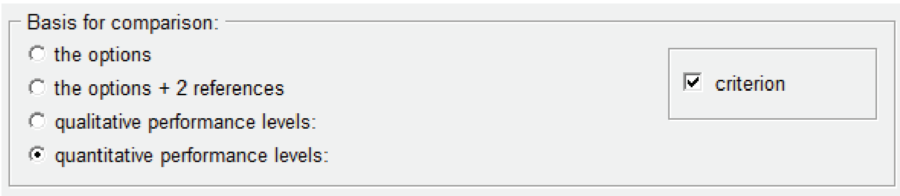


Figure 6 - MACBETH Basis for Comparison (Self Benchmarking)
Source: Authors

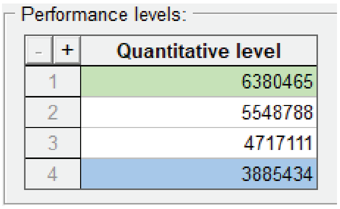
Once the decision tree is finished, we begin with the manual introduction of data for each year and its related (appropriate) KPI (Figure 7). In Figure 7 we only see the Core KPIs because it is an example. The complete Table of Performances contains 42 KPIs.

Table of performances

Options	PAx	AM	OD	Cargo	Destinations
2014	3885434	42379	3691162.3	5667.539	45
2015	4308845	46086	4093402.75	6007.279	47
2016	4625314	45840	4394048.3	6626.457	46
2017	5108817	48661	4853376.015	10715.97	65
2018	6380465	57909	6061441.75	12561.95	76

Figure 7 - MACBETH Table of Performance
Source: Authors

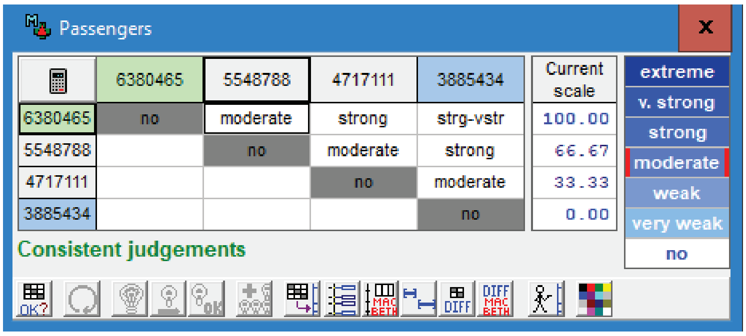
When we have entered all data we have to mark performance levels. To obtain these it will be necessary to take from each KPI the biggest and smallest values of the 5 years period. The biggest one will be the upper reference (marked in green in Figure 8) and the smallest one the lower reference (marked in blue in Figure 8). The two central data are 1/3 and 2/3 of the *distance* between upper and lower references. Figure 8 is an example for the KPI Passengers of Airport 4. For all other KPIs, the exercise is the same.


Performance levels:

	Quantitative level
1	6380465
2	5548788
3	4717111
4	3885434

Figure 8 - MACBETH Performance Levels
Source: Authors

With the levels of development already marked we proceed to insert the judgments. Judgments are one of the reasons why we have chosen M-MACBETH. In this step the opinion of the specialists is incorporated, which makes our study realistic. We see in Figure 9 how the table incorporates the judgments of the specialists, separated between different performance levels.


Passengers

	6380465	5548788	4717111	3885434	Current scale
6380465	no	moderate	strong	strg-vstr	100.00
5548788		no	moderate	strong	66.67
4717111			no	moderate	33.33
3885434				no	0.00

Figure 9 - Matrix of Judgements
Source: Authors

Figure 9 is an example for the KPI Passengers of Airport 4. Each KPI of the study has its own matrix that has been constructed based on specialists inputs. We verify that the judgments are consistent and we scale them from 0 to 100 as depicted in Figure 10.

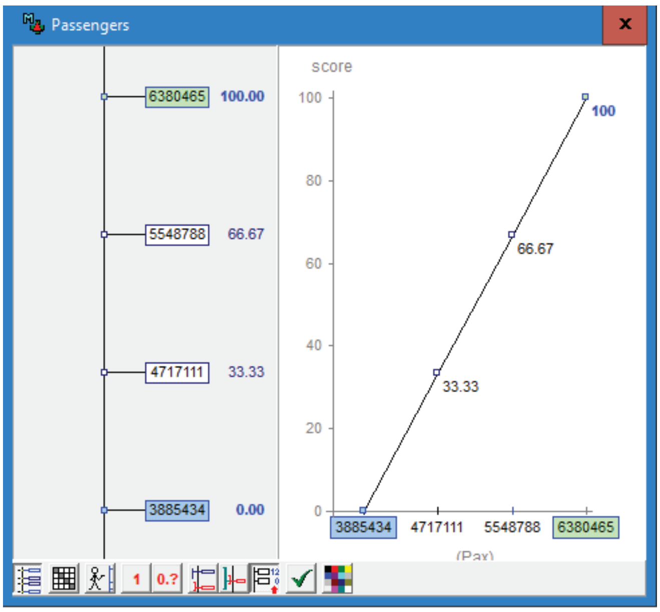


Figure 10 - New Scale
Source: Authors

Again, Figure 10 is an example for KPI Passengers of Airport 4. For each KPI we construct a new scale. Thus, we achieved data in a punctuation scale from 0 to 100. Now we are ready to apply the weights. Again we apply for the specialits opinion. The sum of weights is 100 and the result is that of Table 1.

Table 1 – KPIs Weights
Source: Authors

KPA	KPI	Value %
CORE	Passengers	5.02
	Aircraft Movements	4.46
	OD	3.90
	Freight and Mail Loaded Unloaded	3.34
	Destination-Nonstop	2.79
SAFETY	Runway Accidents	4.73
	Runway Incursions	4.30
	Bird Strikes	3.87
	Public Injuries	3.44
	Occupational injuries	3.01
	Lost Work Time form Employee Accidents and Injuries	2.58
SERVICE QUALITY	Customer Satisfaction	2.32
	Gate departure Delay	2.14
	Baggage Delivery Time	1.96
	Taxi Departure Delay	1.78
	Security Clearing Time	1.78
	Border Control Clearing Time	1.61
	Check-in to Gate Time	1.61
	Practical Hourly Capacity	1.43
PRODUCTIVITY-COST EFFECTIVENESS	Total Cost per Passenger	2.44
	Total Cost per Movement	2.27
	Operating Cost per Movement	2.09
	Aircraft Movement per Gate	1.92
	Total Cost WLU	1.92
	Operating Cost per Passenger	1.74
	Operating Cost per WLU	1.74
	Passengers per Employee	1.57
	Aircraft movement per Employee	1.39
FINANCIAL-COMMERCIAL	Aeronautical Revenue per Passenger	2.35
	Aeronautical Revenue per Movements	2.17
	Non-Aeronautical Operating Revenue per Passenger	1.99
	EBITDA per Passenger	1.99
	Non-Aeronautical Operating Revenue as Percentage of Total Operating Revenue	1.81
	Debt to EBITDA Ratio	1.63
	Debt Service as Percentage of Operating Revenue	1.45
	Long-Term Debt per Passenger	1.26
ENVIRONMENTAL	Carbon Footprint	2.59
	Waste Recycling	2.22
	Renewable Energy Purchased by the Airport	2.22
	Waste Reduction Percentage	1.85
	Energy per Square Meter of Terminal	1.85
	Water Consumption per Passenger	1.48

Once the weights are applied, the punctuation table remains as in Figure 11. We can see below all the weights that are going to be applied. On the left we have the years, as options, and the average of the scores (between 0 and 100), per year, of the 42 KPIs. In the center-right of the Figure we observed scores of PAX, AM, and OD already scaled. Figure 11 is an example of Airport 4 and so in the Figure are missing 39 KPIs. Overall corresponds to Airport 4 efficiency for 5 years. For the other airports, we made the same procedure, with the related data.

Table of scores

Options	Overall	PAx	AM	OD
2014	32.58	0.00	0.00	0.00
2015	41.60	16.97	23.87	16.97
2016	42.55	29.65	22.28	29.65
2017	59.41	49.03	40.45	49.03
2018	69.38	100.00	100.00	100.00
Bom	100.00	100.00	100.00	100.00
Neutro	0.00	0.00	0.00	0.00
Weights :		0.0502	0.0446	0.0390

Figure 11 – MACBETH Table of Scores
Source: Authors

With all data collected and inserted into M-MACBETH, we are ready to proceed with the study.

Case II - MACBETH Peer-Benchmarking

Before starting, it is necessary to clarify that in the studies of Case II we will perform Peer-Benchmarking, that is, the study of the 6 KPAs of 4 airports related to each other during 5 years (2014-2018), as depicted in
Figure 12.

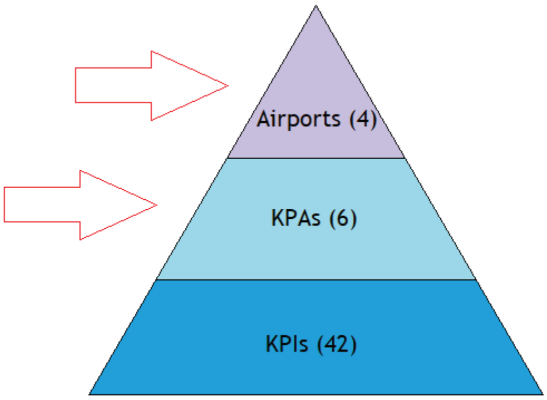


Figure 12 - Triangle of KPAs, KPIs, and Airports
Source: Authors

We emphasize this because the opinion of the specialists is applied in these two areas (Airports and KPAs) by means of judgments matrices and weights. Thus, we start with the process. First, we proceed with the creation of the decision tree, with 4 non-criteria nodes that correspond to the 4 Airports of the study (Figure 13).

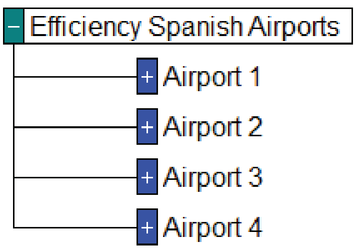


Figure 13 – Peer-Benchmarking Tree non-Criteria Nodes
Source: Authors

Within each Airport, we will have 6 KPAs as node, that is our criteria nodes.

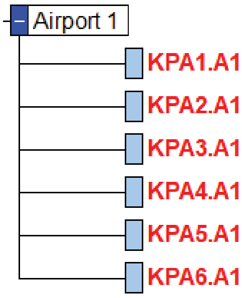


Figure 14 – Peer-Benchmarking Criteria Nodes
Source: Authors

Each Airport is a non-criterion node, with 6 criterion nodes associated. In all places/nodes, we have a KPA followed by A1, A2, A3 or A4 that identified each airport, as it can be depicted from Figure 14. The Figure is an example of Airport 1; for other airports the process is the same.

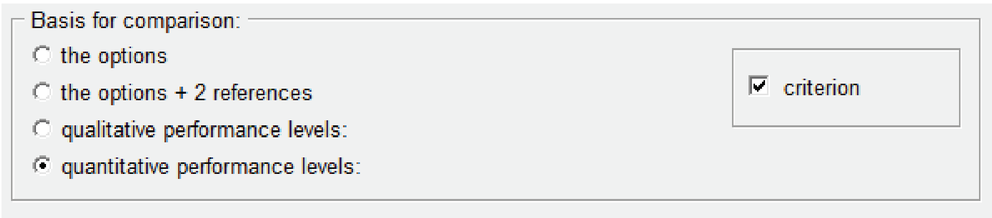
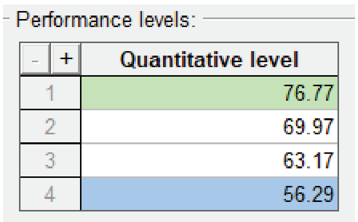


Figure 15 – MACBETH Basis for Comparison (Peer Benchmarking)
Source: Authors

In the nodes of the KPAs, the assigned Quantitative Performance Levels mode is as depicted in Figure 15.


Performance levels:

- +	Quantitative level
1	76.77
2	69.97
3	63.17
4	56.29

Figure 16 – Peer-Benchmarking Performance Levels
Source: Authors

The KPAs data is taken from study of Case I, and inserted in the performance level table as in Figure 16. The biggest score will be the upper reference (marked in green in Figure 16) and the smallest one the lower reference (marked in blue in Figure 16). The two central values are 1/3 and 2/3 of the *distance* between the upper and lower references. These data will be used below in the matrix of judgments. Figure 16 is an example where we use data of KPA 1 of Airport 1. For the other KPAs of the other airports the process is identical, but with related data.

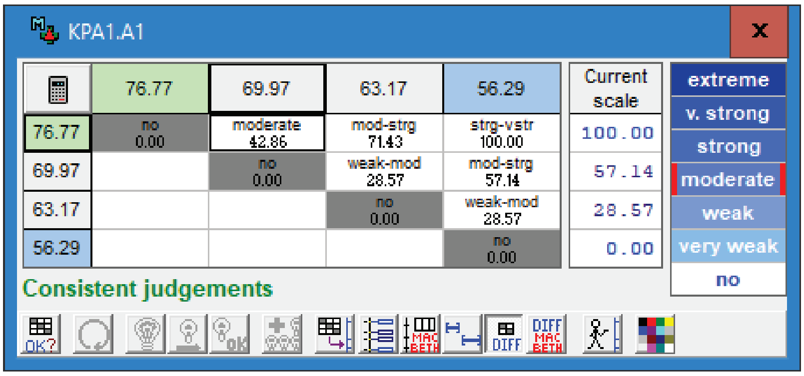


Figure 17 – Peer-Benchmarking Matrix of Judgements
Source: Authors

The matrix of judgments of Figure 17 is that of the corresponding KPA. It is an example of KPA 1 of Airport 1, and we apply to each KPA its own matrix. These are made based on the specialists opinion and it causes the Current Scale depicted in Figure 18 and Figure 19. We underline that these scales take into account the opinion of specialists.

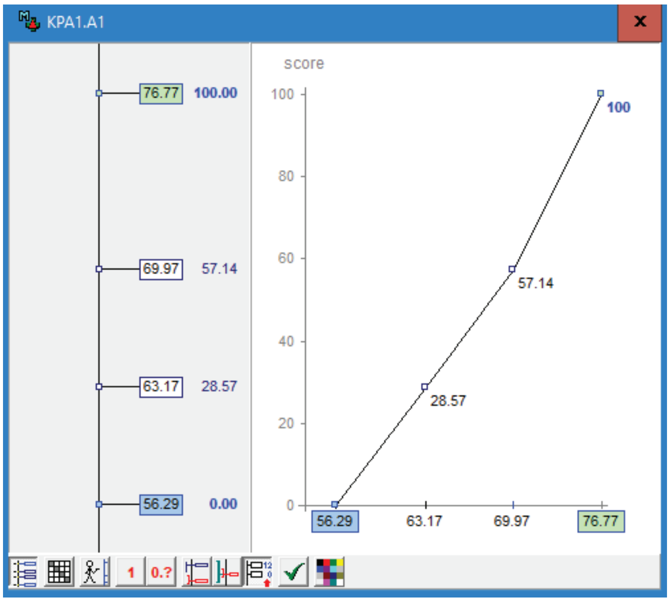


Figure 18 – Peer-Benchmarking Scale
Source: Authors

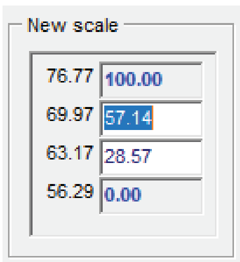


Figure 19 - Peer-Benchmarking Scale
Source: Authors

Finally, we must consider airports weights accordingly to the specialist's opinion, as in Table 2. Table 3 depicts KPAs weights.

Table 2 – Peer-Benchmarking Airports Weights
Source: Authors

Airports	Weights (%)
Airport 1	38,75
Airport 2	30,00
Airport 3	17,00
Airport 4	14,25

Table 3 – KPAs Weights
Source: Authors

KPA	Weights (%)
KPA 1 – Safety and Security	22,00
KPA 2 - Core	20,00
KPA 3 – Productivity / Cost Effectiveness	17,00
KPA 4 - Service Quality	15,00
KPA 5 – Financial / Commercial	15,00
KPA 6 - Environmental	12,00

When choosing weights, specialists were encouraged to take into account several factors ordered from the most to the least important:

- Impact of the airport in GDP;
- Impact of the airport on the Tourism;
- Number of movements and passengers;
- What would be the impact to the country if the airport was disabled;
- If there are close and real transport infrastructures alternatives to the airport.

Conclusion

Through these two case studies, we were able to better understand the functioning of MACBETH and know the strengths and weaknesses of different airports. Case I of the study consists in carrying out a Self-Benchmarking analysis of 4 airports, that is, an internal analysis of each airport over a period of 5 years, where data was introduced for several KPIs within 6 KPAs, balanced by the opinion of specialists/experts. On the other hand, Case II was a Peer-Benchmarking Analysis of 4 airports, that is, to compare these airports along the same period of 5 years. We recall that in Case I we have carried out 4 Self-Benchmarking studies: Airport 1 that owns most of the data of the airport A.S. Madrid-Barajas, Airport 2 that owns most of the data of J.T. Barcelona-El Prat, Airport 3 that owns most of the data of the airport of Valencia, and Airport 4 that holds most of the data of Sevilla airport.

From Case I (Self-Benchmarking), we have drawn these conclusions:

- Regarding Airport 1, we can see the good evolution it has from 2014 to 2018 since the efficiency analysis in 2014 has the value of 35,55 and in 2018 75,27, the highest score of the 4 airports under study. We have verified in this study that the KPAs that have the best punctuation within this airport is KPA 2 – Core, and KPA 3 - Productivity / Cost Effectiveness. While the KPAs that must be improved are mainly KPA 1 - Safety and Security, and KPA 4 - Service Quality;
- Airport 2 has a good evolution of efficiency from 2014 to 2018. In 2014 it receives a score of 27,27 and in 2018 74,64. The KPAs with the best results are KPA 2 – Core, and KPA 3

Productivity / Cost Effectiveness, and the KPAs with the worst results are KPA 1 - Safety and Security, and KPA 4 - Service Quality. We can see that both (the best KPAs and the worst KPAs) are the same as Airport 1. This is due to the centralization of AENA and the application of similar measures as for the group of large airports;

- Airport 3 also has a good evolution of efficiency from 2014 to 2018. In 2014 it has a value of 31,29 and in 2018 it is 70,84. The best KPAs of this airport are KPA 2 – Core, and KPA 3 - Productivity / Cost Effectiveness. Moreover, the worst KPAs that this airport presents are KPA 5 - Financial / Commercial, and KPA 6 - Environmental. It is normal for KPA 5 to be low since AENA focuses on large airports to earn revenue;
- Regarding Airport 4, we can see a good evolution of the efficiency values from 2014 to 2018. It ranges from 32,72 in 2014 to 69,55 in 2018. The best KPAs of this airport are KPA 2 – Core, and KPA 3 - Productivity / Cost Effectiveness. Moreover, the worst are KPA 4 - Service Quality, and KPA 5 - Financial / Commercial.

On the other hand, in Case II (Peer-Benchmarking) we have also worked with Airport 1, Airport 2, Airport 3 and Airport 4 with the respective data. The results of the Peer-Benchmarking study are the following:

- We can see that in the KPA 1 the airport that was the best score was Airport 2 with 62,68 points and the worst was Airport 1 with 43,17 points. For the KPA 2, the best airport was Airport 1 with 48,04 points and the worst airport was Airport 4 with 37,08 points. For KPA 3 the airport that was the best was Airport 1 with 44,58 points and the worst was Airport 4 with 24,61 points. For the KPA 4, the airport which was the best was Airport 4 with 40,43 points and the worst was Airport 2 with 2566 points. For the KPA 5, the best airport was Airport 2 with 51,40 and the worst one was Airport 4 with 35,88. For KPA 6, the best airport was Airport 1 with 34,19 and the worst Airport 4 with 21,34.
- After applying the airport weights, we found that in first position is Airport 1, then Airport 2, then Airport 3 and finally Airport 4.

The only negative aspect of this study has been not to get all the required data from Spanish airports because AENA did not provide them in time. We overcomed this problem using data from similar (American) airports.

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Optimized communication plan and its impact on the contingency plan previously put in place for timely crisis response in the air sector

Lúcia de Fátima Silva Piedade - luciasilvapiedade@gmail.com
Universidade da Beira Inerior
Jorge Silva - jmrs@ubi.pt
Universidade da Beira Interior/CERis IST Universidade de Lisboa

Abstract

Analyze the crises spread in the Organization, taking into account their effects, response time (partial and total) and entities involved. In theory, the goal is to understand how the crisis response should be and how the system responds to the same type of crisis.

There is a gap in the communication plan for crisis response in place. The deepening and exploration of typologies of organizational crises in the air sector, will to optimize the response times that can satisfy or mitigate the worsening of the situations, setting off a new challenge. It is through the methodology of gathering information, readings and research of the subject literature that this will be analyzed based in success cases, typologies of crisis and also models of response time exist.

The study will shine a light on the different crisis typologies as well as their propagation at the Lisbon airport. Leading to the creation of a model or models for a quick and effective response to it. Thus minimizing the response time and eventual recourse due to the analysis of success stories in similar infrastructures.

The objective of this study is to study is the production of a model or several. Therefor optimizing the response time in crisis situations as a result of studies and research on typologies of crisis and their effects in time and in the entities involved.

Keywords

crisis communication; typologies of crisis; aviation; reponse times

Optimized communication plan and its impact on the contingency plan previously put in place for timely crisis response in the air sector

Introduction

Based on previous studies [1], the motivation that guides the accomplishment of the research proposed here was born. The deepening and exploration of other aspects in terms of organizational crises in the air sector unleashes a new challenge. Given the experience gained in the airport system and compliance, we are led to conclude that there is a gap in the communication plan for crisis response. It is on this basis that the idea of studying the typologies of crisis as well as their propagation appears in order to optimize the response time's thus satisfying or mitigating crisis situations, especially when the interference of new social technologies is important for the affectation / alteration and or resolution of the crisis itself.

The crisis is understood as a phenomenon that affects the normal functioning of an organization's activities and creates a significant threat to it: jeopardizing its relations and position with its public as well as its ability to continue to supply products and services; In addition to affecting the image the organization reputation, the industry itself and the sector of activity where the organization acts, it can, in the last instance pose a threat to the very survival of the organization.

During the development of the doctoral thesis entitled "Social technologies and crisis communication in the air sector" [1], a study was carried out that aimed to understand and illustrate (through the elaboration of a communication model in crisis management) of the aviation industry in Portugal have planned the prevention and management of the crisis, from the point of view of communication and relations with its public. It was also an objective to understand and demonstrate the utilization of policy and monitoring of social and institutional technologies of each company that are present during the prevention and management of the crisis in companies in this sector.

It is based on the previous theoretical study then carried out that we will start to develop a new study, this time having as object of study the airport system of the Lisbon Airport, and aiming at objectives that could lead to the production of a model or several for the optimization of response time in crisis situations. This work is based on the development of studies and research on typologies of crisis and their affectation on the time and entities involved.

Specific objectives

- Carry out the survey of the typologies of crisis in the Lisbon Airport, namely air side and land side;
- Analyse the spread of crises in the Organization in terms of their effects, response time (partial and total) and involved entities. In theory, understand how the response to the crisis should be and in practice to understand how the system responds to the same type of crisis;
- Creation of a model or models for response in identified typologies of crisis, minimizing the response time and with possible resort to the analysis of success stories in similar infrastructures.

Work methodology

- Literature review;
- Collection of information, readings and research on the subject. Success stories, typologies of crisis and models of response times in other infrastructures will be analysed;
- Case study, where the methodology set forth in the previous point will be maintained;

- Comparative analysis of the case under study with existing good practices;
- Proposal and validation of the model or models of performance.

Literature review

The concept of crisis, which is nothing more than a phenomenon that affects the development of the organization's normal activity, is an occurrence with a potential negative effect in organization, the company, the industry, as well as its publics, products, services, image and reputation. It disrupts the normal flow of the organization's business, whether by its existence or not, and may not be as catastrophic as to destroy the organization [2].

According to this author, in a crisis in contrast to the problem, the emotions are red, the brain does not always work at its maximum power and events happen so quickly that schematizing a plan of action during a crisis is unthinkable.

Due to new environmental developments, terrorism, and the proliferation of social media with increasing exposure, companies have come to play a key role in crisis management [3]. According to this author, no organization is immune to a crisis, it can arise from inside or outside the organization, and the way in which the crisis is handled can save the organization or destroy it, especially when it comes to how it communicates in the crisis situation.

The Institute for Crisis Management defines crisis as a significant disruption to an organization's business that encourages extensive media coverage. The outcome of public opinion may affect your operations and may still have political, legal and financial impacts on your business.

In the air sector the crisis concept is closely linked to the concept of risk, because the sustainability and viability of the air sector depends to a large extent on risk management ie: identification, analysis, elimination, mitigation and prevention of hazards as described in [4].

Nowadays, the role of communication is to support a well-structured management model that can lead the company to face ever more competitive challenges of a society that becomes more demanding in quality and rights [5].

The air sector is one of the sectors where the occurrence of a crisis can pose serious threats in terms of loss of life, financial loss and public insecurity (as in the food and pharmaceutical industry, for example). However, the air transport sector has a very diverse set of companies and entities with very different missions and organizational natures, so that the position of each company in the face of the threats of a crisis and the management of crisis communication also follow different logics.

In recent years, crises have had a global impact on people. With technological developments people can watch a major disaster unfold, making expectations very high on how organizations respond to and even how they respond to the crisis. Such a source of threat results from the potential damage a crisis can inflict on an organization and its stakeholders [3].

In crisis management, communication has also received particular attention from managers and researchers [6]. The message conveyed, the information that is shared, the communication channels and their recipients are key components in communication in crisis situations and whose management may dictate the survival or non-survival of the organization.

Crisis management is defined as a process to strategically plan the removal of some of the risk and uncertainties from the negative occurrences of a crisis, which could put the organization in control of its own destiny [2].

Crisis managers have an incessant and continuous work to minimize the likelihood of a crisis situation, as well as to prepare the organization for the day that it emerges [3].

Business models need to change, companies need to transform to respond appropriately to the impact and demands of social media, do we will stop looking for the news, they will come to us or even we will create them [7].

According to Rainie [8], current technologies are still far from realizing any possible future scenario in its entirety, however, represent a potential evolution from current trajectories.

For many organizations, social technologies are a threat because of their open-channel nature and lack of technical and human resources to monitor and manage these technologies. From this arises the need to define and implement in organizations a responsible policy for the use of social technologies, oriented to internal audiences and external audiences [9].

According to the [10], we can conclude that many executives report significant benefits when using a new generation of workplace communication tools. The latest results suggest that social tools promise new levels of internal benefits and may eventually bring about deeper changes in the organization in terms of communication, making the business more effective and improving the work method of its employees.

The technological changes have created an environment that forces the organizations to follow the constant evolution of the necessities, behaviors, activities and expectations of the clients. Companies that provide effective customer service by partnering with a collaborative community environment will be in a better position to extend the relationship with their customers over time [11].

Today the business world is unpredictable and volatile thus becoming more complex every day. Companies have seen risk as a necessary evil, which should be minimized or mitigated whenever possible.

Risk is defined as the likelihood of unwanted effects arising from exposure to a hazard. It is often expressed as an equation: Risk = Probability x Consequences.

According to Fearn Banks [2], crisis communication is concerned with the transfer of information to a specific audience, whether to prevent a crisis, recover from a crisis, maintain or improve reputation.

Through effective risk assessment, organizations can also better coordinate multiple responses by effectively addressing risks that threaten the various business areas or functions. More importantly, an effective risk assessment produces a forward-looking view, allowing organizations to avoid risks and also provide a better and clearer approach to the risks they face.

According to the International Civil Aviation Organization (ICAO) [4] aviation safety and security is the identification, analysis and elimination (and / or mitigation of an acceptable or tolerable level) of hazards, as well as the risks that threaten the viability of an organization.

History shows that airplane accidents / incidents not only result in loss of life, but also affects business aspect, so the need for risk assessment is critical, as is the implementation of a system and adequate planning for the control of accidents.

Assessing the level of risk is an important task, and it is necessary to determine the level of risk based on its probability and consequence.

For this, ICAO defined several risk analysis matrixes that allow its control and mitigation, in the most diverse situations in the aerial sector; however the risk of the involvement of new technologies in this sector, has not yet been included in these rules, and has been gradually defined in the crisis management plans in the companies of the sector.

Emergency, Communication and Contingency Plans

The Emergency Plan of the Airport defines the sequence of actions of the operations that must be put in place to control each of the possible emergency situations that occur in the Airport and in the surroundings.

The purpose of the Emergency Plan is to coordinate the actions of the various emergency actors that play a part within the area of responsibility of Lisbon Airport.

With it, the goal is to minimize its consequences by protecting people and property that may be affected.

Type of emergencies

EMERGENCY INVOLVING AIRCRAFT

- Aircraft Accident: Action to be taken when an accident or fire with an aircraft occurs on or off the Airport. It is considered an Aircraft Accident outside the airport when it occurs more than 1 km from its respective perimeter;
- Total Emergency: Action to be taken when it is known or strongly suspected that an approaching aircraft has technical problems and may cause an incident. We can also consider at this point, accidents not related to aircraft, such as Natural Accidents;
- Local Prevention: Action to be taken when an approaching aircraft is known to have technical problems, which by their nature normally do not entail serious difficulties in landing safely;
- Airplane Bomb Threat: Action to be taken when a bomb threat has been received and validated as sufficiently serious by the Threat Assessment and Analysis Team;

Aircraft Seizure or Divertion: Action to be taken when it is known that an aircraft has been hijacked or diverted; the following are some examples of anomalous situations that could lead to the implementation of any of the previous situations.

On Air (Air Traffic Service) decision of:

- Landing gear failure;
- Motor failure;
- Serious hydraulic or electronic problems (controls, navigation, radio);
- Traces of smoke in the aircraft;
- Loss of fuel, loss of pressure in the cab.

In the ground (STA decision, SOA (Airport Operations Service), SSLCI (Rescue and Fire Fighting Service)):

- Incident during parking;
- About train heating;
- Aborted take-off.

Situation of extreme weather condition for the operation as:

- Wind shear;
- Heavy rain or hail;
- cross winds of the order of 15 knots, in the 20-knot service runway or in a burst scheme within the same values;
- Heavy thunderstorms.

EMERGENCIES NOT INVOLVING AIRCRAFT

Fire on the premises: Any type of fire that may occur in the airport or on the infrastructure belonging to the airport;

Off-Airport Fire: A fire that may constitute a danger to the flights or to the airport infrastructure to which the foreign fire services must take action. The contact with the firemen of the airport can originate in the STA, Police or private individuals, these in turn will trigger warning to the external action Fire department in the indicated place;

Natural Disaster: Any type of natural disaster that could cause damage at the airport or on aircraft;

Facility Pump Threat: Action to be taken when a bomb threat is received and validated as sufficiently serious by the Threat Assessment and Analysis Team;

Incident involving Hazardous Materials: May occur independently or as a result of an emergency with an aircraft. Such an incident is not necessarily limited to the existing load within the aircraft, but may occur while the cargo is at the loading terminals, in transit or during loading and unloading operations;

Sabotage and Armed Attack: Actions aimed at producing damage, destruction of facilities, equipment and aircraft. Require immediate intervention by the Security Forces;

Crowd Control: Action to be taken by the Security Forces, when there is strong evidence or evidence that there will be public order changes, in the airport grounds (land side or side air);

Fire in the GOC (Joint Operation Group - pool of aviation fuel suppliers): Fires that may occur in the facilities of the Joint Operation Group.

Crisis communication plan

The term "communication" tends to become too broad and leads to incorrect interpretations of some procedures or responsibilities, so it becomes necessary to separate what is meant by "operational communication", where all intrinsic steps to contingency situations or emergency in the act of coordinating, informing, advising, soliciting support and making known to the various local actors. The Operational Communication is mapped in the procedures of the Contingency Plan and the Emergency Plan of the Airport, whose procedures activate the Crisis Communication Plan [12].

General objectives:

- Map the maximum number of possible situations in order to guarantee measures that will guarantee a timely response to all the public affected by the occurrence and those considered as priority;
- Ensure that all levels of management have sufficient information to implement and maintain an effective crisis management system;
- Define the main roles in crisis communication management within the Communication Directorate;
- Establish protocols with the communication areas of all stakeholders identified in the Contingency Plan and in the Emergency Plan in order to ensure greater effectiveness in the coordination of the information to be provided to the media and the public in general.

Operational Objectives:

- Avoid additional operational constraints;
- Control flows and agglomeration of passengers;
- Control crowds;
- Ensure continuity of operation without constraints;

• Ensure continuity of operation, even with calculated constraints;
• Ensure reliable, up-to-date information to all stakeholders;
• Reassure stakeholders and users.

Institutional objectives:
• Inform all stakeholders and users;
• Control reputation.

The crisis communication plan is about two distinct plans, with proper communication procedures and appropriate to the situations: Contingency Plan and Emergency Plan.

IROPS (Irregular Operations) contingency plan

The Contingency Plan [13] aims to minimize the impact that disruptive events and irregularities in the operation can cause to passengers. It was developed by the Operational Management team in Humberto Delgado Airport, in Lisbon, and contains coordinated procedures with the main stakeholders. This plan also intends to be the repository of previous cases of disruption and also integrate the procedures of each partner, as well as the foreseeable interaction between them, when applicable.

Plan for IROPS:

• Identifies airport systems considered critical to the operation, the disruption of which could undermine the welfare of passengers;
• It covers procedures of the operational and technical areas and aims to guarantee the needs, comfort and safety of the passengers;
• Establishes coordinated actions to prevent and anticipate problems as well as actions necessary for immediate response to unforeseen situations that may arise, either on board the aircraft or at the terminal, whenever there are disruptions or significant delays that constitute irregularities of the operation.

Causes of IROPS:

• Adverse weather conditions;
• Seismic or volcanic events;
• Reduction of capacity or of airport and / or air traffic facilitation;
• Technical problems (with aircraft, systems and / or equipment, power failures);
• Safety breaches and labor problems.

The phases of IROPS, to be considered in terms of planning and actions, are:

• Increase in the number of passengers and / or airplanes;
• Capacity constraints;
• Off-hours or non-scheduled operation (divergent flights);
• Prolonged stay (passengers and / or aircraft).

The situations described above may also affect the capacity of the various airport subsystems, and even cause a severe impact on the airport's operations and, consequently, its normal response capacity.

There were 14 large areas related to critical system failures, equipment, and meteorology, among others, ordered as follows:

01 - Disruption due to abandoned baggage
02 - Disruption in accesses AHD (Airport Humberto Delgado)
03 - Disruption in the luggage terminal

04 - Weather disruption
05 - Disruption due to air traffic
06 - Industrial disruption
07 - Disruption due to failure of computer network or systems
08 - Disruption due to power failure
09 - Disruption due to lack of fuel
10 - Disruption due to epidemic or contagion
11 - Disruption due to interruption of operation on the track
12 - Disruption due to the need to close areas
13 - Failure to supply water
14 - Command failure and control of light signalling

At the end of the disruptive situation, all relevant information, such as documentation completed at the time of the disruption, should be collected, which will be submitted to the IROPS Committee, which will systematize it for further analysis and thorough evaluation of the event, for the purpose of review the quality of response.

It is critical that an integrated, consistent and authentic communication response to an event, incident, or accident uses all available channels to interact with internal and external partners and other stakeholders.

The Head of Communication has the function of monitoring and taking control of all the content placed on the website and social networks until the normalization of the situation.

Conclusion

The case study of fuels at Lisbon Airport is under development, and after comparative study and analysis (from the first event and the second with the same typology - strike in the fuel supply), with existing good practices, conclusions can be reached that could lead us to the concretization of a model that can respond quickly and efficiently.

We are analyzing the spread of crises in the organization regarding their effects on response times and involved entities with a view to minimizing response times with possible success stories for producing a model.

This work is under development and results are expected soon.

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Los ingresos auxiliares frente al desarrollo del transporte aéreo

Daniel Montero Ferreiro - dmonteroferreiro@gmail.com
Universidad de Buenos Aires
Carolina Analia Berretta - carolina_berretta@hotmail.com
Universidad Nacional de Rosario

Abstract

El objeto del trabajo es demostrar que la desagregación de servicios en ingresos auxiliares no ha favorecido a un mayor desarrollo de la actividad del transporte aéreo. Por el contrario, los consumidores experimentan malestar frente a las nuevas experiencias de compra.

El diseño de la investigación garantiza el cumplimiento de todos los pasos de la metodología científica de una investigación, con un planteamiento de problema concreto, la hipótesis y abordando las diferentes variables que han llevado al desagregado de los servicios de transporte aéreo. Se analizan los marcos teóricos correspondientes y se lleva adelante un trabajo de campo con encuestas a los pasajeros. En efecto, se abordan las conclusiones que confirman la hipótesis planteada.

La experiencia de los pasajeros a la hora de comprar un billete de avión es frustrante actualmente. Son muchas las dudas que los invaden respecto a qué servicios están incluidos en la tarifa y, por ende, poseen un nivel alto de insatisfacción al tiempo que manifiestan una degradación del servicio en general. Por otra parte, esta política abordada por las aerolíneas para intentar hacer frente a las LC Carriers, parece una herramienta de marketing que no ha tenido en cuenta al consumidor.

El aporte al conocimiento está dado por hacer investigación frente a una moda que le ha quitado servicios a los pasajeros, bajo el pretexto de cobrar por lo que los pasajeros realmente utilizan; como si esa fuera la única razón por la que habría una mayor demanda de transporte aéreo. Por el contrario, se demuestra que los usuarios de transporte aéreo no fueron tenidos en cuenta y que el nivel de frustración frente al escenario imperante es elevado.

Keywords
Ancillaries; Servicios; Calidad; Tarifa

Los ingresos auxiliares frente al desarrollo del transporte aéreo

INTRODUCCION

Desde que British Airways implementó el Revenue Management hace más de tres décadas, aparece una faceta en el negocio del transporte aéreo que genera discusión y confusión entre los consumidores hasta la actualidad: cuál es el precio justo del servicio que recibo. En efecto, el Pricing refiere al proceso para determinar los niveles tarifarios, combinados con servicios incluidos o restringidos en un mercado de origen-destino determinado. Mientras, el Revenue Management es el siguiente proceso que determina cuántos asientos estarán disponibles para cada nivel tarifario.

Juntos, han creado una desconcertante variedad de precios para los consumidores que simplemente quieren saber cuánto tienen que pagar por viajar en avión de un lugar al otro [1]).

A ese escenario de por sí complejo, las aerolíneas tradicionales, han ido poco a poco incorporando una práctica ya creada por Southwest hace varias décadas, pero maximizada por RyanAir y otras compañías LCC en los últimos años. Desagregar servicios que un pasajero espera recibir se ha vuelto una práctica incipiente en Sudamérica que provoca malestar en los usuarios de transporte aéreo, como veremos más adelante.

Las estrategias teóricas para establecer los precios por parte de las aerolíneas son tres:

- Precio basado en los costos, es decir por lo que cuesta producir más un margen, práctica aplicable en un irreal escenario de competencia perfecta.

- Precio basado en la demanda, es decir por lo que los consumidores están dispuestos a pagar.

- Precio basado en el servicio, es decir en la calidad de los servicios que se incluyen en el transporte.

Como todos los mercados de origen / destino son heterogéneos, en la práctica las aerolíneas aplican un mix de estas tres estrategias.

Al principio, las aerolíneas low cost ofrecieron mejores tarifas, basándose en desarrollar economías de escala en su estructura de costos. Pero fue el marketing y el avance de las tecnologías de información y las comunicaciones, las que impulsaron definitivamente el desagregado de los servicios de una aerolínea como siempre se habían conocido: surgen los ancillaries o servicios auxiliares.

Ahora mismo, lo que motiva a las aerolíneas tradicionales a llevar adelante esta práctica es seguir un modelo que en la región Sudamericana tiene por objeto que se sumen nuevos usuarios al transporte aéreo en detrimento de otros medios de transporte, según rezan cada una de las campañas comerciales de las empresas y también el mensaje político de gobiernos como el de Argentina.

Según la Real Academia Española, el marketing es el conjunto de estrategias empleadas para la comercialización de un producto y para estimular su demanda.

Pero surgen dos cuestiones clave respecto a los ancillaries frente a esta definición: observamos que los usuarios de transporte aéreo no fueron tenidos en cuenta, al tiempo que la demanda se estimuló debido a la fuerte desregulación en los derechos de tráfico en la mayoría de los grandes mercados.

Como en toda propuesta de marketing, hay una empresa líder que ofrece consultoría en este sentido: Idea Works Company desarrolló una definición de ingresos auxiliares que ha sido ampliamente aceptada por la industria de las aerolíneas.

Son ingresos más allá de la venta de boletos generados por las ventas directas a los pasajeros, o indirectamente como parte de la experiencia de viaje. [2]

Define también a los ingresos auxiliares utilizando estas categorías: características a la carta, productos basados en comisiones, actividades de viajero frecuente, publicidad vendida por la aerolínea y los componentes a la carta asociados con una tarifa o paquete de productos.

Para agregar un poco más de claridad a esta clasificación, Idea Works Company ofrece estas definiciones:

- Características a la carta: representan los elementos en el menú de ingresos auxiliares y consisten en las comodidades que los consumidores pueden agregar a su experiencia de viaje aéreo. Por ejemplo: ventas a bordo de alimentos y bebidas, facturación de equipaje y exceso de equipaje, asientos asignados o mejores asientos dentro de la misma cabina, etc.

- Productos basados en comisiones: Las actividades de ingresos complementarios también incluyen las comisiones ganadas por las aerolíneas en la venta de alojamiento en hoteles, alquileres de automóviles y seguros de viaje. La categoría basada en comisiones involucra principalmente el sitio web de la aerolínea, pero puede incluir la venta de productos libres de impuestos y de consumo a bordo de aeronaves.

- Programas de viajero frecuente: la categoría de viajero frecuente consiste principalmente en la venta de millas o puntos a socios del programa, tales como cadenas de hoteles y compañías de alquiler de automóviles.

- Publicidad vendida por la aerolínea: ingresos generados por la revista en vuelo, mensajes publicitarios y colocación de muestras y productos de consumo basados en tarifas.

- Tarifa o paquete de productos: Las aerolíneas pueden asignar una porción del precio asociado con un paquete de clase económica como el equipaje facturado, el embarque anticipado y el espacio adicional para el espacio para las piernas.

En la misma línea, la IATA viene trabajando en los últimos años en el NDC (New Distribution Capability) para que las aerolíneas recuperen los inventarios de sus asientos que han confiado a los GDS, empleando tecnologia con lenguaje XML. Esta tecnologia justamente les da mayores posibilidades de desagregar Servicios y convertirlos en Servicios auxiliares.

Muchas aerolíneas creen que el NDC permitirá incrementar su facturación, justamente por los ancillaries, diversificándolos a la venta de Servicios que los pasajeros necesitan en los destinos que viajan. Algunas confían incluso, que podran desplazar a los tour operadores en el armado de la cadena de valor de los viajes. [3]

Para la próxima década, el NDC será el facilitador de la aparición de Nuevos jugadores en la distribución de los Viajes aéreos que, sin compartir la información con el estándar del XML, no hubiera sido posible.

Quien más información disponga del cliente o del cliente potencial, contará con las mejores herramientas para generar la venta. Así, a mediano plazo el NDC será terreno para Google, Apple, Facebook, Ebay, Mercado Libre o Amazon, por encima de cualquier OTA, Metabuscador, GDS o las propias líneas Aéreas. Y eso también supondrá costos para las aerolíneas. El empoderamiento que esas empresas tendrán, puede hacer que los costos sean inclusive mayores que los que hoy pagan las aerolíneas por la distribución. Ese empoderamiento, puede hacer que los beneficios buscados por los ancillaries sean truncos.

METODOLOGIA Y ANALISIS

Se analizan las variables más determinantes respecto al planteamiento del problema, al tiempo que se realiza un Trabajo de campo, mediante la formulación de encuestas con enfoque estadístico, evitando que los resultados estén sesgados por grupo etario, género, Viajes de negocio o placer y viajeros frecuentes.

La innovación en los ingresos que se pretende, contrasta con la realidad de los resultados de cada una de las categorías dadas por la Consultora IdeaWorks.

En efecto, los ingresos genuinos que no tienen que ver con una desagregación de los servicios, no alcanzan al 15% del total de los ingresos por servicios auxiliares, como se exhibe en el Gráfico Nro. 1.

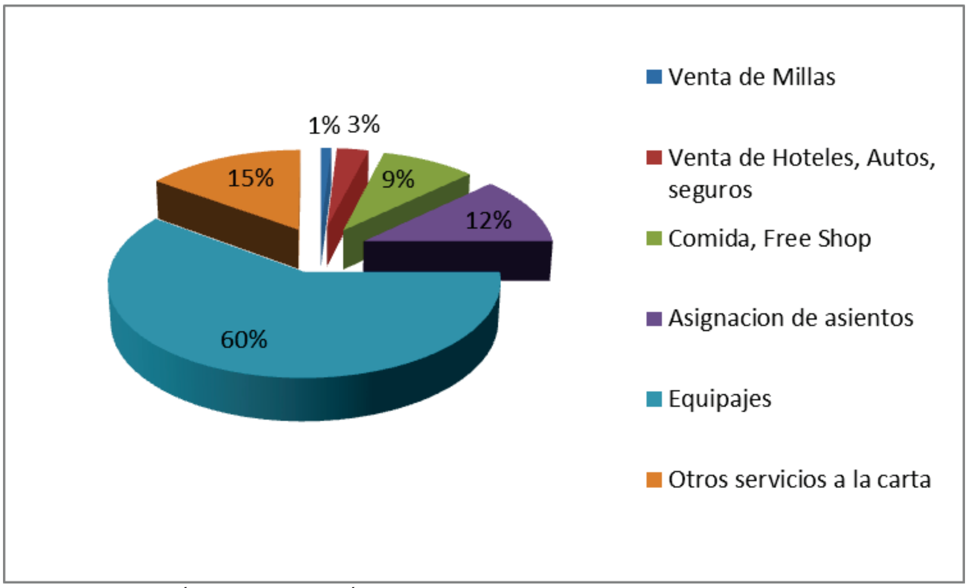

Gráfico 1. Elaboración propia en base a datos de IdeaWorksCompany

Esta Consultora instala la idea de que las aerolíneas que desagregan sus servicios acceden a una mayor liquidez, cuando en realidad la mayor parte de ellos se obtienen al momento de la emisión del billete y son servicios que anteriormente se incluían y ahora se desagregaron para mostrarse aparentemente más baratas.

En el último lustro hubo un aumento mundial de pasajeros cercano al 40% en un contexto de crecimiento del PIB de solo casi el 5%. Los ingresos por servicios auxiliares de las aerolíneas se incrementaron el 118% en ese mismo período, al tiempo que las aerolíneas que los han adoptado se han duplicado.

Lo mismo sucede con la participación de los ingresos auxiliares en los ingresos totales de las aerolíneas, un poco más del 5% en 2013 al 11% en el 2018.

Sin embargo, los ingresos totales de las aerolíneas apenas aumentaron el 12%, lo que permite inferir que el precio de los pasajes aéreos ha ido a la baja en los últimos 5 años, como se desprende del análisis de los datos de la Tabla Nro. 1.

Conceptos en miles de millones	2013	2018	% Variac
Ingresos Globales	720	812	12,78
Ingresos Auxiliares	43	93	118,08
Pasajeros transportados	3.048	4.257	39,67
PIB	77.219.000	80.935.000	4,81

Tabla 1. Fuente: Elaboración propia en base a IATA, IDEA WORKS COMPANY y el Banco Mundial

Es decir, la estrategia de marketing pareciera estar dando resultado, en un contexto de mayor desregulación, el cual es difícil de mensurar su impacto; y en el orden de que las TIC´S han evolucionado hasta estar presentes en el bolsillo de cada pasajero. Para las aerolíneas se hace necesario mostrar tarifas más bajas, en mercados de orígenes y destinos con fuerte oferta y demanda.

La tendencia generalizada de buscar nuevos modos de generar ingresos más allá del billete, implica un mayor uso del teléfono móvil al punto que las aerolíneas han pasado de pedir a los pasajeros que apaguen los móviles, a que paguen con ellos todos los servicios auxiliares posibles.

De acuerdo al trabajo de campo realizado en Aeropuertos de la Ciudad de Buenos Aires, se colectaron encuestas de un tamaño de muestra tal que, por principios estadísticos, definen una tendencia concluyente.

En el trabajo realizado se buscó conocer la opinión de los usuarios de transporte aéreo frente a este nuevo escenario en el que las aerolíneas desagregan servicios para convertirlos en ingresos auxiliares y la consecuente experiencia de compra actual.

Cuando a los encuestados se les preguntó qué consideración les merecía el actual escenario de desagregación de servicios por parte de las aerolíneas, el 70% considera negativamente que así sea, conforme se observa en el gráfico Nro. 2.

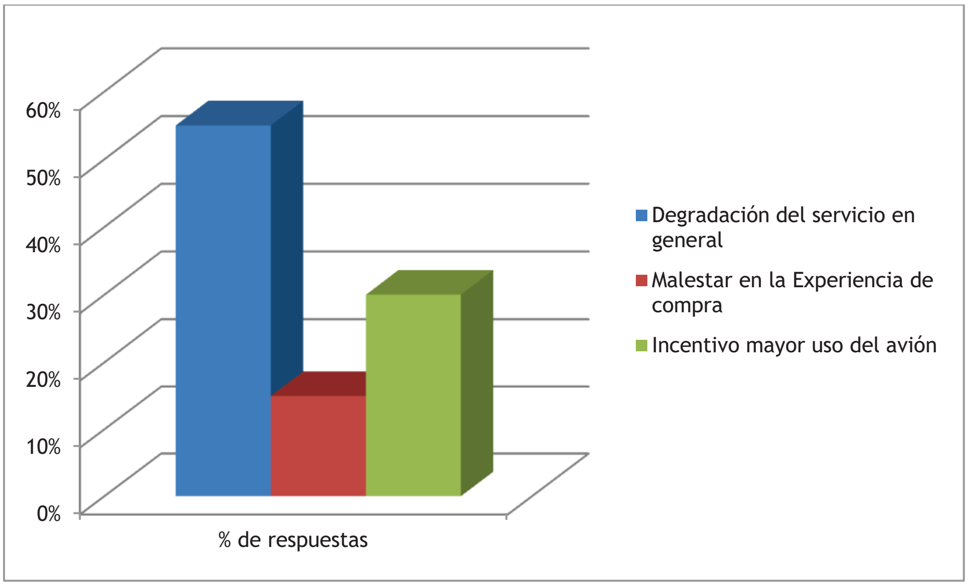

Gráfico 2. Fuente: Elaboración propia en base a encuestas

A pesar de ello, en el Gráfico Nro. 3 se observa que casi dos terceras partes de los encuestados, conocen perfectamente bien qué servicios están incluidos en la tarifa que están pagando cuando adquieren un billete de pasaje, lo que demuestra una significativa mejora del deber de información de las aerolíneas y las agencias de viaje.

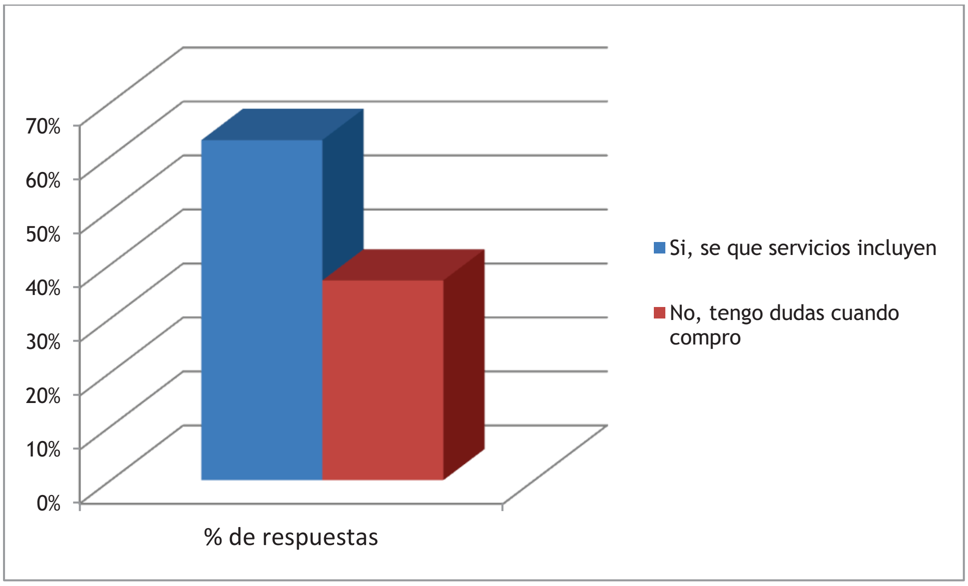

Gráfico 3. Fuente: Elaboración propia en base a encuestas

Pero cuando a los encuestados concretamente se les pregunta si están de acuerdo en esta desagregación de servicios por parte de las aerolíneas, solo el 30% responden afirmativamente, lo que da la idea clara que la opinión de los consumidores no ha sido tenida en cuenta, lo cual queda plasmado en el Gráfico Nro. 4.

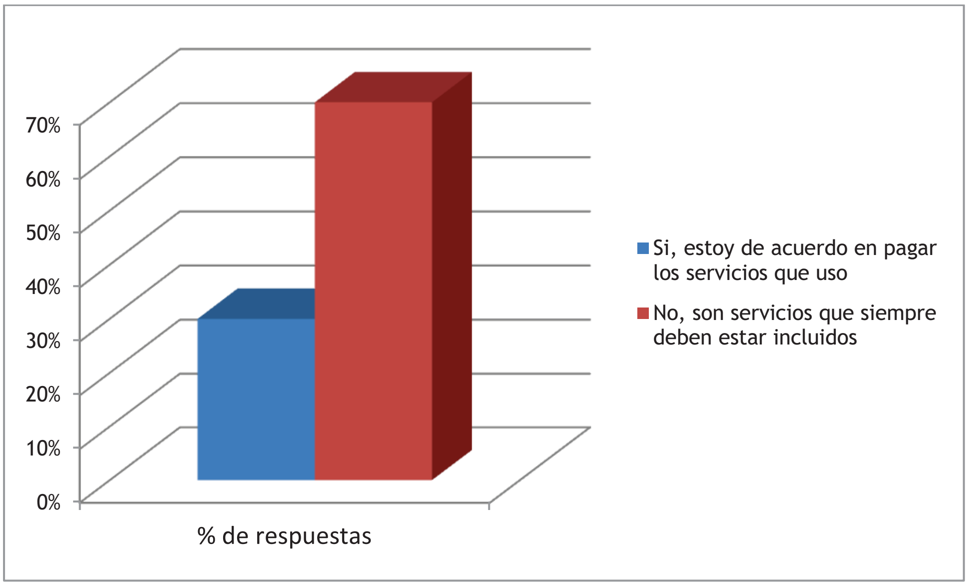

Gráfico 4. Fuente: Elaboración propia en base a encuestas

La literatura especializada presenta ciertas diferencias al definir la satisfacción, sin embargo, cabe destacar que se pueden identificar tres componentes generales en la satisfacción: es una respuesta (emocional, cognitiva y/o comportamental); la respuesta se enfoca en un aspecto en determinado (expectativas, producto, experiencia del consumo, etc.); y finalmente, la respuesta se da en un momento particular (después del consumo, después de la elección, basada en la experiencia acumulada, etc). De allí que se pudiera tener un primer acercamiento al término de satisfacción al entenderla como una respuesta generada en el individuo bajo un contexto determinado en un momento, también, particular.

Los consumidores pueden sentirse satisfechos con un determinado aspecto de la experiencia de elección o consumo, pero insatisfechos con otro, en este caso la satisfacción y la insatisfacción son entendidas en dimensiones diferentes (ej.: una persona puede estar satisfecha con la funcionalidad del producto pero no estarlo con la experiencia de compra del mismo, servicio mal prestado). [4]

Tanto es así, que en Europa se viene palpando un cambio de prioridades de parte de los usuarios, es decir, el precio ha dejado de ser determinante en la elección de una aerolínea. Este cambio sumado a el aumento en el precio del combustible y las presiones salariales, ha hecho que las principales aerolíneas de bajo costo lentamente adopten prácticas de compañías tradicionales para mantener su vigencia y hasta incluso para sobrevivir. [5]

Es ciertamente curioso, mientras esa conversión sucede en Europa, las prácticas comerciales de las low cost están en auge en paises como la Argentina.

CONCLUSIONES

La llegada de las aerolíneas low cost a Latinoamérica obliga a las aerolíneas tradicionales a repensar su modelo de negocio para ser competitivos en el mercado, copiando las prácticas de otras regiones del mundo, sin haber tenido en cuenta la opinión de los usuarios de este medio de transporte.

La estrategia de marketing desarrollada contrasta con la realidad que perciben los usuarios de transporte aéreo. Mientras las aerolíneas difunden la idea de que los pasajeros pagan por los servicios que utilizan, así volar es más económico, se percibe de parte de los usuarios un nivel alto de insatisfacción.

Los pasajeros sostienen que a igualdad de servicios que las aerolíneas prestaban, la tarifa promedio se mantiene, habiendo complejizado el proceso de compra, motivo por el cual manifiestan una degradación del servicio en general.

Este nuevo modelo no implica una baja en el precio de la tarifa, como se ha difundido a la opinión pública, sino en una nueva modalidad de compra.

Este desdoblamiento ha permitido que las aerolíneas tradicionales capten pasajeros que elegían otros medios de transporte, en tramos relativamente cortos, donde los pasajeros no demandan más que el servicio de transportarse.

La experiencia de los pasajeros a la hora de comprar un billete de avión es frustrante actualmente. Sigue habiendo dudas respecto a qué servicios están incluidos en la tarifa.

El avance de las TIC´S le ha dado a los pasajeros un acceso a la información de ofertas que conduce a las aerolíneas a desdoblar la tarifa, desagregando muchos de los servicios que siempre estuvieron incluidos, con el fin de ser competitivos.

El aumento de los ingresos por servicios auxiliares no ha mejorado significativamente los ingresos totales de las aerolíneas, como la industria intenta mostrar.

No se observa que la implementación de los ingresos por servicios auxiliares sea un factor determinante para el desarrollo del transporte aéreo.

Por el contrario, en todos los mercados donde los Servicios auxiliares se han implementado, el desarrollo del transporte aéreo obedeció estrictamente a una flexibilización en las políticas públicas de transporte para que más jugadores ingresen en los mercados, con más libertad para acceder al mercado de Capitales, más libertad para hacer negocios y más libertad de precios.

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RED IBEROAMERICANA de investigación en transporte aéreo

RIDITA

Air Transport Sustainable Development Social and Environmental Strategies

Air budJet: a VTOL virtual operator company in Portugal

Manuel Mendes Duarte - m_m_duarte@hotmail.com
University of Beira Interior, Covilhã, Portugal
Maria E. Baltazar - mmila@ubi.pt
University of Beira Interior, Covilhã, Portugal; CERIS, IST University of Lisbon, Lisbon, Portugal
Jorge Silva - jmrs@ubi.pt
University of Beira Interior, Covilhã, Portugal; CERIS, IST University of Lisbon, Lisbon, Portugal

Abstract

Creation of sustainable transportation service for a new and virtual airline company that uses VTOL aircraft in order to increase mobility and flexibility in Portugal.

This study started with the VTOL concepts, peripherally and accessibility, and business models and plans reviews. The air service characterization was then carried out using localization and trajectory optimization algorithms, thus allowing to elaborate two applications (software): one for clients to book their flights and another that compiles flight's data booked by clients and optimizes flights routes/trajectories.

With this study, it is possible to depict the viability of the economic-financial results of the new virtual company and the application development results with the optimized trajectories.

The development of this air service will increase accessibility and mobility in all regions of Portugal and companies that cannot afford the costs of executive aviation, too. In order to facilitate the booking of the flights, an application was created for the client in order to optimize the company costs related to this air service, and thus to make the cost of a trip more appealing; a second application was elaborated that optimizes the trajectories of the aircraft.

Keywords

VTOL Aircraft; Business Model and Plan; Peripheral Regions; Network Optimization

Air budJets: a VTOL virtual operator company in Portugal

1 - Introduction

In the last decades, there has been a migratory increase from peripheral areas to large urban areas, a behavior conditioned by natural and human factors. It is, in fact, on the coast that most of the cities are located, becoming true poles of attraction and population establishment, for the job offer, generated by the intense commercial and industrial activity and by the many services and facilities that are provided to its population. New transport networks were built (not only at the road level but also at sea and air) that allowed these centers to become ones of attraction and fixation of companies (which activity and contacts became facilitated). Increased population in large cities, because of business growth and increased employment, contributes to increased road traffic, air pollution, noise, road accidents, travel time within cities, among other factors. On the other hand, there are, however, companies that by specific factors are attracted to the regions away from the large urban centers – the peripheral regions. In the absence of transport networks as big as the ones offered at large urban centers, firms located in peripheral regions are faced with the obstacle of distance to external markets. A new means of transportation has been developed in recent years and promises to reach the market very soon, Vertical Take-Off and Landing aircraft (VTOL), that will revolutionize the concept of aviation in the world. These aircraft will be essential to develop a new concept of executive aviation. Thus, in this work, we present a possible solution that will improve the mobility and speed of movement of companies located in large urban centers and peripheral regions.

The main objective of this paper is to present a virtual company that operates VTOL aircraft, ensuring the technical and economic viability of the resulting business plan. There is also a set of sub-objectives that we want to accomplish: to calculate the ideal location of VTOL parking bases, to design two applications for flight booking and to optimize the trajectories, and to create a model and a business plan for a sustainable service of VTOL.

2 - State of the art

Vertical take-off and landing aircraft (VTOL)

The development of technology is progressing rapidly, especially technology linked to the aircraft industry and the development of passenger drones and "traditional flying cars". These vehicle concepts have been developed since the 1980s and there are already several prototypes, most of which can take off and land vertically. A VTOL vehicle is an aircraft that takes off, flies and lands vertically, with no runways needed. For this project, the definition of VTOL excludes any type of helicopter. Although traditional helicopters operate in the same way, most are poorly energy efficient. Many companies are currently focused on electrical or hybrid-electric designs with VTOL capabilities. These vehicles, popularly called "flying cars" or passenger drones, are designed to [1]:

- Accommodate between two and five passengers or the equivalent load weight;
- Be highly energy-efficient, with low or zero emissions;
- Be quieter than a traditional helicopter.

Despite the technological progress and many potential applications of these aircraft, there are several challenges to be considered such as regulation, certification, infrastructure, and air traffic management.

Regulation: From the regulatory standpoint, the Federal Aviation Administration (FAA), as other equivalent agencies around the world, and transportation regulatory agencies need to assess the requirements for these types of transportation: Is a pilot license required? What airspace can these occupy? What are the airworthiness requirements of the vehicle? There has been progressing since the FAA has already begun discussing certification options with some manufacturers and believes that initially these vehicles should be manned, then autonomously assisted and then converted into a fully autonomous aircraft at a later stage [1].

Technology: In terms of technology, there are several considerations for manufacturers of VTOL's [1]:

- In a GPS denial environment, these vehicles would need sensors on board, such as radar, optical and geolocation sensors. Although these technologies exist and are being used in autonomous cars, they would have to be enhanced to provide the long-range sensing and recognition capabilities required to handle the multidirectional and convergence speeds associated with autonomous flight;
- These vehicles would require advanced technologies, such as artificial intelligence and cognitive systems, to enable advanced detection and prevention capabilities. Machine learning can be essential as operations go from piloting to autonomous: a vehicle would need to learn from the pilot's actions for thousands of operating hours to become fully autonomous over time;
- Energy management is crucial: carry a load of energy enough to carry passengers or cargo, maintain a margin of safety and recharge for the next flight. While battery technology is improving rapidly to increase passenger and cargo capacity and extend the ranges of passenger drones, it needs to improve further, or alternatives will have to be found.

Infrastructure: A broad network of vertiports would require new infrastructures or modify and prepare existing infrastructures such as heliports, roofs of large public buildings and unused land. To create a truly unified traffic management system, it may be necessary to install additional infrastructure along predefined flight corridors to assist in high-speed data communication and geolocation [1]. Figure 1 illustrates an example of integrating a VTOL transport network into the urban environment and the infrastructure used.

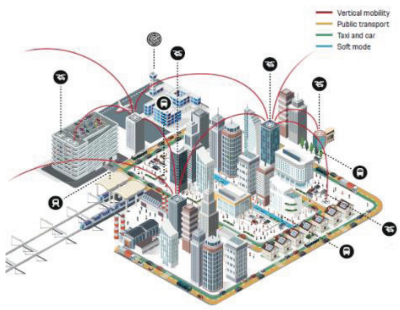

Figure 1: Example of integration of a VTOL transport network in urban areas. Source: [2].

Air traffic management: A robust air traffic management system would have to ensure safe and efficient VTOL operations, which would meet the requirements of the FAA and the European Aviation Safety Agency (EASA).
Safety: For VTOL's adoption of passenger scale, operators of these vehicles would need to demonstrate a near-perfect safety record, covering both mechanical integrity and safe operations.

Peripherally and accessibility

Geographic approach of periphery: From the geographical point of view, the periphery can be considered as the location beyond the range that limits an area, precisely at the maximum distance from the respective geographic center. However, and regarding regional development, the periphery should also reflect the distance to the most relevant economic activity/activities in the region, country, or even a group of countries [3]. In this sense, the periphery is marked by both the physical configuration of the territory and the geographic distribution of economic activities within it. That is: from the relationship with regional development it is observed that the periphery is synonymous with relative accessibility - or inaccessibility, to the economic activity, as it is distributed geographically throughout the territory [3].
Economic approach of periphery: The conditions of relative centrality or periphery influence the industrial sector, both regarding investment decision-making and regarding competitive efficiency. In other words, variations in the periphery degree are reflected, in the direct ratio, in distance costs. The simplest way to assess distance costs in peripheral regions is to analyze

the costs incurred by companies in, for example, transporting products to the market and accessing services and/or materials. These costs are lower for businesses located in the center. Transport costs are not the only costs attributable to the distance in peripheral regions, considering technological advances in recent years, telecommunication and access to information costs are further examples of what these regions must endure at higher levels than in central regions. Increased economies of scale (coupled with progress towards full European integration) also end up influencing the Center-Periphery relationship in areas such as industry growth and regional economic development. Central location, as it facilitates contact with broader market areas, leads - as a rule, to economies of scale in production, lower product costs, and significant sales increases. Companies located in central regions may also incur higher costs related, for example, to labor or value of space, against those in the periphery [3].
Accessibility: The concept of accessibility is intrinsic to the periphery. Accessibility translates the relevant opportunities for interaction between companies and industries, distributed and confined to a given space. Reflecting the costs inherent to the distance in monetary terms, access time to the information, organizational adjustments, and other terms end up marking the differences between the region's degrees of economic activity. The term accessibility closes (at least) two concepts: location and market potential (or economic), any significant enough so that it does not go unnoticed in the approach to the theme that we intend to do [3].
Market Potential: Simplistically, the designation of market potential is closely linked to the concept of population density [3]. If we look at the distribution of the main urban centers in Portugal (or if we look more closely at the population density of the country), easily we can conclude that a large part of the population is concentrated on the coast (except for the Alentejo coast). Moreover within a territorial band covering Lisbon, Sintra, Vila Nova de Gaia and Oporto councils [4]. Outside this central nucleus, a considerable number of regions (Cascais, Loures, Braga, and Matosinhos) with high population emerge. Outside this ring, in turn, we find other critical territorial spaces that assume specific relevance in the national context, such as Amadora and Almada [4]. This irregular distribution of the Portuguese population is conditioned by natural and human factors. However, more than natural factors, human ones are currently those that best explain the regional asymmetries observed in population distribution [5]:

- **The job offers:** generated by the intense commercial and industrial activity and by the numerous services and equipment available to the population;
- **The existence of a dense transport network on the coast:** reinforced by port and airport intense activity, is a factor of attraction and fixation of numerous national and international companies that see, in this way, their activity and contacts facilitated, also contributing to fixing the population.

When we look closely at the map of the distribution of purchasing power *per capita* by the municipality and compare it to the population density map by the municipality (Figure 2), we conclude that wealth seems to be concentrated in the central regions.

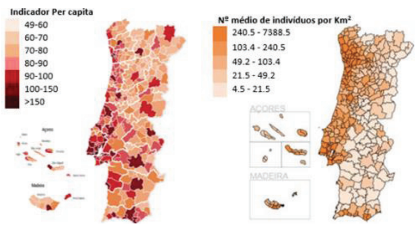

Figure 2: Distribution of Purchasing Power *per capita* by Municipality (left) [6] and population density map by the municipality (right). Source: [7].

Location and Access Time: Until very recently, and with due regard to transport network failures and bad quality of roads, road distance was a tool used to assess market potential in any region, especially on the (economic) cost of market access. Currently, the distance has been relegated to a secondary plan, considering the time of access. The occurrence of this change is due not only to the increase in the quality of the networks but also to the progressive use of various modes of transport and to the variety of goods which have been transported.

Moreover, the access time, we verified the change that this parameter would operate in the traditional model of accessibility based solely on distance. Let us see: specific peripheral regions (island regions, for example) in an analogous situation can benefit compared to others located in continental spaces; especially if island populations use the airplane as a general mean of transport. At the same time, many regions located on the mainland do not have any aerodrome locally open to commercial traffic, being completely dependent on ground means of transport to meet their communication needs, and considerable time is required to travel - by road or by railway. However, this does not allow us to infer that island spaces have (always) good accessibility. They depend on a single mode of transport, with infrequent connections, and on a limited range of destinations [3]. Thus, to evaluate the relative centrality/periphery of a region, we should keep in mind: the volume of economic activity maintained with other regions, including the markets with which goods and services are transacted, sources and opportunities for acquiring raw materials and components, and access to specific information and business activity support services; and regional accessibility face of the economic activity regarding distance costs.

Business models and plan

Business model (BM) concept is relatively new, making its first peek at the beginning of this millennium, during the araising of *e-commerce* transactions. Driving forces such as outsourcing and offshoring procedures, better economic perception and substantial financial restructuration have also boosted BM notions [8]. There is no overall established theory defining business models. Instead, there are several designations proposed by different authors. According to Osterwalder and other authors, a BM is how an organization creates and delivers value to customers, delineating the business logic necessary to generate profit. In other words, BM is commonly associated as the company's blueprint, revealing how an organization does business and interacts with other entities to generate profit. To sum up, a BM is a collection of organizational roles, system functionalities, and detailed mechanisms descriptions and relationships among parties [8]. A business plan describes what the new activity intends to fulfill. They usually have two different uses: inside and outside the company. Inside the company, the plan helps to develop a "roadmap" with the steps to follow while the plan and strategies are implemented. Outside the company, it gives to the stakeholders and potential investors the business opportunity that the company strives for and how it plans to do so [9]. To prepare a business plan, it is necessary to conduct at least three main studies [10]:

- **Market Study:** where a comprehensive and sectoral analysis, a market analysis, a strategic analysis and finally a marketing plan are carried out;
- **Technical Study:** where a production plan or operations and human resources and organizational plan are drawn up;
- **Economic-Financial Feasibility Study:** where an economic-financial plan and a sensitivity analysis are made.

3 - Methodology

Traveling salesman problem

The Traveling Salesman Problem (TSP) is the name that usually occurs to a series of real problems that can be modeled in terms of Hamiltonian cycles in complete graphs. The TSP considers a set of cities - in one of which the salesman leaves (city-based or depot). He must visit all the cities or a subset of them, and the goal is to optimize one or more objectives (distance traveled or the associated costs). TSP is defined in directed and non-directed graphs [11]. The different heuristics procedures to solve the TSP are:

- The Nearest Neighbor Rule (NNR);
- The cheapest cost insertion rule;
- The Lin's r-optimal heuristic;
- Christofide's Heuristic.

The NNR was chosen for this work because it delivers minimal distance traveled. We applied this algorithm in the company application to calculate the minimum cost route, complementing the Clarke and Wright algorithm.

Clarke and Wright algorithm

The problem of determining optimal routes consists of determining routes to be performed by vehicles that, departing from a single location, the depot, will serve the other locations, the customers, with the required quantities of a good and so that the total cost is minimal. The capacity limitations of each vehicle will have to be respected and it is assumed that each locality is served once by a single-vehicle. The management objectives usually relate to the minimization of cost/distance or fleet size. Much of the literature on vehicle routing has been concerned with problems having the following features [12]:

- A single commodity is to be distributed from a single depot to customers with known demand;
- Each customer's demand is served by one vehicle;
- Each vehicle has the same capacity and makes one trip;
- The total distance traveled by each vehicle cannot exceed a specified limit;
- Each customer must be serviced within a specified time window;
- The objective is to minimize the total distance traveled by all vehicles.

The Clarke and Wright algorithm was applied in the application to calculate what was the best routes to take when a VTOL aircraft leaves a vertiport parking spot to transport passengers.

The compensation heuristics

In a location problem, we intend to install equipment in order to best serve a set of communities whose location is known. To solve a problem of location and multiple-choice we use the Compensation Heuristic, which has the following characteristics:

- We admit installing/constructing the equipment/service in all possible locations;
- We determine the costs associated with the movement of each customer to all possible equipment;
- We focus on the set of equipment/movements with lower cost;
- We compare the cost to move each customer from the equipment determined with each one of the other equipment;
- If any cost/change is compensating (a negative value), we admit installing this new equipment too.

We use compensation heuristic to determine the ideal location for the installation of a vertiport parking spot.

4 – Case study

Service characterization

<u>The company</u>: Since the objective of this study is to create an air transport service optimized to operate in peripheral and central regions, this section presents a (fictional) aviation company and the personalized services provided by companies located in Portugal. The company has two objectives. The first one is to revitalize transport in peripheral regions (hard to reach places, where travel time to an urban center and international airports is more than 2 hours), increasing the accessibility of these regions and offering greater flexibility to the companies located there. The second one is to revitalize urban transport in the metropolitan areas of Lisbon and Porto by creating an air transport network in a 100 km area around these cities, allowing users to escape from road traffic and thus save time on their journeys. Therefore, *Air budJets* is an aviation company that offers executive flights of small distance (between 100 and 300 km) and very short distance (less than 100 km). The next examples can help to understand these services:

- **For the first service:** a car trip from Castelo Branco airfield to Lisbon airport takes about 2 hours (120 minutes) with 277 km. If this trip is made on *Air budJets*, we can see that the distance from the trip will decrease to about 188 km (a decrease of 89 km) and will take about 20 minutes, depending on the aircraft used (a reduction of about 100 minutes). Figure 3 shows the routes for this example.

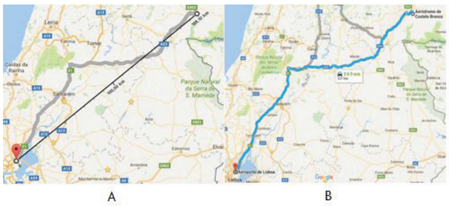

Figure 3: Travel between Castelo Branco and Lisbon Airport by *Air budJets* (A) and by Car (B). *Source:* Google Maps.

- **For the second service**: a car trip from Seixal to Lisbon airport takes about 32 minutes with 29 km. If this trip is made by one of *Air budJets* VTOL aircraft, we can see that the distance from the trip will be reduced to about 15 km (a decrease of 14 km) and would take about 5 minutes, depending on the aircraft to be used (a reduction of about 27 minutes). Figure 4 shows the routes for this example.

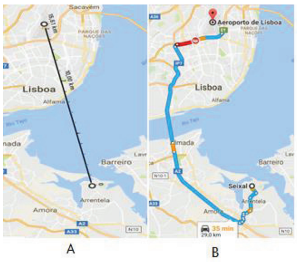

Figure 4: Travel between Seixal and Lisbon Airport by *Air budJets* (A) and by Car (B). *Source:* Google Maps.

Vehicle: German enterprise called Lilium Aviation is working on a 100% electric short-haul private jet that may, at last, fulfill the promise of the flying car. The company was founded in 2015 by a group of four engineers and doctoral students from the Technical University of Munich and developed in a European Space Agency-funded business set up. The company's aircraft concept promises flight without the flight infrastructure. It will require an open space of just 225 square meters — about the size of a typical back garden, to take off and land. The Lilium Jet can cruise as far as 300 kilometers at very brisk 300 kilometers per hour and reach an altitude of three kilometers, and it recharges overnight from a standard household outlet [13]. The Lilium Jet (Figure 5) consists of a rigid winged body with 12 flaps. Each one carries three electric jet engines. Depending on the flight mode, the flaps tilt from a vertical into a horizontal position. At take-off, all flaps are tilted vertical, so that the engines can lift the aircraft. Once airborne, the flaps gradually tilt into a horizontal position, leading the aircraft to accelerate. When they have reached complete horizontal position, all lift necessary to stay aloft is provided by the wings as on a conventional airplane [13].

Figure 5: Lilium Jet aircraft (Lilium GmbH, 2018). Source: [13].

The beauty of this system is its simplicity. In comparison to existing concepts, Lilium Jets require no gearboxes, no foldable or variable pitch propellers, no water-cooling, and no aerodynamic steering flaps; just tillable electric engines [13]. The Lilium Jet has the highest possible structural efficiency. As it can provide differential thrust from the engines in cruise flight, no stabilizing tail is necessary. The design of the electric engines ensures a very low drag coefficient in cruise flight, leading to a higher speed and range. The energy consumption per seat and kilometer thereby becomes comparable to an electric car, but the jet is 3 times faster. The Lilium Jet uses an integrated high-lift system. The objective is to increase the lift of the wings even at low speeds to save energy. While hovering is very energy-consuming, as an aircraft must provide thrust equal to its own weight, the dynamic lift of wings consumes much less energy to stay aloft. So, it is important to create as much dynamic lift from the wings as possible, even at very low speeds [13]. As the engines always maintain attached flow on the surface of the flaps, the Lilium-Jet is highly maneuverable in any flight condition. It can do climbing, curves and high-rate sinking in any phase of a transitional flight. This feature is highly important when flying in narrow corridors in urban areas or for avoiding unexpected objects during a transition flight [13].

Trajectories: As previously stated the first *Air budJets* service aims to increase urban mobility within major cities. Therefore, to determine the advantages that the VTOL aircraft have in relation to the other transport modes, distance data were collected between several locations in three regions of Portugal: Lisbon, Porto, and Coimbra.

Location of *Air budJets* bases in each region: To land and take off the Lilium VTOL aircraft requires a space of 15m by 15m minimum, or 225m^2. In addition, it will be necessary to build facilities to store the aircraft, recharge the batteries or exchange passengers. For this, 3 different types of infrastructure were defined [14]:

- Vertiport parking spot: with the ability to land and take off, it allows the recharge of the batteries or exchange and still parks several aircraft;
- Vertiports: they have space to land and take off, allows the recharge of the batteries or exchange;
- Vertistops: they only have the space to land and take off, to leave passengers or goods.

By applying the compensation heuristic to each of these regions we determine the ideal location for the installation of a vertiport parking spot. The optimization of transport networks is fundamental to increase the efficiency of complex transport systems. Given several possible locations for vertiports and vertistops (locations where VTOLs can land and take off), choosing their location from a subset of these possible locations will have specific implications on installation and transportation costs. This choice will also be influenced by the total number of the population served by the VTOLs and their suitability over other means of transport. Thus, with the compensation heuristic, it was possible to determine that the best location of *Air budJets* base/vertiports parking spots for the regions of:

- Lisbon was Almada;
- Oporto was Penafiel;
- Coimbra was Coimbra.

Optimization of *Air budJets* routes: Since it is intended to connect by air the previous sites of the three Portuguese regions, it is necessary to optimize the routes that the aircraft will use to reduce the cost associated with their displacement. For this purpose, two applications have been developed: one for the client to enter the data of his trip, namely the place of departure, arrival, day and time and if he wants to share the flight or prefers to do the direct flight; and another application that checks if there are two or more customers who want to travel in a short time and do not mind sharing the flight. For the sharing flights, it calculates the best route using the Clarke and Wright heuristics and, if necessary, the heuristic of the traveling salesman. This application will facilitate the elaboration of the routes. That is, is possible to calculate all the possible routes, the associated costs and the time spent. As previously mentioned, the second service will allow trips of distances up to 300km. From cities located on the periphery of Portugal, it is possible to connect a large part of the western territory in Spain. Thus, the cities of Bragança, Covilhã, Évora and Vila Real de Santo António (V.R.S.A) will serve as points of connection among the regions of Porto, Coimbra, and Lisbon with other cities in Portugal, and several cities in Spain. This will also allow a greater speed of access between the respective cities of the periphery with the central cities of Portugal and important cities of the western region of Spain. The mapping of the connection routes between Lisbon, Porto, and Coimbra with Bragança, Covilhã, Évora and V.R.S.A and the western region of Spain is shown in Figure 6.

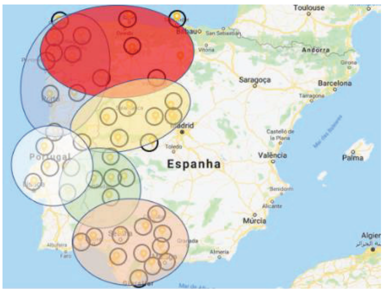

Figure 6: Mapping of routes with a distance greater than 100km from *Air budJets*. *Source:* own elaboration.

In turn, the second service of *Air budJets* will be short-haul flights (up to 300 km): this will allow difficult-to-reach and localized regions at great distances and large travel times to have greater mobility and faster access to services essential for their development. To recharge the aircraft to be able to return to the respective vertiport parking spot, all locations that are more than 150 km from vertiports parking spot have the possibility of recharging the batteries and back. To determine the cities with vertiports, the distances between all the cities were calculated and in order not to exceed the value of 300 km of VTOL autonomy.

Business model

We have filled out the information required to produce an *Air budJets* business model canvas, as in Figure 7.

Customer segments: This component of canvas defines the different groups of people or organizations that a company seeks to reach and serve [15]. Customers are fundamental to the survival of companies and so to better satisfy them a company needs to group them into distinct segments, each with common needs.

Value propositions: The value proposition component describes the set of products and services that create value for a specific Customer Segment [15]. With a combination of customer-driven elements, values can be quantitative (e.g. price, service speed) or qualitative (e.g., design, customer experience). The value propositions are mainly represented by mobility, speed, low price, straight transport, accessibility, and convenience.

Channels: Communication, distribution and sales channels make up the company's interface with customers. Channels are the point of contact for customers and play an important role in their overall experience [15]. The channels will consist of awareness, commercials, website, application, and events.

Customer relationships: The customer relationship component describes the types of relationships a company establishes with specific customer segments. A company should clarify the type of relationship it wants to establish with each customer segment. Customer relationships will be made through dedicated personal assistance, automated services such as a website and an app.

Key resources: This building block states the most crucial assets to make the business model function, this is, the resources for the company to create and offer a value proposition, reach markets, maintain relationships with customer segment and earn revenues. Human resources include pilots and co-pilots, loadmasters, technicians, maintenance personnel and ground crew.

Key activities: They are the most important actions that a company must perform to operate successfully. Like key resources, they are needed to create and deliver the value proposition, reach out to markets, maintain customer relationship, and make a profit. Key activities are essential to keep aircraft airworthy, keep routes optimized and aircraft distribution balanced.

Key partnership: This building block illustrates the partner and suppliers' network necessary to make this business feasible. The key partners block shows how relevant it is for a company to form partnerships to improve their business models and reduce risk. Thus, this study must take in consideration VTOL's manufacturers, marketing companies, takeoff and landing places.

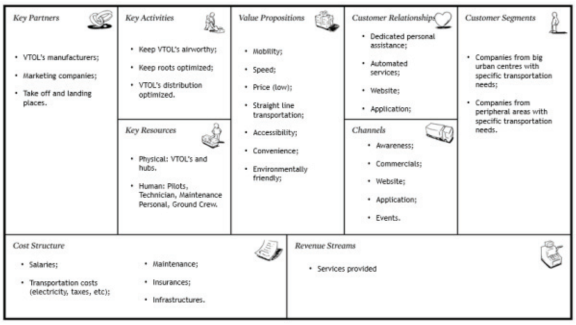

Figure 7: Business model canvas filled. Source: own elaboration.

For the preparation of the business plan of *Air budJets*, a programmed excel document was used, made available by Professor António José Pires, from Institute for Small and Medium-Sized Enterprises and Innovation (IAPMEI), to assist in the creation of this business plan. Because this excel has a very large size, this is not included in this paper. As necessary inputs we consider the revenue streams and the cost structure, which include the vehicle operation, vehicle acquisition cost, vehicle life, piloting and avionics costs, infrastructure burden, vehicle maintenance costs, chargers, and indirect operating costs. As such, we assumed assumptions, the necessary inputs and finally the outputs and related results. A small part of the necessary variables to create a business plan are shown in table 1.

Table 1: Some variables from the business plan. *Source:* own elaboration.

Inputs / Activity year	2026	2027	2028	2029	2030	2031
Income: Services	4 064 640	4 485 600	5 692 800	6 589 200	6 760 320	6 913 920
Energy (Electricity)	366 796	372 297	377 882	383 550	389 303	395 143
Maintenance of VTOL's	256 307	260 152	264 054	268 015	272 035	276 116
Aircraft (paid in 12 years)	12 126 413	-	-	-	-	-
Batteries (payable in 5 years)	563 687	-	-	-	-	-
Infrastructures (paid in 25 years)	3 690 000	-	-	-	-	-
Other Costs	4 687 213	1 017 109	1 017 671	1 018 216	1 018 768	1 017 362
Financing / Year of activity	2026	2027	2028	2029	2030	2031
Investment = Fixed Capital + FMN	20 755 226	0	0	0	0	0
Cash flow	0	2 319 625	2 301 939	3 157 764	3 502 443	3 529 932
Associated interest rate	8,85%	---	---	---	---	---
Results / Year of activity	2026	2027	2028	2029	2030	2031
Services provided	4 064 640	4 485 600	5 692 800	6 589 200	6 760 320	6 913 920
EBITDA	2 257 431	2 583 301	3 780 388	4 575 322	4 827 223	4 970 247
NET INCOME FOR THE PERIOD	-437 727	-111 856	1 067 227	1 674 558	1 970 017	2 177 489

5 – Discussion of the results

App's development

As mentioned earlier, the technology associated with this service is sustained in the development of two applications: the application of the client and the application of the company. When the client initializes the application, a first page is opened (Figure 8) where he can choose the type of flight: private or shared flight.

Figure 8: Client's application: first page - private or shared flight. *Source:* own elaboration.

Source: own elaboration.

Private flight (Figure 9) allows a direct flight with the number of passengers that he wants, choose the date and time of flight and the places of departure and destination. The shared flight allows a shared flight, provided that the total number of passengers is less than 4, where it is possible to choose between one of the already marked flights or to choose a new flight. After choosing the type of flight, he will be asked to fill out a form with data related to the flight.

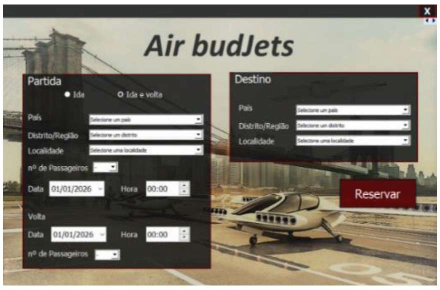

Figure 9: Client's application: Form - Private Flight. Source: own elaboration.

After fulfilling the requirements, it is then possible to book the flight by clicking the reserve button; all data is stored in a database. In the case of being a shared flight (Figure 10), the presentation is different as it can be seen in Figure 10. When the fields are filled in, a table is displayed showing the flights already reserved for that destination, and if the client wishes, he can choose to select that flight, sharing it with the one who booked it, thus reducing the cost of the flight. If he doesn't want to do that, the customer can fill out the form with the data that he wants and book a new flight. In turn, this new flight will be visible in the table of reserved flights. With the collection of all flights marked (inputs), the company's application goes into operation. This application can be divided into two parts, the business part, and the user part. The part of the application business is the part that applies the algorithms of optimization of trajectories and optimizes the optimal trajectory. On the user side, as shown in Figure 11, one can see from the upper right a list showing all reserved flights. As we fill in the information of the date, time and place of departure, this list is filtered according to the submitted information, appearing only flights with these characteristics. Finally, in the lower part of Figure 11, one can see the information on the optimized trajectories. Showing, in the end, the result of the shared flights already optimized, is possible to visualize the optimal trajectory.

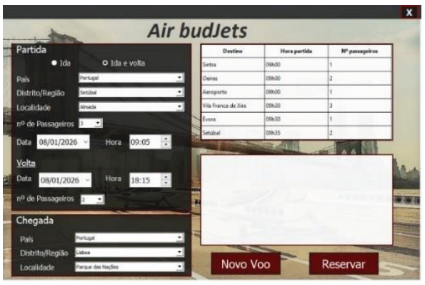

Figure 10: Client's application - form for a shared flight. Source: own elaboration.

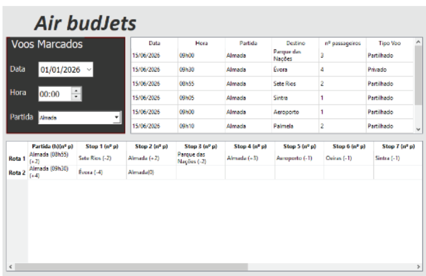

Figure 11: Company application. Source: own elaboration.

Business Plan

The income statement is the report that shows us the details of income and expenses over a certain period of time. It gives us the information if the company during that period had profit or loss. Looking at the results of the 5-year period, we observe that although we have a negative net result during the first two years of activity, i.e. the company will suffer losses in these two years of activity, it is expected that from then these values will be positive, that is, the company will profit in the third, fourth and fifth year of activity. We can see that there will be a positive evolution over the years, which reinforces the importance of this project. From the project's point of view, we can see that the cash flow available to be distributed among all the holders of company financing sources has a growing tendency, being negative in the first year of activity, but positive in the following. The WACC is used for two important functions in financial management: to calculate the value of the company when used as the discount rate of future cash flows, and to evaluate the viability of new projects, operating as "minimum rate" to be exceeded to justify the investment. The updated flows refer to the cash flow in the company cash, that is, to the amount of cash received and spent by a company during a defined period of time, in this case annually; in the example of *Air budJets* we have a negative updated flow in the first year and positive in the following. In turn, the cumulative updated flows are negative up to 5 years of activity, going from positive to negative in that year. The sum of all inflows and outflows of money over the life of an updated project for the present moment is given by the VAL, totaling 3 815 286€. The Internal Rate of Return (IRR) is an indicator used to measure the profitability of investment projects. The higher the IRR, the greater the project's profitability. As the IRR is superior to the WACC, the project is viable [16]. Finally, we note that the payback period is 5 years.

Comparison between actual transportations and Air budJets transportation

By examining all cases, travel times would be greatly reduced if transportation was done on a VTOL aircraft. It should be noted that:

- In the case of VTOL's, we considered the time of taking off and landing, as such, we assume 3min of duration;
- Cruising speed of 240 km / h for distances exceeding 20 km, and 150 km / h for distances up to 20 km; the maximum speed of 300 km / h was not considered;
- The price per place is considered if the vehicles are at their maximum capacity, i.e. 4 passengers in the taxi, 5 people in the car, 4 passengers in VTOL.

Within the examples of travel/travel possibilities, there is some information that should be highlighted due to their characteristics. The following example was chosen because they showed a journey from the periphery to the coast within Portugal.

Table 2: Example of a trip from Covilhã to Lisbon airport. *Source:* own elaboration.

Departure City	Arrival City	Transport type	Km	Time	Price	Price per seat
Covilhã	Aeroporto Lisboa	Train + Subway	-	3h55	18,80 €	18,80 €
		Bus + Bus	273,57	4h23	18,20 €	18,20 €
		Car (consumption: 5l/100km)	271	2h30	51,35 €	10,27 €
		Taxi	271	2h30	258,25 €	64,56 €
		VTOL (Year 1)	215,23	00h57	170,03 €	42,5 €

6 – Conclusion

It was possible to create two applications (APPs), one that allows the customer to book the flights and another for the company to register the flights and optimize those that are possible. The economic-financial study of the business plan shows great profitability and the sustainability of the business developed. The sum of all inflows and outflows of money over the life of an updated project for the present moment is given by the VAL, totaling € 3 815 286. We can also see, that the payback period, that is, the period that the project takes to generate earnings is 5 years. In the development of the application, some difficulties arose due to the quality of the computers on which we developed the software, making the whole process of

compiling and testing the software slower. Consequently, it was not possible to test the software for most of the locations we wanted, and thus the simulation was done only in the Lisbon area. When comparing the transport done by a VTOL aircraft with other means of transport, the travel time is much lower when done by a VTOL, being the price quite competitive when compared to a taxi, but much higher than the other modes of transportation. such as the bus, train or personal car.Due to the current work and acquired knowledge and experience, it's believed that the next steps in this work should cross the following research lines:

- Increase *Air budJets'* operating area throughout all the Iberian Peninsula and other locations around South (Mediterranean) and West Europe region;
- Improve application by adding other (or replacing the referred) route optimization algorithms;
- Optimize the business plan with the use of more aircraft and more vertiports/vertistops to decrease the price per km

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Pilots performance and flight safety: the case of cognitive fatigue in un-pressurized aircraft cabins

João Artur de Freitas Rocha - joaoarturfr@hotmail.com
University of Beira Interior
Jorge Miguel dos Reis Silva - jmrs@ubi.pt
University of Beira Interior; CERIS/IST, Universidade de Lisboa

Abstract

The purpose of this study is to understand the impact, evolution and perception of cognitive fatigue as a contributory factor on the occurrence of incidents and accidents, on unpressurized aircraft.

This study use the science principles present in the Fatigue Management Guide for Airline Operators (FMG) [1] to evaluate data obtained by four methods of measuring cognitive fatigue [2] These consist in two objective measures, Psychomotor Vigilance Test (PVT) and an actiwatch (Readiband 5), and two subjective measures Samn-Perelli 7-point fatigue Scale (SPS) and sleep diaries. It is also obtained results from a survey related to this theme.

From this research are draw conclusions of the influence and evolution of cognitive fatigue on the operations of unpressurized aircrafts and it is understood the difference between perceived cognitive fatigue and the real cognitive fatigue accumulated by the pilot. Is also drawn findings from a launched survey related to this theme.

In this case study the focus will fall upon general aviation where there are no way to control and monitor the fatigue element, the cause of most incidents and accidents that occur in Portugal as concluded by analyzing several GPIAAF final reports using HFACS [3]. Normally this type of research is conducted within airline operators, that are already a very restricted and controlled domain of civil aviation, instead of within general aviation.

Keywords

Cognitive Fatigue; Human Factors; Accidents Investigation and Prevention; Pilots Performance

Pilots performance and flight safety: the case of cognitive fatigue in unpressurized aircraft cabins

I. Introduction

In the early days of aviation, one believed that approximately 80% of accidents were caused by mechanical failures, and the other 20% by human error. Today due to the development of technology and the implementation of better and more rigorous maintenance on aircrafts, mechanical failures only cause 20% of accidents and human error takes the other 80% [1],[2].

In national territory (Portugal), and after an analysis of all final reports of accidents and incidents from 2010 up until 2017, it was easily verifiable that most accidents occur in the domain of general aviation. An in-depth analysis on the data of 66 final reports related to non-pressurized aircrafts and using The Human Factors Analysis and Classification System (HFACS) concluded that 81.82% of the final reports had indices of Human Factors (HF). On the premises of the results obtained and displayed above, came to our attention that HF on general aviation is a subject where there is a lack of studies and regulations.

In this study, the object under evaluation will be the performance of the pilots in non-pressurized aircraft, more specifically the case of cognitive fatigue and flight safety. The objective is to understand the impact of cognitive fatigue as a contributory factor on the occurrence of incidents and accidents, by using the science principles present in the Fatigue Management Guide for Airline Operators (FMG) [3]. It will also be interpreted the evolution of cognitive fatigue, and its impact in the pilot performance throughout the operation of the aircraft; simultaneously it will be drawn a comparison of the fatigue experienced by the individuals that took part in this study and the real deterioration of their alertness measured by the equipment utilized.

II. Methodology

The development of this study began with a literature review of HF and final reports of occurrences from GPIAAF. From the review of the final reports from 2010 to 2017 it was taken the HF that had indices of being present during the accidents and incidents using HFACS. Then, from this review of final reports it was concluded that the HF with more frequency was at the level of unsafe acts that is linked with cognitive fatigue. With this an exhaustive research was made on fatigue, its impact on the operation of aircraft, existing legislation and methods for measuring it (Figure 1).

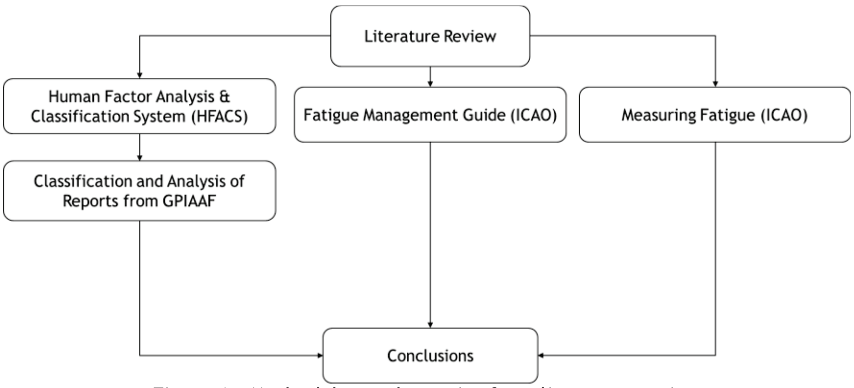

Figure 1 – Methodology schematics from literature review
Source: own elaboration

After gathering all information, a case study was established with an experimental work where were we used 4 methods to measure fatigue: 2 objective measures (Psychomotor Vigilance Task (PVT) and

Actiwatch) and 2 subjective measures (Samn-Perelli 7-point fatigue scale (SPS) and Sleep diaries). An analysis was made to the experimental work results, and from this analysis conclusions were withdrawn to respond to the objectives of this study (Figure 2).

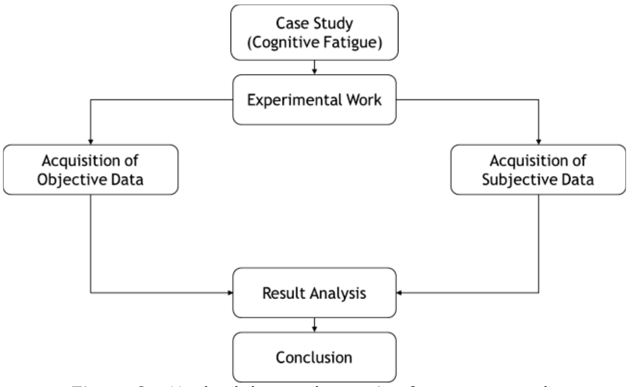

Figure 2 - Methodology schematics from case study
Source: own elaboration

III. The Human Factor in aviation

The human element is indeed the most versatile and valuable factor in the aviation system, but it is also the most vulnerable to influences that affect its performance. When the pilot has these lower performances, it is often classified in several documents as “pilot error”, which indicate where there was a failure, but does not indicate why it occurred or why did the performance of the pilot was not on the optimal level for operation. The HF refers to the individuals daily work situations, relationships with machines, processes, and the surrounding environment. In a more concrete way, it is a science applied to the ergonomics that we normally consider to cover the adaptation to the work or the work conditions, in order to improve the performance of a worker [4].

Although HF are connected to most accidents, the reporting systems are not developed based on them. As a result, most accident databases are not compatible with a traditional analysis of human error, making it difficult to establish an intervention strategy to attenuate the occurred human error. To resolve this problem, a human factor analysis and classification system (HFACS) [5] has been developed, in order to detect the occurrence of HF, therefore allowing an improvement in the investigation of accidents. Based on the concept of active and latent failures [6], HFACS has four levels of failure, Figure 3. In this study the level regarding organizational influences will not be used, because this study only refers the cases of general aviation and SPO of helicopters and airplanes where organizations are not always involved.

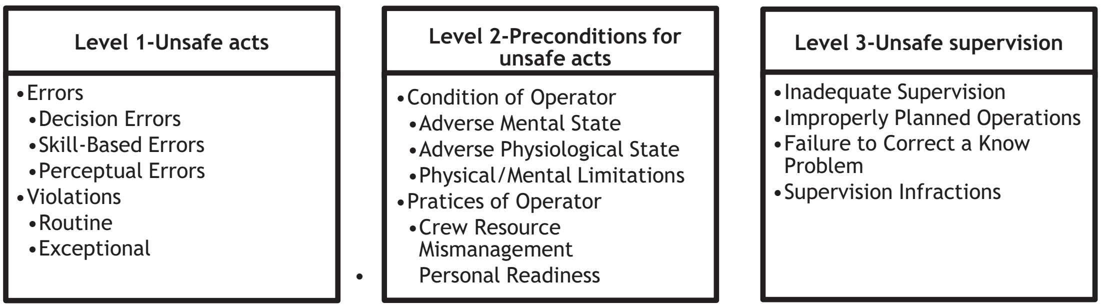

Figure 3 – HFACS levels
Source: own elaboration based on [5]

Statistics of HF in Portugal

The implementation of the HFACS, to the final reports of incidents and accidents of the GPIAAF from 2010 to 2017 [7], allowed the acquisition of the data presented in Table 1. The case studies are only for general aviation and SPO of helicopters and airplanes, where the use of aircraft with non-pressurized cabs predominates.

Table 1 - Classification of final reports using HFACS
Source: own elaboration

Ano	Unsafe acts	Preconditions for unsafe acts	Unsafe supervision	Total
2017	5	0	0	5
2016	2	0	1	3
2015	8	0	1	9
2014	15	1	3	19
2013	1	1	0	2
2012	15	3	0	18
2011	9	8	2	19
2010	67	5	5	77
Total	122	18	12	152

Using the data from the previous table, the following graph (Figure 4) was drawn with the percentage of each level of HF per year. From this figure is perceivable that the cause of most accidents/incidents in Portugal is at the level of unsafe acts that are related to cognitive fatigue.

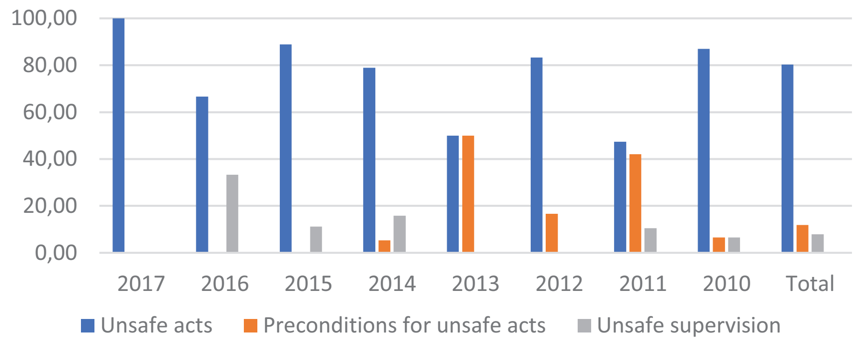

Figure 4 - Percentage of HFACS levels on final reports of accident and incident from 2010 to 2017
Source: own elaboration based on Table 1

This relation to cognitive fatigue is associated to the fact that fatigued people often experience increased Reaction times (RTI), reduced attention, impaired memory, withdrawn mood, inaccurate flying, poor decision making and loss of situational awareness. According to ICAO, fatigue is characterized as a physiological state of reduced mental or physical performance capacity, result of the lack of sleep, prolonged wakefulness, circadian phase or workload (mental and/or physical activity), and may impair the level and the ability of a crew member to operate an aircraft or perform safety-related tasks [8].

So fatigue can be described as a reduced ability to perform operational tasks and can be considered as an imbalance between physical and mental effort of all wake activities (not only those of operation) and recovery from this effort, which requires sleep (except recovery from muscle fatigue) [3]. Mental fatigue, which may include sleepiness, is related to the decrease of attention and ability to perform complex or simple tasks when compared with the regular efficiency of an individual [9]. The fatigue that is studied in this work is that caused by the lack of sleep or inadequate sleep. This type of fatigue is known as "cognitive fatigue" or mental fatigue and is directly linked to reduced alertness, reaction time (RTI), thus impairing the decision making of the operator [10]. Fatigue can be divided into three categories [9], but for this study it is taken in consideration circadian fatigue that is directly related to the circadian body clock [3].

IV.Scientific Principles and Measurements for Fatigue Management

Following the Fatigue Management Guide for Airline Operators [3], there are four focal points on managing fatigue that can be seen on Figure 5.

1-Circadian Cycles and Effects on Sleep and Performance	2-Sleep-Wake Homeostasis and the Sleep Drive	3-Factors that Affect Sleep Quality	4-Influence of Workload on Fatigue
• The circadian body clock affects the timing and quality of sleep and produces daily highs and lows in performance capacity on various tasks.	• Periods of wakefulness need to be limited. Getting enough sleep (both quantity and quality) on a regular basis is essential for restoring the brain and body.	• Reducing the amount or the quality of sleep, even for a single night, decreases the ability to function and increases sleepiness the next day.	• The workload can contribute to crew member fatigue. Low workload may unmask physiological sleepiness while high workload may exceed the capacity of a fatigued individual.

Figure 5 - Points on managing fatigue from the Fatigue Management Guide for Airline Operators - Source: own elaboration based on [3]

An ideal amount of sleep per night may vary between individuals, but it is clear that sleep cannot be sacrificed without consequences. Sleep has a vital role in memory and learning, maintaining alertness, performance, mood, general health, and well-being. So, sleep is one of the crucial points of this study.

Based on the data presented in Figure 4 is easily concluded that the HF most present in incidents and accidents in Portugal is at the level of unsafe acts, but due to limitations on the investigation of incidents and accidents is difficult to affirm that fatigue is the cause of these unsafe acts. The cycle of work\fatigue\sleep is a normal part of a healthy human life, due to changes in the circadian body clock; fatigue appears since most of these changes are associated with sleep. A normal adult is expected to sleep between seven to nine hours uninterruptible a day that should include both Rem (Rapid eye movement) and non-Rem (non-Rapid eye movement) phases. So, is easily understandable that the issue with fatigue is a matter of sleep regularity and quantity/quality; not forgetting that workload is also an important factor and has its weight on fatigue. The fact is that fatigated individuals are often very poor judges at accessing their own state of alertness.

To conduct this study, it was used two types of output data, being them subjective data and objective data. These two types of acquisition give the possibility of having a perception of which is the impairment between the feeling of fatigue and the actual state of the operator. It is used two methods of data acquisition for each type of data – as depicted in Figure 6, taken from the ICAO, Measuring Fatigue, by Dr. Michelle Millar, Technical Officer (Human Performance) [11].

Subjective data	Objective data
• Samn-Perelli 7-point fatigue scale (SPS) • Sleep diaries	• Actiwatch (Readiband 5) • Psychomotor Vigilance Task (PVT)

Figure 6 - Types of data and methods utilized in this study
Source: own elaboration

A. Samn-Perelli 7-point Fatigue Scale (SPS)

This scale is easy and quick to fill and causes minimal disruption during aircraft operation. It is used in many studies, which gives a possible benchmark for comparing results [11]. But because it is a subjective scale, it has some disadvantages, such as easily presenting errors and not always reflecting reliable results, since the human error of wrongfully perceiving fatigue is always a contributing factor [12]. The scale is described from points one to seven as a function of the operating time, the points being marked by predefined periods of time, having the classification as shown in Figure 7.

Samn-Perelli 7-point Fatigue Scale Classification	
	1 - Completely alert, wide awake;
	2 - Very alert, but not at peak;
	3 - Slightly alert, somewhat fresh;
	4 - Some feeling of tiredness, less than fresh;
	5 - Moderately tired;
	6 - Extremely tired, very difficult to concentrate;
	7 - Completely exhausted, unable to react and operate effectively.

Figure 7 - Samn-Perelli 7-point Fatigue Scale Classification
Source: own elaboration

In this case study, the SPS fatigue scale is implemented using the table presented in Figure 8. This table is to be filled during flight with the classification system presented above and taking into consideration the type of flight as shown in Table 2. These rates are given in pre-determined time periods in accordance with the duration of the flight, as depicted in Table 3. In the table to be filled there are spaces too for the input of PVT test results.

Date: Time: Type of flight:

Time:	T1	T2	T3	T4	T5	T6	T7	T8	T9
Fatigue level from 1 to 7:									
PVT test (ms)	Before:					After:			

Figure 8 - SPS fatigue scale table
Source: own elaboration

Table 2 – Fulfilment of SPS table according to the type of flight
Source: own elaboration

Type of flight	Procedimento	
Long	Fill according to the time periods present in Table 4	
Circuit	Stop and go, Full-stop and taxi back	Fill after landing, in the phase of preparation for a new take-off
	Touch and go	Fill after a before the flight

Table 3 – Time periods according to the time of flight
Source: own elaboration

Time of flight	<2 hours	>2 hours
Time period	15 min	30 min

B. Sleep Diaries

The sleep diaries are a useful tool to be used along with other measures to perceive the sensations had by an individual in relation to the quantity and quality of sleep. This type of data permits a comparison between objective periods and quality of sleep, measured by polysomnography or an equal method, and the perceived time and quality of sleep. The diary to be used in this study was constructed based on the sleep diaries of the National Sleep Foundation [13], and contains a section for the input of results from the PVT test.

C. Actiwatch (Readiband™ 5)

Actiwatches are devices capable of monitoring activity, estimating sleep periods and their quality, and various other parameters depending on the device in question. These have advantageous characteristics, such as the fact that they are not intrusive to the operation and are easy to administer. As in the case of the present study, they are used in conjunction with the subjective measures, SPS and sleep diaries to cross data and make conclusions. The Readiband™ 5 captures sleep data with high resolution, using an algorithm that scored as "Sleep" when is detect a minimal activity over a period of time and was validated with an accuracy of 93% when compared to clinical polysomnography [14]. However, since it is difficult to differentiate lying quietly in bed from lying in bed asleep, the algorithm occasionally may slightly overestimate sleep time [15]. The data acquired by the Readiband, is analyzed by the SAFTE™ (Sleep, Activity, Fatigue, and Task Effectiveness) algorithms that uses a person's sleep data acquired by the Readiband™ 5 and analyzes them within the context that is scientifically known about human sleep and fatigue. When a person's accurate sleep data is acquired over a period of days, the SAFTE™ fatigue model applies complex algorithms to analyze it and produce a SAFTE Alertness Score, as in Figure 9. The alert state is the quantification of fatigue impairment, on a scale ranging from 0% to 100%. With this, we can reliably compare effects of fatigue in operational situations as shown in the FAA report, Flight Attendant Work / Rest Patterns, Alertness, and Performance Assessment: Field Validation of Biomathematical Fatigue Modeling [16].

	SAFTE™ Alertness zone	Percentage of time spent in each	Reaction time slowed by	Blood Alcohol Concentration (BAC)	Risk of accident or serious error
High	90 - 100	54.6	5%	0%	Very Low
Reduced	80 - 90	38.1	18%	0%	Low
	70 - 80	7.2	34%	0.05%	Elevated
Low	60 - 70	0.0	55%	> 0.08%	High
	0 - 60	0.0	100%	> 0.11%	Very High

Figure 9 – Example of a SAFTE™ alertness score
Source:[10]

D. Psychomotor Vigilance Task (PVT)

The psychomotor abilities of an individual, relate the cognitive functions with the physical movements. In the PVT test, it is measured the psychomotor speed by looking at an individual's ability to detect and respond to rapid changes in the environment, such as the presence of a stimulus. The PVT is an important tool in determining an individual's alertness by assessing RTI, movement time and vigilance, thus giving a level of impairment. In this study, it is used a smartphone application called Sleep-2-Peak as an evaluation tool of the operator response time.

This application will allow a later comparison of RTI when alert or in the context of prolonged wakefulness, to identify which are the changes related to cognitive fatigue. This test has a duration of 3-minutes, as opposed to the 10-minutes gold standard PVT test, making it easier to apply in studies with short evaluation times. It was already validated that this choice of shorter duration as a low effect on results since on the longer 10-minute test even severely sleep-deprived individuals will be able to compensate by increasing effort, which will result in inadequate performance. Thus, a valid and sensitive alertness test will capture subtle changes in fatigue-related behaviour, even in a very brief period on a task [17].

To start the test, it is only necessary to open smartphone application, click on “Do Test”. After its conclusion the result is written on the referred space of the provided sleep diaries and Samn-Perelli 7-point fatigue scale table.

V. Study Implementation

During the whole period of this study, the individual always kept the watch on the wrist from the beginning, except during the bath or activities that may cause the watch to be in direct contact with water. After three days of sleep data obtained by the actiwatch the SAFTE^{TM} fatigue model can produce alertness score results, after which the period of data collection inherent to this study began. This data was obtained by following a daily procedure repeated from the 4th day of the study until the last one.

This daily procedure began with the completion of the sleep diary part described as “Fill in the morning after waking up”, and the realization of the PVT in which the result is noted in the same sleep diary part. When performing PVT tests, it is only needed to open the application and select the button “start test”. Before the operation of the aircraft a PVT test is performed and as soon as the activity ends. The results from these PVT tests were noted in a designated space on the Samn-Perelli 7-point scale table, as in Figure 5. During the operation of the aircraft, the Samn-Perelli 7-point scale table was filled according to Table 2 and Table 3. This process ends at bedtime with the PVT test and fulfilment of the sleep diary on the part described with “Fill in the evening before going to sleep”, with the result from PVT test and answering to the remaining questions. Figure 10 is a schematic to demonstrate the daily processes realized by our pilots involved in the study.

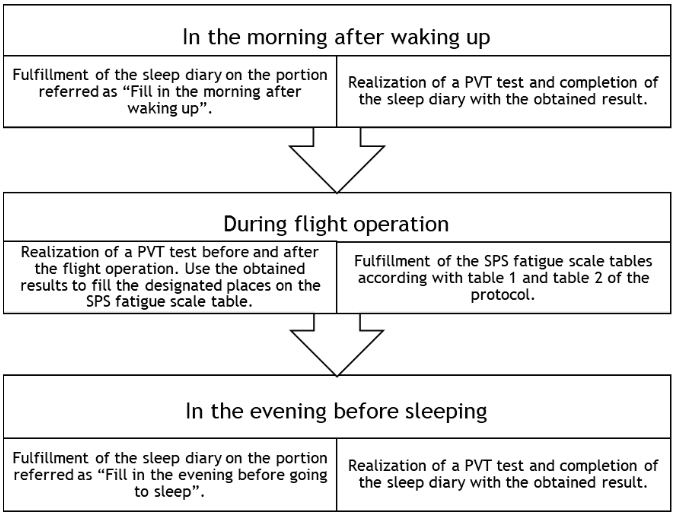

Figure 10 - Daily procedure for each individual
Source: own elaboration

VI.Results and Analysis

Using the methods and their implementation as described above we obtained the results for the study time period, from the three pilots evaluated. With these values and the theoretical information gathered, it was made an analysis of the results. It is used colours to differentiate between good and not so good (bad) values; this set of colours is presented in Table 4.

Table 4 – Set of colours and classification
Source: own elaboration

Colours	Red	Yellow	Green
Classification	Bad	Intermediate	Good

- **Pilot 1:**

The pilot 1 is 33 years old and has 240 flight hours, he does not have caffeine, alcohol or exercise habits. Using the best RTi (223 ms) measured on the PVT tests and assuming it is the fastest RTi of this individual, Table 5 was constructed in order to understand how the values of RTi from the PVT tests influence the risk of accident or serious error.

Table 5 – Risk of accident or serious error classification by RTi (Pilot 1)
Source: own elaboration

Reaction time slowed [%]	RTi [ms]	Risk of accident or serious error
5%	234.15	Very low
18%	263.14	Low
34%	298.82	Elevated
55%	345.65	High
100%	446.00	Very high

By comparing the data from the SPS before during and after the flight, with the SFATE alertness values and the PVT test before and after, it is possible to obtain an evolution of the pilot's fatigue level and its risk. Table 6 shows the condition of the pilot on the days in which he flew.

Table 6 – Data from flight days (Pilot 1)
Source: own elaboration

Flight (nº)	Date	Hour of flight	Duration [min]	Time slept [hours]	Awakenings (actiwatch)	Awakenings per hour	PVT after sleep [ms]	PVT before sleep [ms]
1	26/May	15:00	30	7.3	0	0.00	291	275
2	1/June	17:00	30	6.7	8	1.19	283	261

In the frist day of flight, the pilot had a good quantity and quality sleep but his RTi after sleep was 30.49% worse than the fastest PVT test. From the data of Table 7, there are no variations on the SPS level and the variations on the SAFTE are negligible but in an alertness zone with very low risk. The RTi values of the before and after flight showed a 10.75% increase in RTi. The pilot started and finished the flight with a level of low risk of accident or serious error since is RTi did not pass an 18% increase in RTi. There were no changes in the performance of the pilot due to cognitive fatigue.

Table 6 – Data from pilot 1 flight nº1 and flight nº2
Source: own elaboration

	Flight nº1			Flight nº2		
	Before flight	During flight	After flight	Before flight	During flight	After flight
Time [min]	0	15	30	0	15	30
SPS	1	1	1	1	1	1
SAFTE [%]	92.2	92.1	92	88.4	88.7	89
PVT [ms]	251		278	251		237

In the day of the second flight, the pilot had an almost good quantity and a poor-quality sleep and his RTi after sleep was 26.91% worse than the fastest PVT test. From the data of Table 7 there are no variations on the SPS level and the variations on the SAFTE are negligible but in an alertness zone with low risk. The RTi values of before and after flight showed a 5.57% improvement. The pilot started and finished the flight with a level of low risk of accident or serious error, since his RTi did not pass the 18% increase, and by the end of the flight was near de 5% of increase in RTi getting close to the level of very low risk of accident or serious error. There were no significant changes on the performance of the pilot due to cognitive fatigue but, it is noticeable that even with worse values of SAFTE score, the quantity and quality of sleep, the RTi values were better than in first flight.

- **Pilot 2:**

The pilot 2 has 48 years old and has 400 flight hours; he has exercise habits with an average of 37 min of exercise per day, and the caffeine and alcohol intake are not relevant. Using the best RTi measured

(236 ms) on the PVT tests and assuming it is the fastest RTi of this individual, Table 8 was constructed in order to understand how the values of RTi from the PVT tests influence the risk of accident or serious error.

Table 7 - Risk of accident or serious error classification by RTi (Pilot 2)
Source: own elaboration

Reaction time slowed [%]	RTi [ms]	Risk of accident or serious error
5%	247.80	Very low
18%	278.48	Low
34%	316.24	Elevated
55%	365.80	High
100%	472	Very high

Table 8 - Data from flight days (Pilot 2)
Source: own elaboration

Flight (nº)	Date	Hour of flight	Duration [min]	Time slept [hours]	Awakenings (actiwatch)	Awakenings per hour	PVT after sleep [ms]	PVT before sleep [ms]
1	22/May	11:00	60	7.8	1	0.13	256	246
2	25/May	17:00	30	6.3	2	0.32	259	256
3	31/May	18:00	30	5.8	1	0.17	287	266
4	1/June	18:00	30	6.9	7	1.01		

In the day of the first flight, the pilot had a good sleep quantity and quality and his RTi after sleep was 8.47% worse than the fastest PVT test (Table 9). From the data of Table 10, there are no variations on the SPS level but he evaluated himself with some level of fatigue. The variations on the SAFTE are negligible but in an alertness zone with very low risk. The RTi values of the before and after flight showed a 1.19% decrease in RTi. The pilot started and finished the flight with a level of low risk of accident or serious error since is RTi did not pass an 18% increase in RTi and his final value was really near the 5% mark that is as very low risk of accident or serious error. There were no significant changes in the performance of the pilot due to cognitive fatigue.

Table 9 - Data from pilot 2 flight nº1 and flight nº2
Source: own elaboration

	Flight nº 1					Flight nº 2		
	Before flight	During flight			After flight	Before flight	During flight	After flight
Time [min]	0	15	30	45	60	0		30
SPS	2	2	2	2	2	2		2
SAFTE [%]	98.2	98.2	98.1	98	97.8	92		92.4
PVT [ms]	251				248	270		277

The second day of the flight the pilot had a good sleep quantity and quality and his RTi after sleep was 9.75% worse than the fastest PVT test. From the data of Table 10, there are no variations on the SPS level, but he evaluated himself with some level of fatigue. The variations on the SAFTE are negligible but in an alertness zone with very low risk. The RTi values of the before and after flight showed 2.59% increase in RTi. The pilot started and finished the flight with a level of low risk of accident or serious error since is RTi did not pass an 18% increase, but his final value was really near that mark that would increase the risk of accident or serious error to “elevated”. There were no significant changes on the performance of the pilot due to cognitive fatigue but the pilot was already fatigated on the beginning of the flight and after the flight, as he almost presented an elevated risk of accident or serious error.

The third day of flight the pilot had a poor quantity but a good quality of sleep and his RTi after sleep was 21.61% worse than the fastest PVT test. From the data of Table 11 there are no variations on the SPS level but he evaluated himself with some level of fatigue. The variations on the SAFTE are from a reduced alertness zone to a high alertness zone but in low to very low risk. The RTi values of the before and after flight showed 1.10% increase in RTi; however, his values end near the point of passing from a low level of risk to an elevated level of risk. There were no significant changes on the performance of the pilot due to cognitive fatigue but the pilot was already fatigated on the beginning of the flight, more than the last (second) flight, and after this flight he almost presented an elevated risk of accident or serious error just like the previous (second) flight.

Table 10 - Data from pilot 2 flight nº3 and flight nº4
Source: own elaboration

	Flight nº 3			Flight nº 4		
	Before flight	During flight	After flight	Before flight	During flight	After flight
Time [min]	0		30	0		30
SPS	2		2	2		2
SAFTE [%]	89.8		90.4			
PVT [ms]	272		275	268		272

On the fourth flight, the pilot had a poor quantity but almost good and a poor-quality of sleep and there are no values for the PVT test. From the data of Table 11 there are no variations on the SPS level but he evaluated himself with some level of fatigue. The are no values on the SAFTE alertness score. The RTi values of the before and after flight showed 1.49% increase in RTi; his values were better than the last two flights (second and third) but worse than the first one. The level of risk from RTi values had a low level of risk. There were no significant changes on the performance of the pilot due to cognitive fatigue but the pilot was already fatigated on the beginning of the flight and his risk level remained the same - a low level of risk.

- **Pilot 3:**

The pilot 3 has 32 years old and has 180 flight hours; he has a high caffeine intake of 4.08 (average) coffees per day but no alcohol or exercise habits. Using the best RTi measured (240 ms) on the PVT tests and assuming it is the fastest RTi of this individual, Table 12 was constructed in order to understand how the values of RTi from the PVT tests influence the risk of accident or serious error.

Table 11 - Risk of accident or serious error classification by RTi (Pilot 3)
Source: own elaboration

Reaction time slowed [%]	RTi [ms]	Risk of accident or serious error
5%	252.0	Very low
18%	283.2	Low
34%	321.6	Elevated
55%	372.0	High
100%	480	Very high

Table 12 - Data from flight days (Pilot 3)
Source: own elaboration

Flight (nº)	Date	Hour of flight	Duration [min]	Time slept [hours]	Awakenings (actiwatch)	Awakenings per hour	PVT after sleep [ms]	PVT before sleep [ms]	Caffeine
1	21/May	09:00	50	7.4	3	0.41	327	342	4
2	30/May	19:00	55	3.6	0	0.00	260	287	4
3	1/June	17:30	40	7.3	3	0.41			
4	1/June	20:00	20						

In the first flight, the pilot had a good quantity and an intermediate quality of sleep. His RTi after sleep was 36.25% worse than the fastest PVT test (Table 13). From the data of Table 14, there are no variations on the SPS level but, he evaluated himself with some to no level of fatigue. The variations on the SAFTE are negligible but in an alertness zone with very low risk. The RTi values of the before and after flight showed a 29.07% decrease in RTi. The pilot started with a high risk of accident or serious error and finished the flight with a very low, since is RTi pass an 34% increase in RTi and his final value was below the 5% mark that means a very low risk of accident or serious error. The pilot started the flight with a high level of risk but during the flight was able to recover to a very low risk; it is very likely that his caffeine intake was a mitigating factor in the recovery from his high level of fatigue.

Table 13 - Data from pilot 3 flight nº1 and flight nº2
Source: own elaboration

	Flight nº 1				Flight nº 2			
	Before flight	During flight		After flight	Before flight	During flight		After flight
Time [min]	0	15	30	50	0	15	30	55
SPS	2	1	1	1	2	1	1	1
SAFTE [%]	92.3	93.2	94.1	94.7	82.7	83	83.4	84
PVT [ms]	344			244	250			240

In flight number 2 the pilot had a bad quantity and a good quality of sleep that, as referred before, had a great recovery from his last (previous) day. His RTi after sleep was 8.33% worse than the fastest PVT test. From the data of Table 14 there are no variations on the SPS level but he evaluated himself with some to no level of fatigue. The variations on the SAFTE are negligible but in an alertness zone with low risk of accident or serious error. The RTi values of the before and after flight showed a 4% decrease in RTi. The pilot started and finished with a very low risk of accident or serious error since his RTi did not pass the 5% increase in RTi. There were no significant changes in the performance of the pilot due to cognitive fatigue but, the pilot was with a very low level of risk during his flight; so, cognitive fatigue did not have an effect in this flight but, as in the last (previous) flight, the caffeine must have been a mitigating factor in regulation of fatigue.

In flight number 3 the pilot had a good quantity and an intermediate quality sleep. There were no values for his RTi after and before sleep. From the data of Table 15 there are no variations on the SPS level but he evaluated himself with no level of fatigue. The variations on the SAFTE are negligible but in an alertness zone with low risk. The RTi values of the before and after flight showed a 3.78% increase in RTi. The pilot started and finished with a low risk of accident or serious error since his RTi did not pass an 34% increase in RTi but was above the 18% increase mark. There were no significant changes on the performance of the pilot due to cognitive fatigue but the pilot was with a low level of risk during his flight; there were no data on the caffeine consumption, so it is not possible to know if it was used as a mitigating factor.

Table 14 - Data from pilot 3 flight nº3 and flight nº4
Source: own elaboration

	Flight nº 3			Flight nº 4		
	Before flight	During flight	After flight	Before flight	During flight	After flight
Time [min]	0	15	40	0		20
SPS	1	1	1	1		1
SAFTE [%]	87.3	87.5	87.9	90.3		90.7
PVT [ms]	264		274	240		246

The fourth flight was executed in the same day as the third flight, so the conditions before flight were the same in terms of sleep quantity and quality. The RTi value to have in the mind is the one at the end of his last (third) flight, since it is the last available data of his performance. In the last (third) flight his performance in terms of RTi slowed, but from the data of Table 15 the RTi values of the before and after flight show a 2.5% increase RTI, but in an alertness zone with very low risk contrary to the last (third) flight. Between the last (third) and this flight, the pilot recovers his values of RTi but this time there are no data on caffeine consumption, so it is not possible to presume if this recover was made with caffeine as a mitigating factor or not. There were no variations on the SPS level and the variations on the SAFTE are negligible. There were no significant changes in the performance of the pilot due to cognitive fatigue since he remained with good values in all evaluated aspects during his flight.

VII. Conclusion

The HF has always been a big concern in the aviation sector and even more for the sub-sectors that have almost none to none regulation to attenuate the problems associated with the "Human" element and is by conducting studies in the fields of human performance that we can find ways to mitigate the probabilities of "human error".

The pilots that participated in this study had normal lives during the test period, and so it was possible to observe the fatigue accumulated by these individuals. From the data collected was not possible to see any relations between the self-evaluation fatigue scale SPS and the objective data from the PVT test and the SAFTE alertness scores. Except the fact that on some of more extreme days of fatigue it had an impact on the values of SPS.
Before, during and after the flights the levels of SAFTE score never passed the point of lower risk of accident or serious error, but this can be explained by the short periods of flight made in this type of aviation, particularly by our test pilots. On the PVT tests, some pilots had values that may be considered near or in the elevated risk of accident or serious error but in most cases, they remained on the spectrum of very low to low risk.

A very important conclusion of this study is that most individuals that fly in this segment of aviation have normal lives and jobs that promotes some type of cumulative fatigue in their bodies, due to work schedules, restriction of sleep hours and workloads, so it is up to the pilot to understand his condition before operating an aircraft. And here is the biggest problem concerning safety because all our pilots were poor judges of their performance. So, cognitive fatigue can be a cause or one of the causes of occurrences related to unsafe acts on the segment of general aviation as depicted, for example, from Pilot 3 data. If it was possible to have more factors under evaluation it would have been more perceptible how this type of fatigue evolves and with a greater, more diversified group of subjects and flights, it would be possible to make more conclusive affirmations.

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Análisis histórico de los principales contaminantes emitidos por motores de aeronaves civiles

Juan Ignacio D Iorio - juanignacio.diorio@ing.unlp.edu.ar
Grupo Transporte Aéreo – UIDET GTA-GIAI, Departamento de Aeronáutica, Facultad de Ingeniería, Universidad Nacional de La Plata, Argentina
Alejandro Di Bernardi - cadibern@ing.unlp.edu.ar
Grupo Transporte Aéreo – UIDET GTA-GIAI, Departamento de Aeronáutica, Facultad de Ingeniería, Universidad Nacional de La Plata, Argentina

Abstract

Estudiar la evolución histórica de los contaminantes emitidos (cantidades) por los motores a reacción de las aeronaves civiles.

Este es un análisis estadístico realizado a través de la base de datos proporcionada por la Organización de Aviación Civil Internacional (OACI), que se completa con los datos obtenidos durante la certificación de los motores. También se utilizarán algunos datos de publicaciones propias de este GTA, y algunos de bibliografía para obtener indicadores con el fin de interpretar los datos de evolución histórica.

Es evidente que las cantidades de los contaminantes más importantes derivados de la combustión han ido disminuyendo a través de los años. Más allá de esto, es interesante analizar las cantidades y características de los motores en relación a ciertas características.

Lo más importante de esta publicación es relacionar algunas características de los motores para poder asociarlas a los cambios en los niveles de contaminantes, es decir, a construir ciertos indicadores para distinguir las medidas que más contribuyeron a disminuir los productos de la combustión nocivos, y poder proponer nuevas.

Keywords

motores; contaminación; emisiones; aeronaves

Análisis histórico de los principales contaminantes emitidos por motores de aeronaves civiles.

D.Social and Environmental Strategies

Introducción

Este trabajo está fundamentalmente basado en los datos proporcionados por OACI en la certificación de los motores aeronáuticos, condensados en una base de datos de uso público [1], en función de los requisitos establecidos en el Anexo 16 al convenio de Aviación Civil Internacional [2]. Para contextualizar los datos y conclusiones obtenidas, en primera medida se analiza información sobre flotas operativas, potencias involucradas y crecimiento de las operaciones a nivel mundial. En función de estos indicadores se evalúan los resultados y se concluye con respecto a ello.

Desarrollo

Como se citó anteriormente, resulta necesario establecer ciertas condiciones de contorno para realizar una correcta apreciación de los resultados obtenidos. Para ello se analiza primeramente el crecimiento del tráfico aéreo a través de los años. Con datos del Banco Mundial [3], incluyendo entradas de la OACI y entidades de aviación civil, se obtienen los valores totales de despegues de aeronaves (ciclos) a nivel mundial para el período 1970-2017.

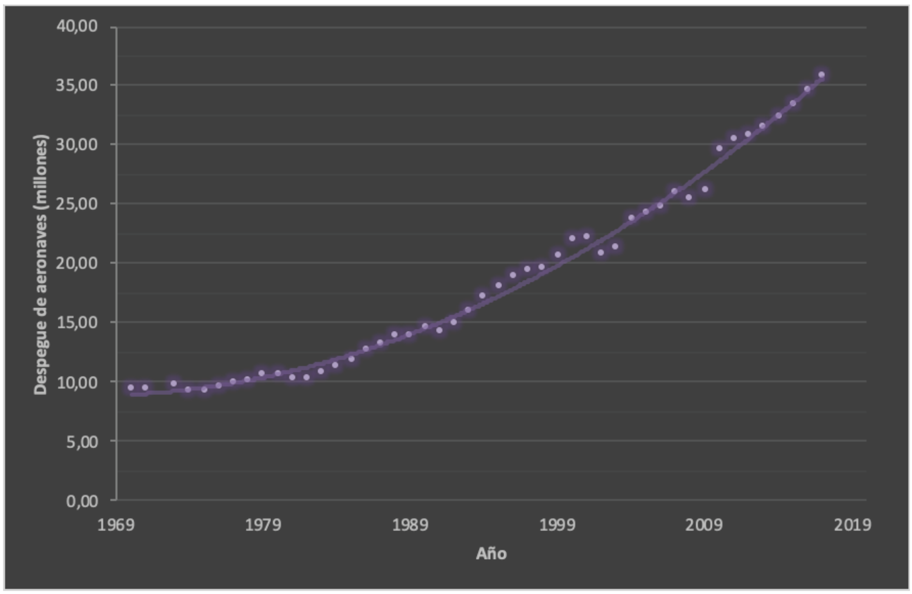

Figura 1 – Despegues de aeronaves a nivel mundial.

Puede observarse un incremento constante a través de los años, sobrepasando los 35 millones de despegues para el año 2017 (último con información disponible). Con este gráfico puede entenderse los esfuerzos que realiza tanto OACI como las Autoridades de Aviación Civil de los distintos Estados para disminuir las emisiones contaminantes derivadas de la operación aérea. Una vez establecida esta situación, es útil analizar las proporciones de los tipos de aeronaves que son y fueron utilizadas por los operadores civiles, es decir, fuselaje angosto y ancho, para tener una idea de la cantidad de motores, y por lo tanto, de emisiones. De acuerdo a los datos proporcionados por el *Airline Data Project* del MIT [4], se obtiene el siguiente gráfico:

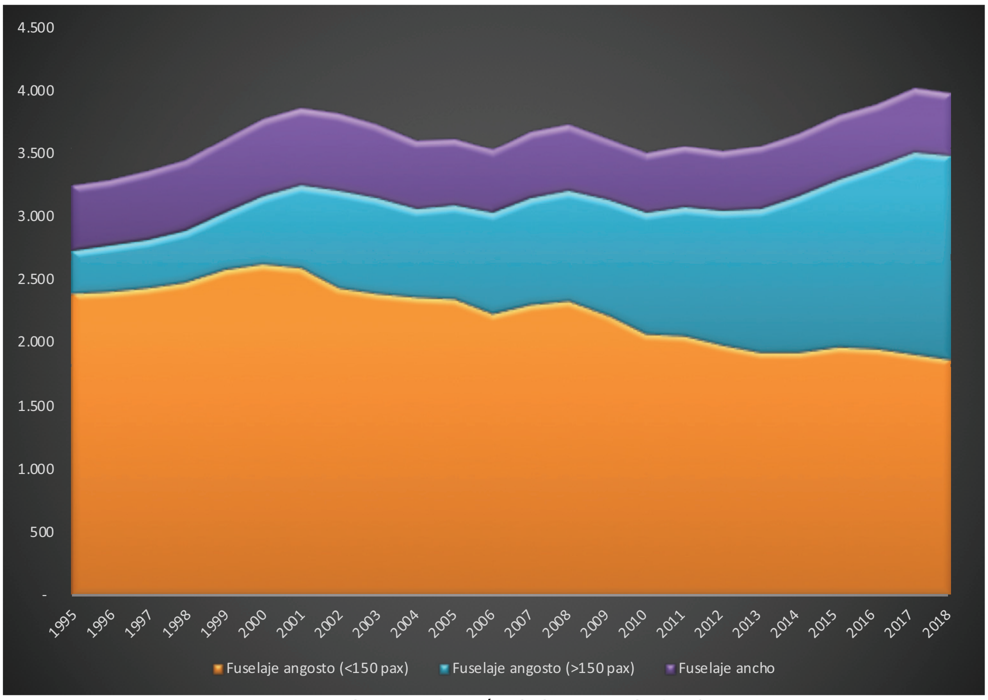

Figura 2 – Flotas en función de los tipos de fuselaje.

Más allá de las restricciones que presenta esta información, siendo las dos más importantes el período analizado (sólo a partir de 1995) y que únicamente se tienen en cuenta operadores de Estados Unidos, es útil para obtener algunas conclusiones respecto a las tendencias actuales a nivel global. Puede observarse una menor utilización de las aeronaves de fuselaje angosto con capacidad para 150 pasajeros o menos, y un aumento en la categoría siguiente; aquellas que poseen capacidad para 150 o más pasajeros y de un solo pasillo, debido a la versatilidad que ofrecen a los operadores, están reemplazando a las aeronaves más pequeñas. El porcentaje de uso de las aeronaves de fuselaje ancho se ha mantenido relativamente constante, aunque su utilización comienza a decrecer por lo citado anteriormente, esto es, que las aeronaves de un solo pasillo ofrecen mayor rango operativo, con lo cual los operadores pueden cubrir rutas que antes sólo podían con aeronaves de doble pasillo, y con un factor de ocupación más alto. Otro hecho relevante, que no se desprende del gráfico anterior, si no de información propia de este GTA, hecha con el análisis de los fabricantes y las aeronaves de fuselaje ancho, es que con el correr de los años las aeronaves de fuselaje ancho tienden a utilizar solamente 2 motores.

Tabla 1-Aeronaves de fuselaje ancho
Fuente: GTA y fabricantes.

Aeronave	Comienzo de producción	Fin de producción	Nº motores	Aeronave	Comienzo de producción	Fin de producción	Nº motores
B-747	1968	-	4	A-340	1993	2011	4
DC-10	1971	1989	3	B-777	1993		2
L-1011	1972	1985	3	A-330	1994		2
A-300	1974	2007	2	A-380	2005		4
Il-86	1980	1994	4	B-787	2007		2
B-767	1981	-	2	A-350	2010		2
A-310	1983	1998	2	B-777X	2019		2
MD-11	1990	2001	3	CR929	2023		2
Il-96	1992	-	4				

De este listado, y teniendo en cuenta las aeronaves actualmente en producción (no en servicio), se deriva en el siguiente gráfico que demuestra lo anterior. No se incluyó el B-777X ya que se encuentra en fase de certificación, y se estima el comienzo de la producción para octubre-noviembre de este año.

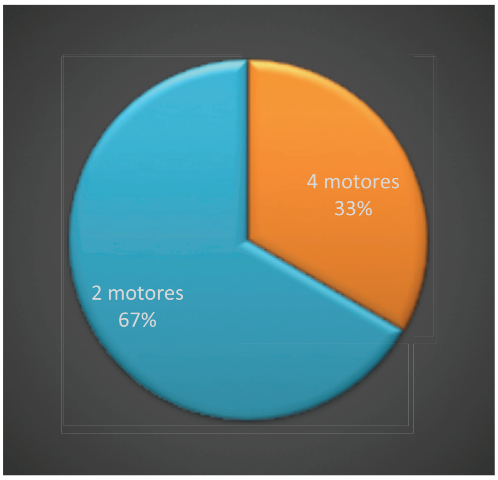

Figura 3 – Aeronaves en producción.

Las dos próximas aeronaves en entrar en servicio también contarán con 2 motores instalados.

Hecho este pequeño análisis del panorama de la flota mundial, los tipos de aeronaves, y las cantidades de operaciones, se prosigue con el histórico obtenido de la base de datos de emisiones [1]. Resulta necesario aclarar que el método utilizado para la certificación ([2] [5]) requiere la medición de hidrocarburos no quemados (HC), monóxido de carbono (CO), óxidos de nitrógeno (NOx), humos, consumo de combustible, entre otros, en el denominado ciclo LTO (*Landing Take-off Cycle*), que implica 4 configuraciones de potencia durante cierto tiempo, a saber (obtenidos de [2]): despegue a 100% de la potencia durante 0,7 minutos; ascenso a 85% de la potencia durante 2,2 minutos; aproximación 30% de la potencia durante 4,0 minutos; y ralentí o taxeo al 7% de la potencia durante 26,0 minutos. Si bien son valores arbitrarios y no representan todos los casos de operaciones, es una buena aproximación para determinar las variables incluídas en [1]. En este caso se presentan dos gráficos obtenidos de [1] para establecer la evolución histórica de variables de peso relativo alto en el desarrollo de los motores, como son la potencia y la relación de *by-pass*.

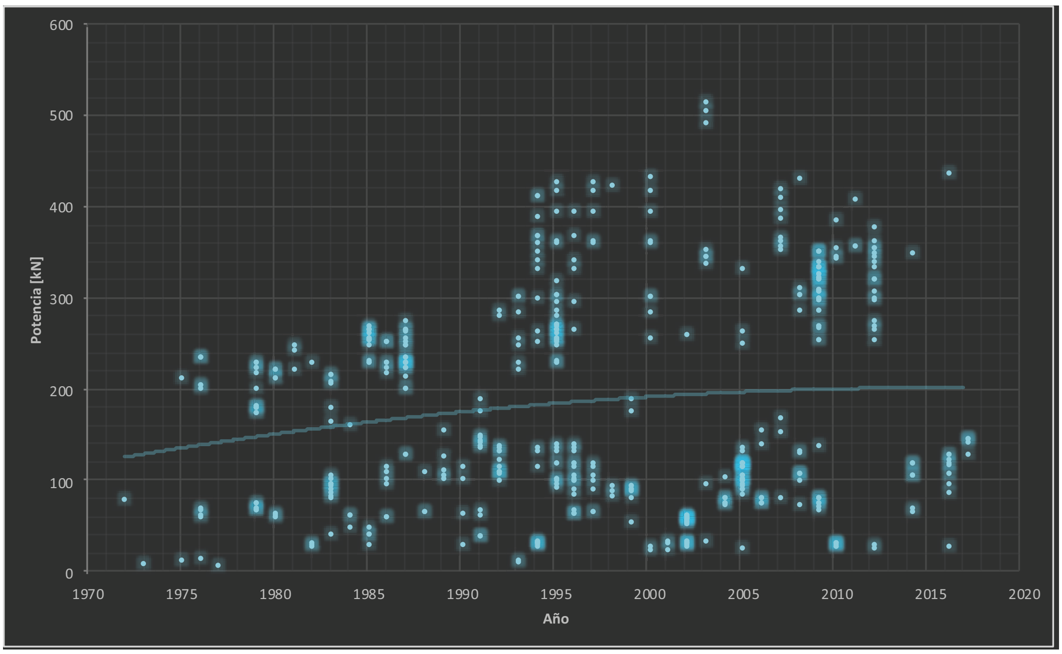

Figura 4 – Evolución de la potencia de los motores [kN].

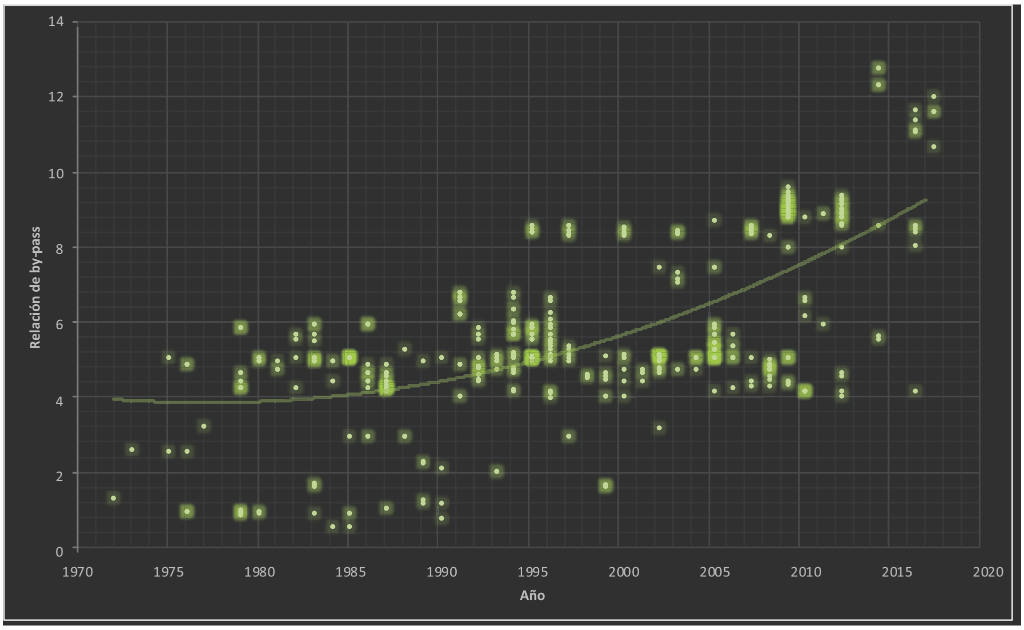

Figura 5 – Evolución de la relación de *by-pass*.

De la figura 4 puede observarse que, si bien las potencias fueron aumentando, se ha alcanzado un cierto balance en los últimos años, lo que demuestra la demanda de motores para los distintos tipos de aeronaves y su participación en el mercado. La figura 5 muestra un crecimiento indudable de la relación de *by-pass*; esto se fundamenta por un lado en el aumento de la potencia a causa de la utilización de relaciones de derivación más altas (el empuje aumenta por la variación de la cantidad de movimiento), así como también las mejoras en la eficiencia que esto produce. La limitación en la utilización de un *fan* más grande es la instalación en aviones más pequeños, ya que no cuentan con la distancia necesaria desde el *pylon* en el ala hasta el suelo. Como corolario de estos gráficos, se incluye uno del consumo de combustible en función del índice de derivación que de alguna manera demuestra la eficiencia anteriormente citada.

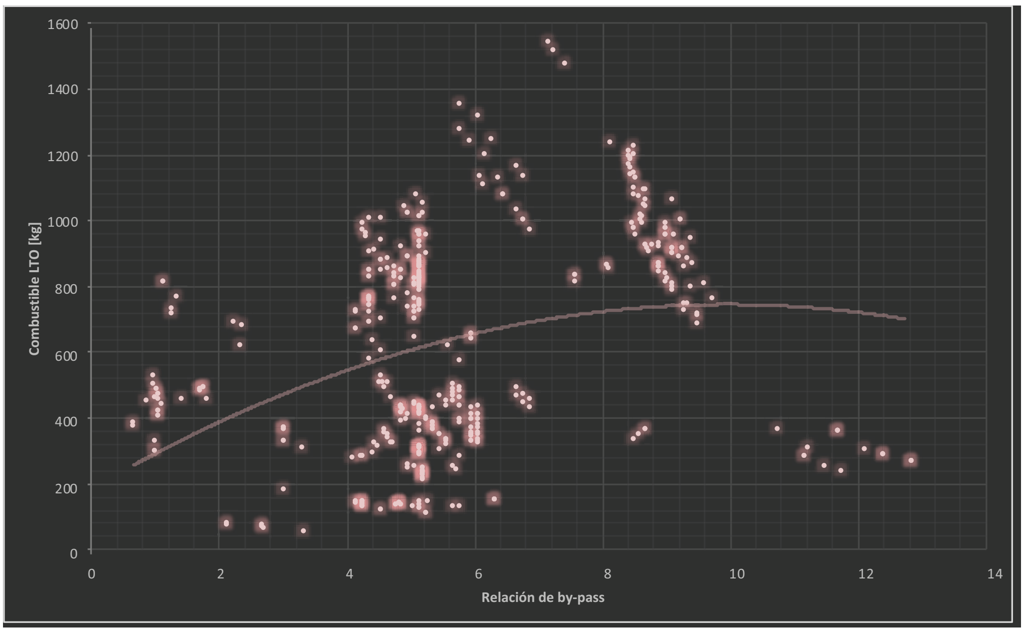

Figura 6 – Consumo de combustible [kg] en función de la relación de *by-pass*.

Luego de esta introducción, se incluyen los gráficos de la evolución de los tres principales contaminantes; HC, CO y NOx emitidos en la totalidad del ciclo LTO en gramos; primero para la totalidad de los datos analizados (505 entradas), y luego haciendo intervalos de potencia arbitrarios con el objeto de visualizar mejor la información.

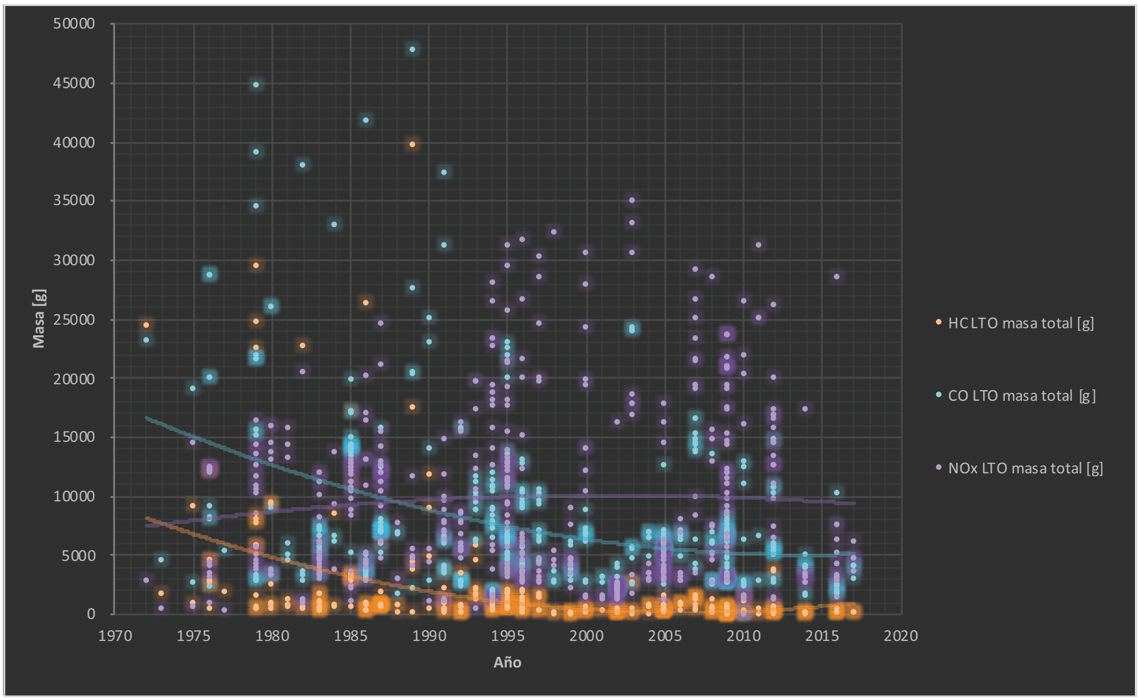

Figura 7 – Evolución de la emisión de contaminantes en el ciclo LTO.

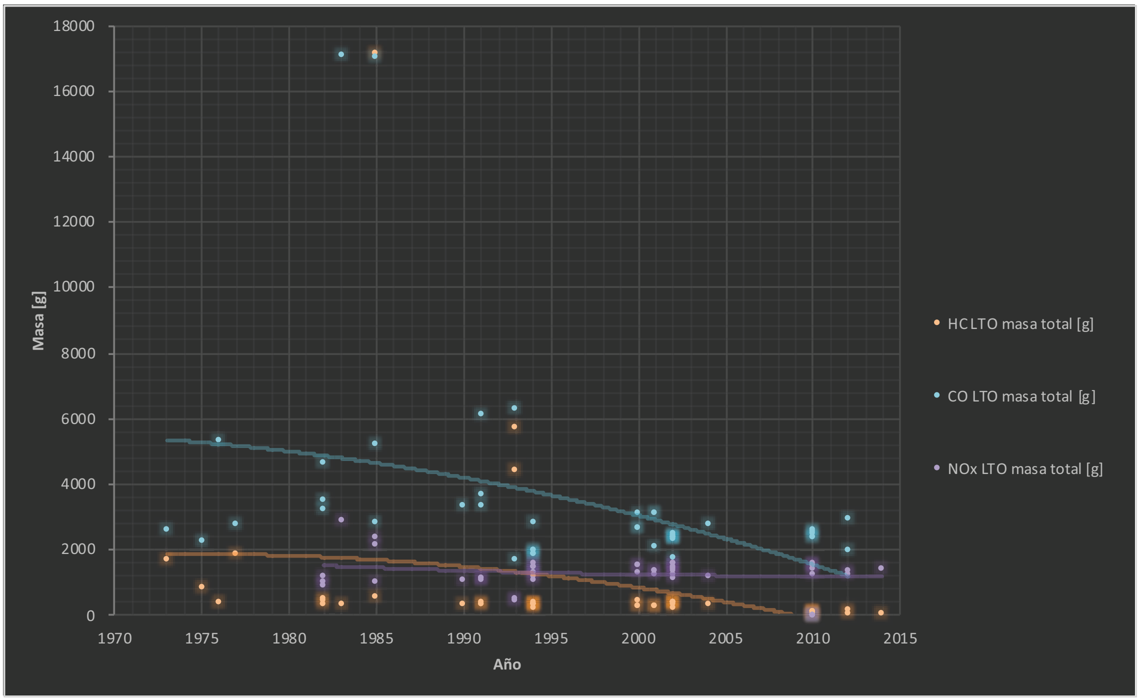

Figura 8 – Evolución de la emisión de contaminantes en el ciclo LTO, potencia de 15,6 a 44,0 kN.

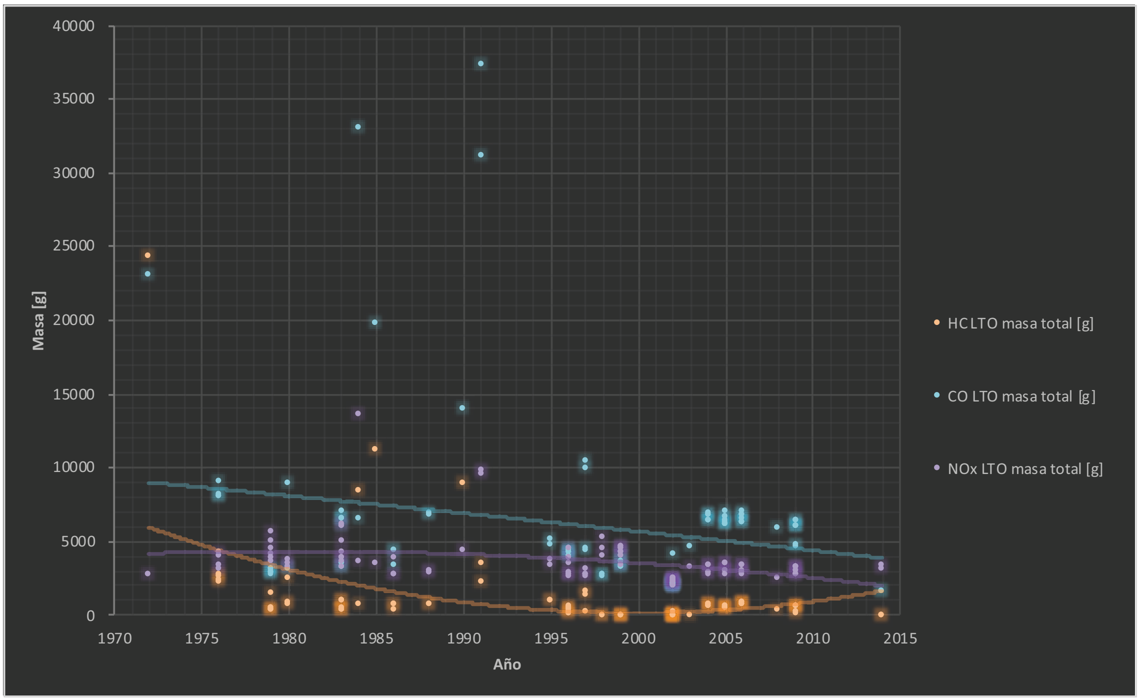

Figura 9 – Evolución de la emisión de contaminantes en el ciclo LTO, potencia de 50,7 a 101,0 kN.

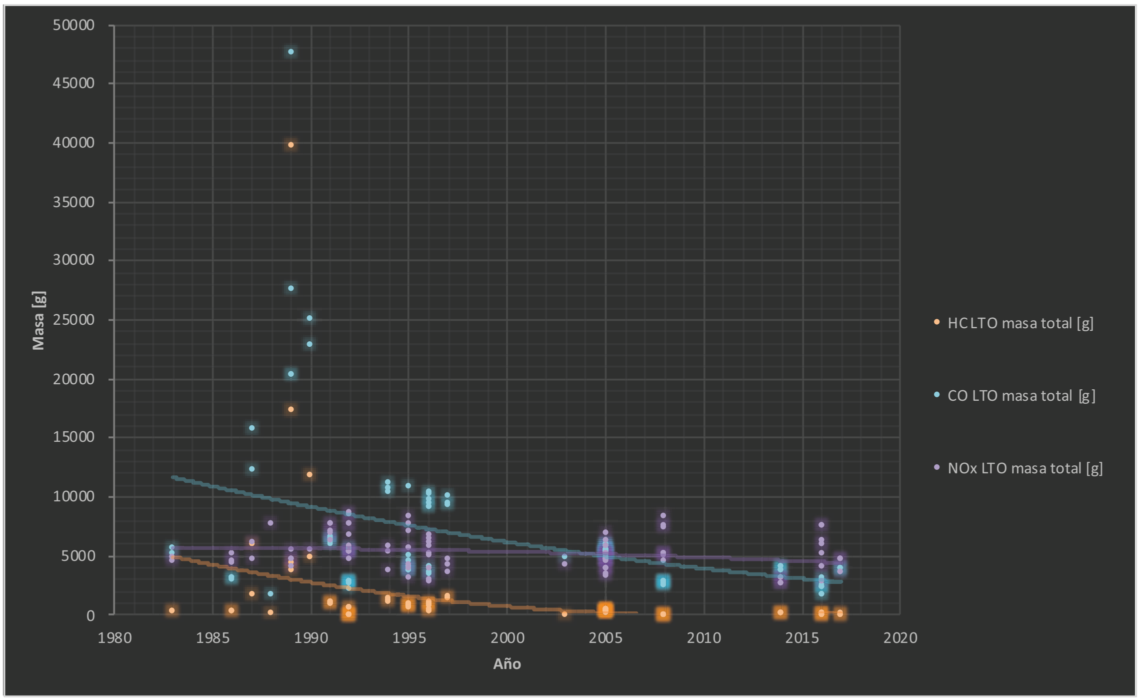

Figura 10 – Evolución de la emisión de contaminantes en el ciclo LTO, potencia de 102,2 a 149,9 kN.

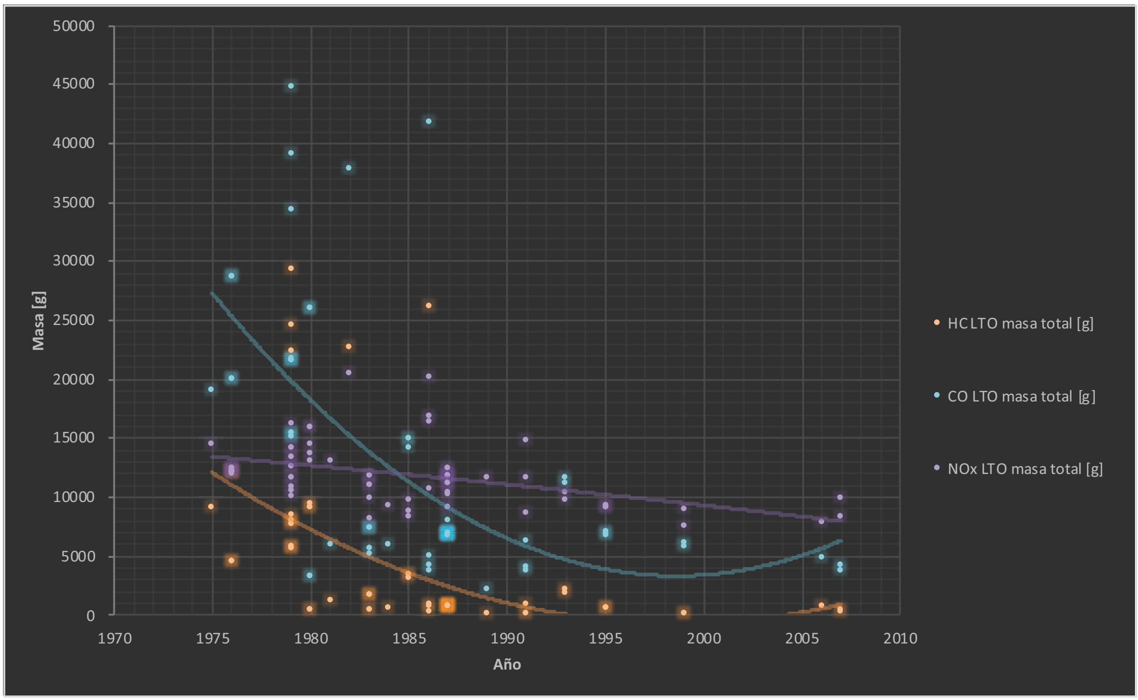

Figura 11 – Evolución de la emisión de contaminantes en el ciclo LTO, potencia de 151,25 a 236,7 kN.

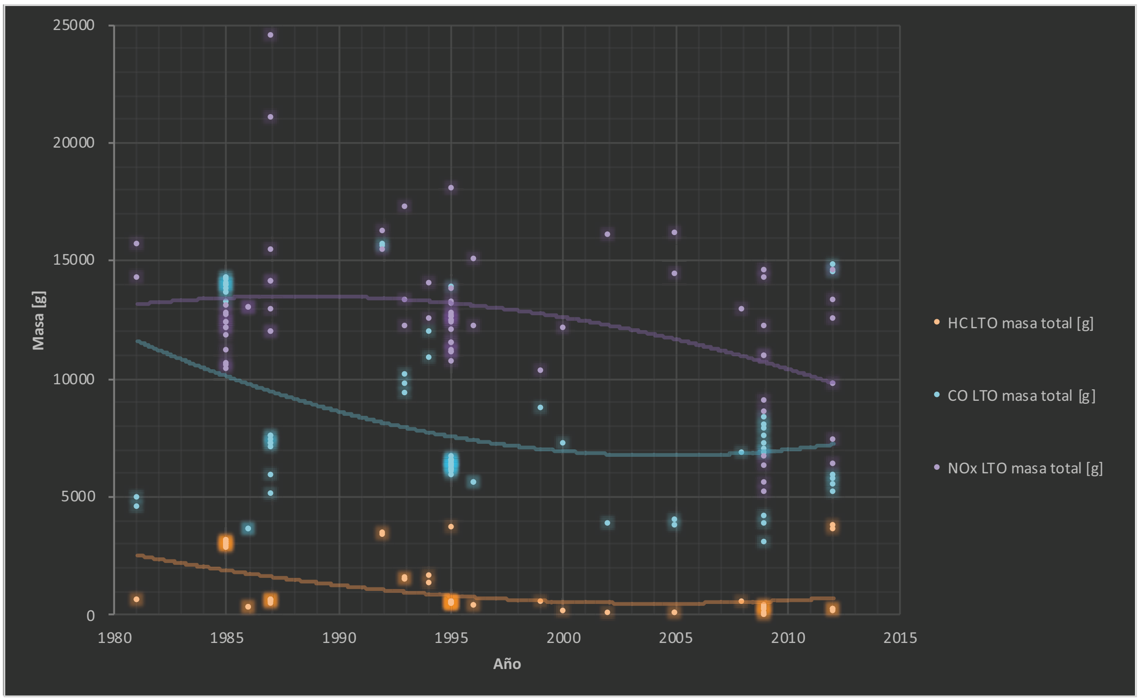

Figura 12 – Evolución de la emisión de contaminantes en el ciclo LTO, potencia de 243,5 a 299,8 kN.

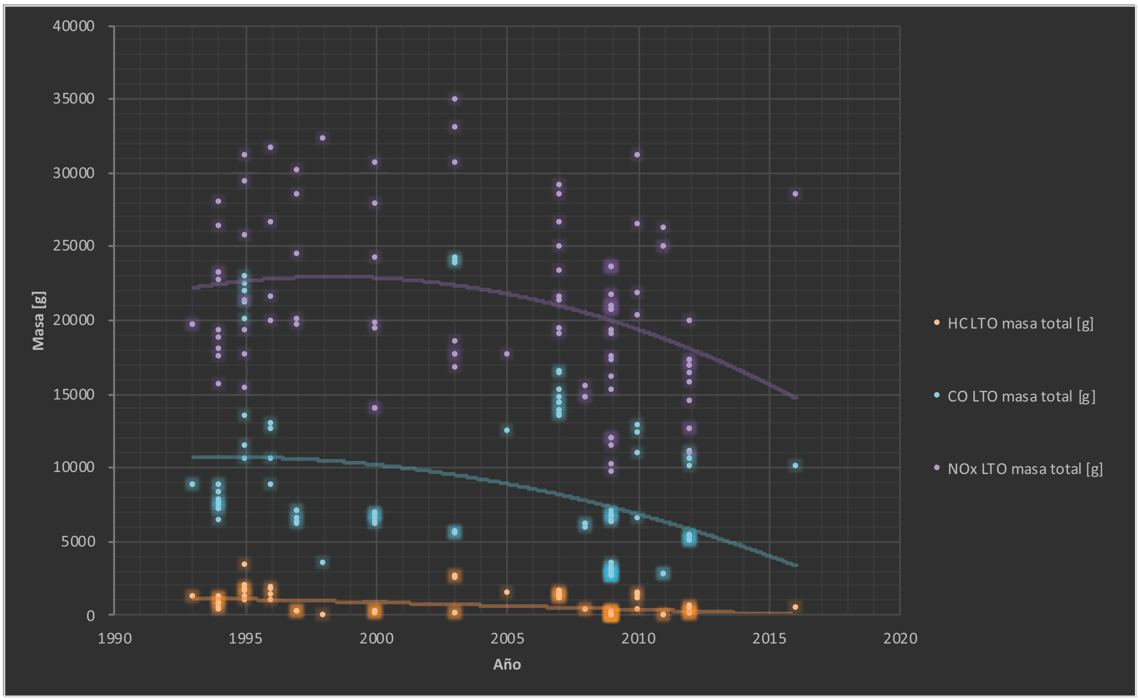

Figura 13 – Evolución de la emisión de contaminantes en el ciclo LTO, potencia de 300,3 a 513,9 kN.

Conclusiones y observaciones

Se pudo analizar la evolución histórica de tres de los componentes contaminantes más importantes presentes en los motores aeronáuticos [6] debido a su toxicidad e interacción con el medio. Se observa claramente como las curvas de HC y NOx son "opuestas" entre si, es decir, que a medida que aumenta una disminuye la otra, razón por la cual siempre se debe alcanzar una solución de compromiso en función de los objetivos propuestos para el diseño del motor, así como también el cumplimiento de la normativa de referencia [2]. Las curvas de CO presentan un comportamiento similar a las de los HC, y también la normativa [2], [7] y [8] busca su reducción constante.

Si bien la reducción en el HC y CO resulta clara a través de los años, independientemente de las potencias involucradas, se debe continuar con esta tendencia para eventualmente llegar a un valor de emisiones neutro. Resulta claro que estas metas son virtualmente imposibles de alcanzar por el comportamiento antes descrito, y por el propio proceso de combustión. Más allá de las mejoras tecnológicas, de los procesos, materiales, etc., el citado proceso siempre va a dejar como residuos los componentes analizados. Es por ello que se plantean ya desde hace algunos años métodos de compensación [8] para, de alguna manera, mitigar los efectos adversos sobre el medio.

Queda pendiente para futuros trabajos realizar un análisis más profundo de la participación de cada tipo de aeronave en el mercado, la cantidad de operaciones por regiones, y el cálculo de emisiones en el mismo sentido, para ponderar y comparar con los métodos de compensación propuestos por OACI y los Estados.

Referencias

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Cuantificación de emisiones de los GSE según operación de aeronaves bajo modalidad LCC y tradicional

Alejandro Di Bernardi - aledibernardi@hotmail.com
Universidad Nacional de La Plata/ Grupo Transporte Aéreo – UIDET GTA-GIAI, Departamento de Aeronáutica, Facultad de Ingeniería
Gustavo Alonso Rodrigo - gustavo.alonso@upm.es
Universidad Politécnica de Madrid (UPM)
Juan Martiarena - juanf.martiarena@gmail.com
Universidad Nacional de La Plata/ Grupo Transporte Aéreo – UIDET GTA-GIAI, Departamento de Aeronáutica, Facultad de Ingeniería
Matías Coppa - matias.coppa@gmail.com
Universidad Nacional de La Plata/ Grupo Transporte Aéreo – UIDET GTA-GIAI, Departamento de Aeronáutica, Facultad de Ingeniería

Abstract
El presente tiene como objetivo cuantificar las emisiones de los principales gases primarios (CO, NOx, HC y PM10), producto de la operación de los GSE (Ground Support Equipment) a las aeronaves, según vuelo LCC o tradicional, en aeropuertos comerciales.
La metodología consiste en identificar los servicios requeridos por las aeronaves según tipo de vuelo (LCC o tradicional); caracterizar la plataforma según sus puestos de estacionamiento y sus correspondientes distancias; e identificar las posibles circulaciones de cada equipo a medida que arriban las aeronaves. La cuantificación se obtiene a partir del modelo desarrollado que tiene en cuenta, tanto la circulación como el servicio propio de cada vehículo en particular.
El trabajo tiene como finalidad la cuantificación y comparación de las emisiones en las operaciones de los GSE para aeropuertos con movimientos de aeronaves LCC y tradicionales. Además, se proponen medidas de mitigación de los gases contaminantes, y a su vez el análisis del aporte relativo de dichas emisiones producto de los GSE con las aeronaves para las configuraciones estudiadas en el ciclo LTO.
La principal contribución a la bibliografía recomendada es la profundización en el estudio de los vehículos de asistencia y sus emisiones generadas durante el servicio (discretizado en etapas y según carga o descarga) junto a las generadas por las circulaciones de los vehículos de asistencia antes, durante y después de las operaciones de las aeronaves.

Keywords
Ground Support Equipment; Emisiones gaseosas; Aeropuertos; Low cost y tradicional

Cuantificación de emisiones de los GSE según operación de aeronaves bajo modalidad LCC y tradicional

Introducción

El transporte aéreo desempeña un papel importante en el desarrollo económico y social sostenible en el mundo. [1] pronostica un aumento de pasajeros del doble de la actualidad para el año 2037, es decir 8.200 millones. Además revela que, en las próximas dos décadas, el sector crecerá a una tasa anual del 3,5%, generando así hasta 100 millones de empleos en todo el mundo. En particular, en Latinoamérica el documento estima un crecimiento del 3,6% alcanzando 731 millones de pasajeros.

Como sostiene Lee en [2], el volumen de pasajeros transportados por una aerolínea ha seguido creciendo fuertemente a una tasa promedio del 5,2% anual durante el período 1992-2005. Los fabricantes de aviones predicen que la flota puede casi duplicarse con respecto a los 20.500 aviones en 2006, a 40.500 aviones en 2026. El volumen del tráfico aéreo mundial se ha ido duplicando una vez cada 15 años desde 1977, y se espera que este este crecimiento continúe a pesar de ciclos de recesión cada vez mayores. Respecto al tráfico internacional de pasajeros, se estima un aumento del 5,1% anual, mientras que el tráfico doméstico crecería a un ritmo más lento del 4,4% (período 2010-2030). A modo de comparación, se observan los datos más recientes (2015) en donde Boeing, Airbus y Embraer, tienen una tasa media anual de crecimiento de 20 años (2014-2034) de 4,9%, 4,6% y 4,9% respectivamente [3]. En particular, la modalidad LCC ha notado un crecimiento similar a la tasa de aviación general de 5% anual apareciendo como un nuevo mercado de interés [4].

Por su parte, la industria de la aviación comprende aerolíneas y otros servicios relacionados con la aviación como aeropuertos, fabricantes de aviones y proveedores de servicios de navegación aérea. Tal como señala el reporte de IATA [5], en 2009, estas se comprometieron a un enfoque unido para reducir las emisiones que abarca tres objetivos: 1. Mejorar la eficiencia del combustible en un promedio de 1.5% anual al 2020. 2. Limitar las emisiones netas mediante un crecimiento sin emisiones de carbono desde 2020 (CNG2020) 3. Recortar dichas emisiones reducirán a la mitad en 2050, en comparación con 2005. Además, en su último reporte [6] destaca que en el año 2017 viajaron 4,1 billones de personas, donde las tarifas aéreas en términos reales promediaron menos de la mitad de lo que eran en 1995, por lo tanto, la red se ha expandido hasta superar 20,000 ciudades origen destino.

En relación al crecimiento observado de la aviación *bajo costo* (***LCC*** Low Cost Carrier), [6] señala que en 2017, el modelo de larga distancia y bajo costo (LHLC) continuó cobrando impulso, siguiendo con prácticas que antes se pensaban ser parte del modelo de *servicio tradicional* (***FSC***- Full Service Carrier): el uso de sistemas de distribución global; de programas de viajeros frecuentes; y del tráfico de conexión o escala, incluidos los servicios LHLC de otras aerolíneas.

La consecuencia directa del mencionado crecimiento es un mayor consumo de combustible y una mayor contaminación gaseosa que afecta la calidad del aire, de vida, la fauna y zonas protegidas en las áreas vecinas a un aeropuerto. Instituciones nacionales e internacionales han puesto en evidencia la preocupación actual que existe por la identificación y cuantificación de las emisiones gaseosas a través de distintos indicadores que ayudan en la toma de decisiones de medidas mitigadoras. Tal es la gravedad, que [7] atribuye 8000 muertes prematuras anuales debido a las emisiones generadas por el vuelo de las aeronaves.

Se observa por lo tanto un crecimiento por la preocupación de la salud producto de las emisiones generadas en los aeropuertos. [8] afirma que tanto los motores principales de las aeronaves como las APU (unidades de potencia auxiliar) y GSE (llamados Ground Support Equipment) son las fuentes más importantes de emisiones contaminantes del aire en un aeropuerto. Estudios en los aeropuertos de Copenhague, Heathrow, Brisbane, San Diego, indican que la incidencia de las emisiones de NOx generadas por los GSE, APU y Motores principales varían con un rango entre 5 a 9%, 2 a 9% y 87 a 93% respectivamente, considerando al aeropuerto en su totalidad. Mientras que también realiza, a nivel general del área de movimientos y a nivel del interior de la plataforma, un inventario de emisiones del aeropuerto de Copenhague (CPH), donde detalla la contribución de los motores principales, APU y GSE. Considerando únicamente el subsistema de plataformas, los GSE contribuyen con 63% de las emisiones de NO_x, el 75% de Material Particulado (PM) y el 24% del consumo de combustible. Lo cual evidencia que el modo de operación de la plataforma (aeronaves-GSE) y la política de uso y asignación de puestos, a partir de su consideración conjunta, son susceptibles de presentar puntos de optimización de la dimensión operacional y ambiental. [9] analiza el impacto de las distintas fuentes en los aeropuertos del Reino Unido, y concluye que las aeronaves son las principales fuentes en relación al PM aportando un %47, mientras que los GSE emiten más del %66 de los gases relacionados a los OC (carbonos orgánicos) y además son responsables del 28% del total del material particulado emitido.

Estudios como [10] señalan de la importancia de las emisiones correspondientes a los GSE en el entorno aeroportuario, alcanzando un 5% en comparación con todas las fuentes (incluyendo el ciclo LTO) respecto al NO_x, pese a no tener en cuenta la contribución por la circulación de dichos vehículos en plataforma. A su vez, [11] afirma que los motores diésel en plataforma son la fuente de emisión que más contribuye a la contaminación atmosférica, ya que emiten NO_x y partículas finas. Continuando con la misma línea, reportes como el de [12] indican que las emisiones de las aeronaves tanto para el NO_x como para los HC predominan en comparación con los APU y GSE analizados, generando entre un 80 y 90% para los aeropuertos estudiados.

El presente se centra en cuantificar la mínima cantidad de vehículos necesarios y su aporte contaminante según las operaciones efectuadas por las aeronaves debido al servicio y a la circulación en plataforma. En este sentido se han planteado tres configuraciones fijando la cantidad de operaciones: con 100% FSC, 100% LCC y 50-50% FSC-LCC.

Tal como afirma [13], la mayoría de los GSE suelen estar asociados con el servicio de la aeronave durante el proceso de cambio del aeropuerto que consiste en las operaciones en tierra que se realizan desde el momento en que los bloques de goma (calzos) se colocan delante de las ruedas de la aeronave hasta el momento en que se retiran los bloques y la aeronave. Durante este período, hay una serie de tareas que se realizan, incluyendo la carga y descarga de pasajeros y equipaje, limpieza y mantenimiento de aeronaves, reabastecimiento y reposición de provisiones, y otros servicios similares. Otras funciones GSE comunes se refieren al servicio y mantenimiento de la infraestructura del lado aéreo y del aeródromo.

Figura 1 Fuente típicas de emisiones en un aeropuerto

Por su parte, los vehículos requeridos para operaciones LCC son mínimos debido al menor requerimiento que, en este estudio, se idealiza y propone la menor cantidad de GSE a fin de observar las diferencias tanto de las emisiones como de la cantidad de vehículos mínimos necesarios. La velocidad, la eficiencia y la precisión son importantes en las operaciones de los GSE para minimizar los tiempos y costos. Básicamente, estas actividades dependen en gran medida del modelo y estrategia de negocios favorecidos por las aerolíneas. En contraste con las aerolíneas tradicionales, los LCC utilizan operaciones más simples y optimizadas. Esto conduce a tiempos reducidos, a un uso más eficiente de la flota de aeronaves y, por lo tanto, a un aumento de millas de pasajeros [4].

En su publicación [14], menciona las principales características que los vehículos LCC podrían tener con el objetivo de eficientizar tiempos y costos, como la aproximación de los puestos de estacionamiento con la terminal y paralelo a la misma para tener autonomía; utilización de escaleras propias de las aeronaves; no requerir de servicios de limpieza, agua ni catering; y disponer del llenado de combustible siempre y cuando sea necesario.

Figura 2 Mapeo de las emisiones en plataforma rectangular

A continuación, se presentan la cantidad de vehículos requeridos según operación tradicional (origen-destino *FSC*) y *LCC* para aeronaves de fuselaje angosto como el A320 o E190 con 100% de capacidad completo:

Tabla 1 Cantidad de vehículos requeridos según operación

Operación	TUG	GPU	Equipaje	Cinta	Bus MR	Bus	Limpieza	Combustible	Agua	Escalera	Catering
Codificación	TUG	GPU	BAG	BEL	BRE	BUS	CLE	FUE	WAT	STA	CAT
FSC	1	1	2	2	1	3	1	1	1	2	1
LCC	0	1	2	2	0	0	0	0	0	0	0

Metodología

A continuación, se detalla el proceso para el desarrollo del modelo integrador que cuantifica la cantidad de vehículos de asistencia necesarios para los movimientos asignados según el tipo de operación y además cuantifica las emisiones de los gases primarios: CO, NO_x, SO_x, HC y PM10 para una plataforma rectangular de los GSE:

- Selección del día de estudio mediante criterio IATA para establecer así la mezcla de tráfico a utilizar, con sus respectivos horarios de arribo y salida,
- Distribución de la mezcla seleccionada en los puestos de estacionamiento,

- Determinación de perfiles de servicio según aeronave para las modalidades estudiadas: FSC y LCC. Análisis de todos los GSE (tiempos de servicio, potencia de motores, factores de carga, entre otros factores considerados), cantidad e identificación para operación correspondiente,
- Procesamiento de los datos en el modelo desarrollado, y
- Resultados, valores de emisión según los gases analizados para la circulación, servicio y cuantificación de los mínimos GSE requeridos para la demanda según la distribución de la modalidad planteada

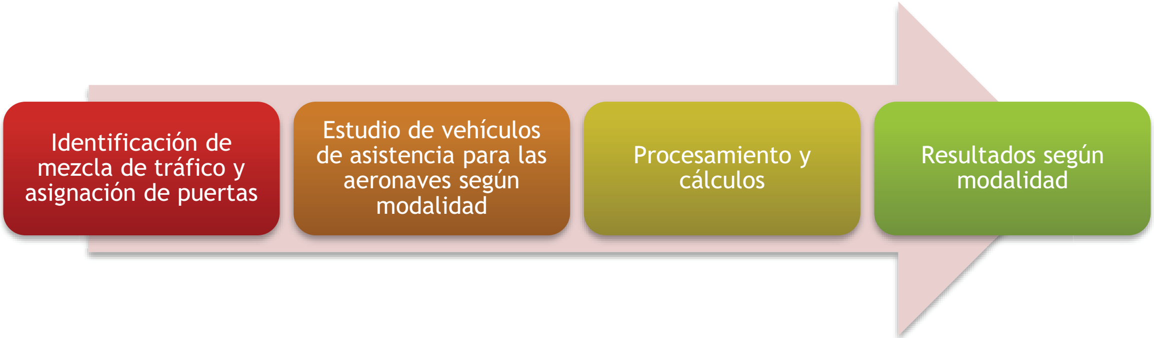

Figura 3 Proceso lógico de trabajo para determinar la contaminación gaseosa y cantidad de vehículos requeridos

El esquema dispone de un orden para cuantificar las emisiones de los GSE que básicamente corresponden a los dos estados propuestos: *servicio* y *circulación*. Para el primero, a partir del modelo sofisticado para el cálculo de las emisiones brindado por la OACI, el presente considera un ajuste debido a la discretización en los procesos de descarga y carga a las aeronaves en los factores de carga y los tiempos según la etapa correspondiente (espera, conexión, servicio y desconexión). Dicha discretización utiliza tiempos observados y asigna factores de carga determinados por la acción de cada vehículo con el objetivo de precisar los valores a una aproximación real.

Se presenta entonces el modelo ajustado correspondiente a las emisiones por servicio de los GSE, donde se propone la discretización en las etapas de espera, conexión, servicio y descarga tanto para la descarga como para la carga de la aeronave:

$$\boldsymbol{E_{i,l}} = P_l . FE_{i,l} . f_{d_t} . \sum_{j=1}^{8} (fc_j . t_j)_i \qquad \text{Ec. 1}$$

A su vez, de manera análoga, se presenta la expresión general para el cálculo de emisiones producto de la circulación, que corresponden a una plataforma tipo de 1600m x 160m, con una velocidad promedio asignada a los vehículos de 20km/hs.

$$\boldsymbol{E_{i,l}} = P_i . FE_{i,l} . f_{c_l} . f_{d_l} . \frac{1}{Vel_l} . d_l \qquad \text{Ec. 2}$$

Dónde,
$E_{i,l}$: Emisión gaseosa del contaminante ‘i’, respecto del equipo GSE ‘l’. $[g]$
P_i: Potencia al freno del equipo GSE ‘l’, $[HP]$
$FE_{i,l}$: Factor de emisión del contaminante ‘i’, respecto del equipo GSE ‘l’, $\left[\frac{g}{HP.h}\right]$
f_{c_l}: Factor de carga del equipo GSE ‘l’
f_{d_l}: Factor de deterioro del equipo GSE ‘l’
Vel_l: Velocidad de circulación en plataforma del equipo GSE ‘l’, $\left[\frac{km}{h}\right]$.
d_l: distancia de traslado del equipo ‘l’, $[km]$.
f_{c_j}: Factor de carga del equipo GSE por cada tiempo discretizado ‘j’, según operación de carga y descarga

f_{d_l}: Factor de deterioro del equipo GSE 'l'
t_j: Tiempos discretizados de los GSE para la carga y descarga, $[h]$.

Los factores de carga son aquellos que afectan la potencia máxima, obtenidos y ajustados en función del relevamiento en campo, la bibliografía de referencia y promediando los valores para los modelos observados según grupo de GSE. A continuación, se puede observar los valores adoptados para el modelo para las operaciones de carga y descarga de equipaje, mercancías y movimiento de pasajeros: dichos factores se han dimensionado en función de las curvas características potencia-RPM, según la motorización de cada vehículo para cada estado operativo. Vale indicar que, para la circulación, se ha considerado un 'FC' considerando a los vehículos en ralentí, es decir, valores de 0,2.

Tabla 2 Promedio de los factores de carga para los GSE según proceso de descarga o carga

	Descarga				Carga			
GSE	espera	conexión	servicio	desconexión	espera	conexión	servicio	desconexión
TUG	0	0	0	0	0,40	0,40	1	0,40
GPU	0	0	0	0	0	0	0,75	0
BAG	0,36	0,36	0,55	0,36	0,36	0,36	0,55	0,36
BEL	0,36	0,36	0,50	0,36	0,36	0,36	0,50	0,36
BRE	0,53	0,53	1	0,53	0,53	0,53	1	0,53
BUS	0,20	0,20	0,20	0,20	0,20	0,20	0,20	0,20
CLE	0	0	0,33	0	0	0	0,33	0
FUE	0	0	0	0	0,25	0,25	0,25	0,25
WAT	0	0	0	0	0,20	0,20	0,20	0,20
STA	0,57	0,57	0	0,57	0,57	0,57	0	0,57
CAT	0	0	0	0	0,53	0,53	1	0,53

Los factores de emisión se obtienen de la base de datos generada por la EPA (United States Envirnomental Protection Agency) generadas a partir de ensayos en banco de los motores sin horas de uso, a máxima potencia y según tipo de combustible. A continuación, se muestra la tabla con los factores de emisión según gas contaminante para los GSE utilizados.

Tabla 3 Factor de emisiones correspondientes al 2010 según GSE

GSE	FE (gr/HP*hs)				
	CO	HC	NOx	SOx	PM10
TUG	1,503	0,327	4,485	0,054	0,285
GPU	0,961	0,297	4,135	0,054	0,247
BAG	3,873	0,369	4,261	0,060	0,502
BEL	2,553	0,381	4,544	0,060	0,396
BRE	0,110	0,130	2,500	0,221	0,167
BUS	0,110	0,130	2,500	0,221	0,167
CLE	0,654	0,255	2,417	0,048	0,070
FUE	0,614	0,245	2,184	0,048	0,064
WAT	0,804	0,290	2,898	0,049	0,128
STA	0,801	0,289	2,891	0,049	0,128
CAT	0,449	0,203	1,037	0,044	0,066

El factor de deterioro amplifica el valor de las emisiones producto de los años de uso. Para ello, se utilizado la ecuación que propone la EPA [15]:

$$f_d = 1 + A.\left(\frac{GSE_{año}}{GSE_{vida\ útil}}\right)^b \qquad \text{Ec. } 3$$

En donde para cada contaminante, se dispone de dos tipos de coeficientes auxiliares para el cálculo de deterioro según su respectivo rango de potencia. Estos coeficientes se encuentran actualizados al año 2010, propuesto para el estudio, con lo que se asume por defecto que los equipos llevan en servicio 9 años; además el factor de deterioro depende del año de servicio y la vida útil promedio del equipo GSE. Con los respectivos coeficientes, en conjunto con los años de servicio y los años de vida útil de cada equipo, se obtienen los factores de deterioro como se muestra en la siguiente tabla.

Tabla 4 Factor de deterioro obtenidos por GSE

GSE	FD				
	CO	HC	NOx	SOx	PM10
TUG	1,086	1,015	1,005	1,000	1,270
GPU	1,120	1,022	1,006	1,000	1,378
BAG	1,092	1,017	1,005	1,000	1,291
BEL	1,109	1,020	1,006	1,000	1,344
BRE	1,100	1,018	1,005	1,000	1,315
BUS	1,100	1,018	1,005	1,000	1,315
CLE	1,120	1,022	1,006	1,000	1,378
FUE	1,086	1,015	1,005	1,000	1,270
WAT	1,120	1,022	1,006	1,000	1,378
STA	1,120	1,022	1,006	1,000	1,378
CAT	1,120	1,022	1,006	1,000	1,378

El tiempo requerido para el servicio de las aeronaves influye directamente en la utilización de las puertas en el aeropuerto y la cantidad de vuelos diarios, y depende en el tipo de aeronave, número de pasajeros, carga y descarga de equipaje [16].

Los tiempos de servicio teóricos asociados a cada aeronave se encuentran en su respectivo Airport Planning Manual. No obstante, tal como se menciona previamente, en el modelo de emisiones propuesto se contempla la caracterización del proceso de asistencia a la aeronave según los tiempos observados en el Aeropuerto Jorge Newberry discretizados en cada estado. Tal como se menciona en la EC. 1 y se indican en la tabla a continuación.

Tabla 5 tiempos de cada GSE según discretización propuesta

GSE	tiempos (hs)			
	espera	conexión	servicio	desconexión
TUG	0,006	0,026	0,032	0,005
GPU	0,000	0,006	1,171	0,006
BAG	0,021	0,006	0,053	0,003
BEL	0,027	0,008	0,200	0,031
BRE	0,020	0,031	0,033	0,024
BUS	0,003	0,018	0,031	0,000
CLE	0,000	1,000	2,000	3,000
FUE	0,236	0,021	0,129	0,031
WAT	0,004	0,005	0,014	0,004
STA	0,004	0,018	0,008	0,000
CAT	0,009	0,028	0,075	0,028

Las distancias de traslado dependen fundamentalmente de la configuración geométrica de la plataforma de terminal de pasajeros y de la ubicación de las áreas definidas (puntos 'base') para estacionamiento de los equipos GSE por lo que se debe tener en cuenta algunas consideraciones para las distancias recorridas, según el tipo de procedimiento propuesto.

Tabla 6 Tipos de Procedimiento según puestos de estacionamiento de vehículos GSE

Tipos de procedimiento	GSE	Puesto de estacionamiento
A	Cinta transportadora Remolque de aeronaves (TUG) Tractor para GPU Escalera de pasajeros Limpieza aguas residuales Abastecimiento Agua Potable	Ubicados en área de espera (ESA) de acuerdo con sus tiempos de servicio por aeronave [1].
B	Tractor carga de equipaje Bus MR (movilidad reducida) BUS	Área de estacionamiento fija [2].
C	Camión catering Camión cisterna de combustible	Los vehículos de catering se encuentran estacionados fuera de plataforma [3]. El camión cisterna tiene puestos de estacionamientos asignados en la planta de combustible dentro del predio aeroportuario.

[1] La secuencia de circulación en plataforma depende de la disponibilidad de cada grupo vehicular de servicio.
[2] Se elige de tal manera que lo óptimo es que el equipo esté siempre en movimiento entre este punto y cada puesto de estacionamiento de aeronave.
[3] Los vehículos tienen una capacidad de carga mayor, de tal manera que estos salen del puesto de estacionamiento y pueden brindar un servicio a mayor cantidad de aeronaves.

A continuación, se presentan consideraciones para cada procedimiento:

Procedimiento tipo A: De acuerdo con la disponibilidad del equipo se puede simular que se traslada entre puestos de estacionamiento temporales (ESA) dependiendo de la cantidad de puestos de aeronave (Tipo C como se encuentran definidos en la configuración de plataforma) que tienen que recorrer para su siguiente servicio.

Procedimiento tipo B: Este grupo vehicular siempre tienen que volver a un área de operaciones fija definida después de brindar el servicio a la aeronave, por lo tanto, es sencillo calcular su distancia de traslado debido a que el equipo se dirige hacia cada puesto de estacionamiento de aeronaves y vuelve a su área fija definida antes de trasladarse a otra aeronave.

Procedimiento tipo C: Como estos equipos cuentan con un puesto de estacionamiento fijo se puede estimar sus distancias de traslado dependiendo del primer arribo y luego la posibilidad de una secuencia de servicio para tres aeronaves más, aunque depende de la capacidad de carga, antes de volver a su puesto de estacionamiento fijo para reabastecerse o descargar residuos.

Para identificar la cantidad mínima de vehículos, el modelo desarrollado identifica el tiempo de circulación de los vehículos una vez arribada la aeronave y los tiempos de las etapas durante el servicio. Luego aplicado el servicio, la circulación correspondiente será para la aeronave siguiente y así sucesivamente. Por lo tanto, la suma de dichos tiempos indicará si el vehículo está disponible o no para asistir a la siguiente aeronave. Es fundamentalmente importante el desarrollo de dicho modelo que considera aquellos tiempos de circulación, que pueden ser críticos, por ejemplo: el tiempo de traslado a puntos extremos de plataforma desde puestos de estacionamiento fijos o temporales de GSE; o tiempo de traslado para la máxima distancia de traslado por tipo de procedimiento de asistencia. Los resultados generan para cada tipo de servicio, la cantidad mínima de vehículos necesarios para la asistencia de las aeronaves en plataforma en el tiempo bajo estudio.

Plataforma de referencia

La plataforma de Aeroparque corresponde a un aeropuerto representativo en Argentina debido a la cantidad de movimientos diarios, contando con una plataforma tradicional rectangular que al discretizarse en el modelo luego se pueden desarrollar y estudiar plataformas con configuraciones geométricas similares tipo ‘I’, ‘L’, ‘U’, ‘C’.

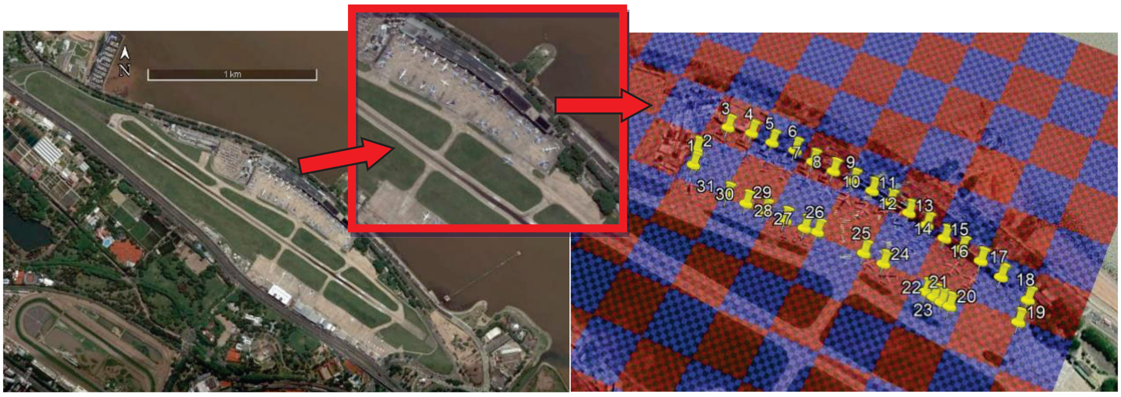

Figura 4 Izq.: Vista aérea del Aeroparque Jorge Newbery y su plataforma aerocomercial de pasajeros estudiada. Der.: Identificación de puestos y ubicación según el mallado propuesto

Mezcla de tráfico analizada

Para el análisis de la mezcla de tráfico se ha identificado el día promedio del mes pico mediante la metodología IATA para el aeropuerto de Aeroparque en el año 2018, resultando ser el 29 de agosto. A continuación, se presenta una tabla que representa la cantidad de movimientos en el día bajo estudio:

Tabla 7 Aeronaves y movimientos (arribos y despegues) para el día promedio analizado

Aeronave	Movimientos
A320	60
B737 800W	126
E190	76
B737 700	42

Resultados

A continuación, se vuelcan los resultados comparativos entre las distintas modalidades propuestas, en donde se puede observar la cantidad de vehículos requeridos para dichas situaciones.

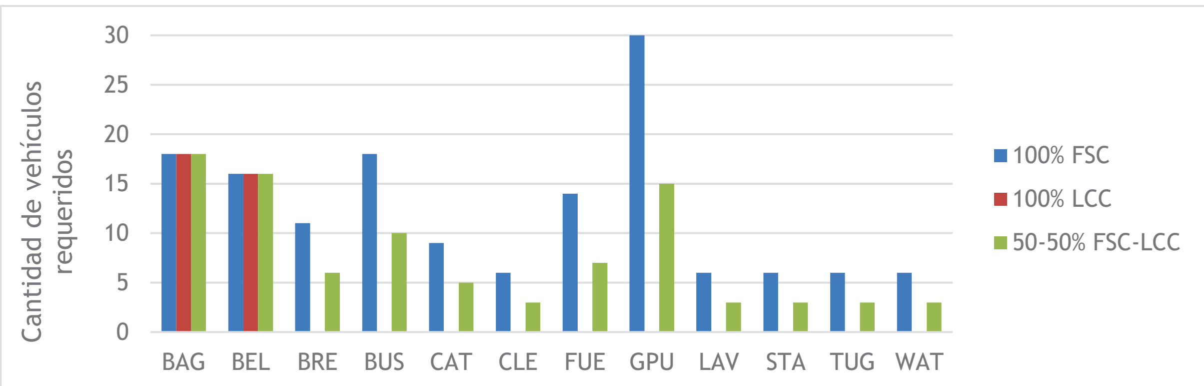

Figura 5 Cantidad de vehículos según operaciones propuestas

Por otra parte, se presentan los resultados que reflejan la cuantificación de las emisiones gaseosas totales según los vehículos requeridos en función de las demandas planteadas. Se puede observar a continuación como los gases CO y NOx son predominantes frente a los otros analizados (en donde se suman entre ellos a fines comparativos con los predominantes).

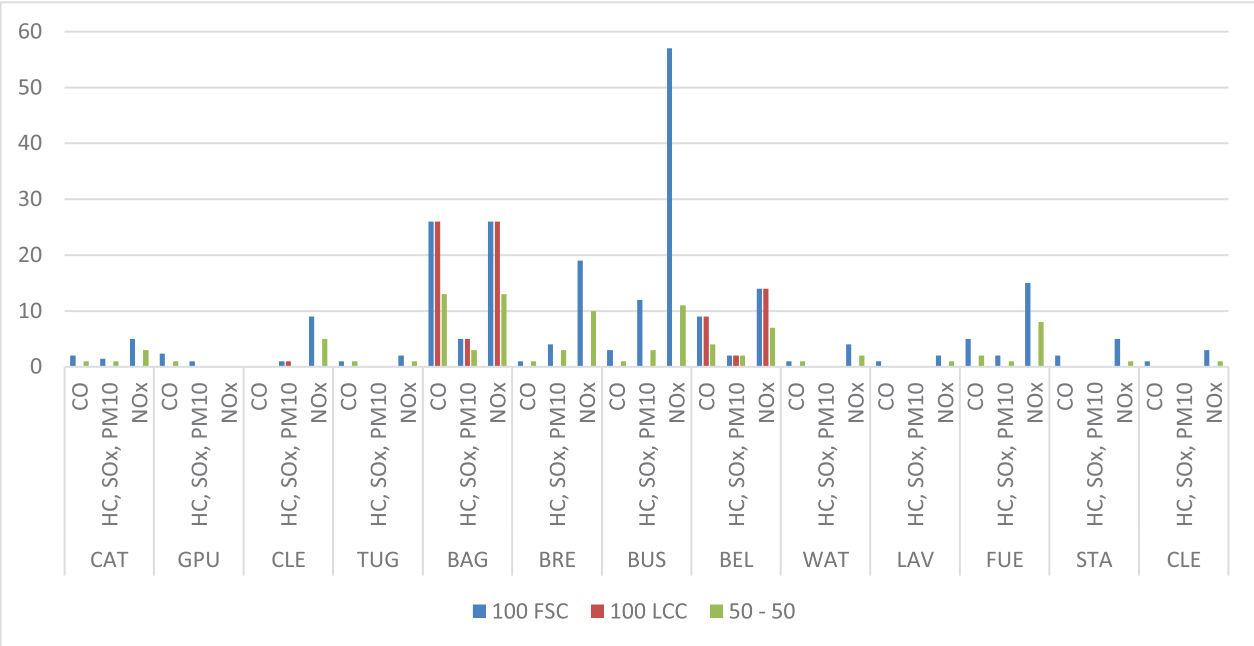

Figura 6 Emisiones en kilogramos según GSE para distintas demandas

En el siguiente gráfico se presenta, el promedio para las operaciones propuestas, la distribución de las emisiones totales, según servicio y circulación.

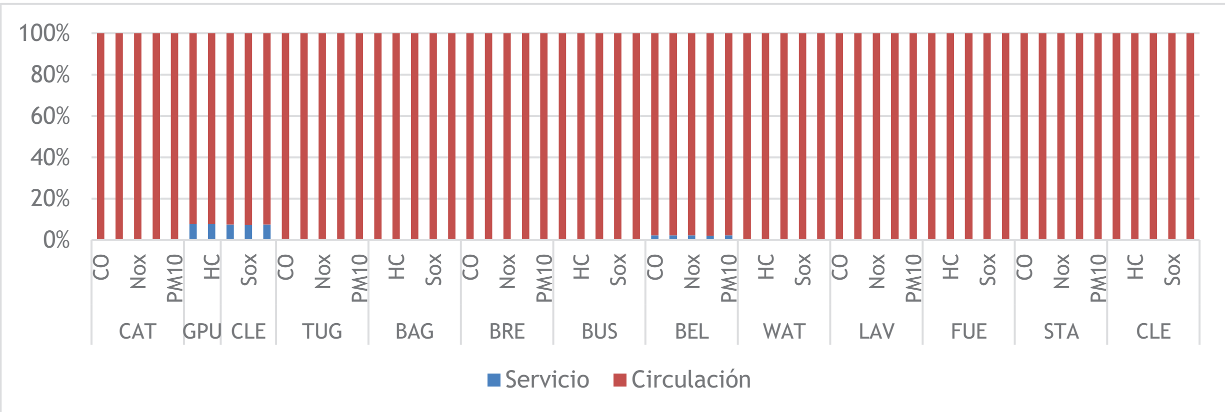

Figura 7 Emisiones generadas por circulación y servicio para diferentes demandas

Conclusiones

De los resultados se puede comparar la cantidad de vehículos requeridos según demanda operativa dentro del aeropuerto, siendo proporcional a esta las emisiones generadas. A su vez, es posible observar que a mayor porcentaje de vuelos FSC, mayor es la cantidad de vehículos requeridos. Esto se debe a la hipótesis planteada en el requerimiento de los GSE según operación. La mayor cantidad de vehículos corresponden a los 'GPU' debido fundamentalmente a su tiempo de servicio y, por otro lado, se puede observar que se requieren de la misma cantidad de vehículos ‘Bagagge’ y ‘Belt loader’, debido a que son independientes de la demanda. Estas observaciones son importantes a la hora de analizar distintos factores que se deben tener en cuenta en las dimensiones de plataforma, respuesta a la demanda operativa, tiempos de servicio, etc.

Respecto a las emisiones totales, se puede observar que el NOx generado por el ‘Bus’ para la operación 100% FSC se destaca por sobre el resto, duplicando a su vez a quien le sigue: los ‘Bagagge’. En cuanto a la operación 100% LCC se puede observar que, a pesar de tener una menor cantidad de vehículos requeridos, las emisiones generadas por aquellos indispensables como el ‘Bagagge’ y ‘Belt loader’ son realmente importantes, duplicando por ejemplo a los valores de los mismos vehículos en la demanda de 50% FSC-50% LCC.

Además, es importante reconocer que el modelo cuantifica emisiones según servicio por etapas y también por circulación. Por lo tanto se puede, además de sumar la contribución total, comparar ambas e identificar aquella que sea preponderante ante la otra con el objetivo de visualizar aquellos GSE que más emiten contaminantes y durante qué proceso. Por lo tanto, es notorio el peso relativo que tienen las emisiones producto de la circulación en comparación con el servicio, promediando estos el 1% respecto al primero, independientemente de la demanda. Estos resultados implican nuevas líneas de estudio: hasta aquí las emisiones provocadas por los vehículos de asistencia correspondían a los servicios sin tener en cuenta los recorridos en plataforma, siendo apenas un 1% en promedio, respecto a las emisiones totales generadas por estos.

Para lograr una caracterización completa de los gases contaminantes producto de la actividad aeroportuaria este tipo de estudio debe ser complementado con el análisis de las emisiones de las otras fuentes presentes en un aeropuerto: parte pública, fuentes puntuales, Ground Access Vehicles (GAVs), entre otros tantos.

Mitigación

Tras analizar distintas bibliografías y analizar los resultados, la mejora de la eficiencia de los motores de los GSE es una de las principales medidas a tomar para disminuir la formación de partículas ultrafinas. Por lo tanto, se propone el reemplazo con motores diésel más actualizados o motores eléctricos. Además, también podría resultar factible proporcionar el suministro eléctrico de los aviones directamente desde la central de suministro, en lugar de utilizar una unidad de suministro portátil (GPU).

Y, fundamentalmente el análisis que surge del corriente estudio y abre nuevas líneas de investigación son la optimización y la buena logística para reducir tiempos y recorridos con el objetivo de minimizar las emisiones en el entorno aeroportuario de los GSE.

Agradecimientos

Se agradece a la Comisión de Investigaciones Científicas (CIC) de la Provincia de Buenos Aires por el financiamiento mediante beca de investigación a distintos autores del presente trabajo.

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Errors and human factors in the passengers screening checkpoints of Brazilian airports from a security culture perspective

Michelle Salgado Ferreira Arcúrio - michelle.arcurio@gmail.com
Universidade de Brasília
Rafael Rodrigues Dias Pereira - rafaelrodriguesx@gmail.com
Agência Nacional de Aviação Civil

Abstract

The objective of this study was to evaluate the potentials errors and human factors related to security culture that might influence the performance of the passengers screening checkpoints of Brazilian airports.

In a previous study the incidence of errors and human factors in the security screening process at Brazilian airports was identified. This finding led to the analysis of team work activity in the screening checkpoints from a security culture perspective. For this purpose, were analyzed items of a self-observation questionnaire based on the theory of Generic Error–Modelling System and the framework recommended by the ICAO.

The results indicated the presence of fundamental elements for the formation of an adequate security culture among the professionals. Otherwise, the data also indicate the presence of human factors associated to the security culture with the potential of negatively influencing the performance of the passenger screening activity.

The research contributes to improve the knowledge of the relationship between security culture and performance in the airport security screening activity. Besides that, it identifies some specific relationship that exists in the Brazilian operational reality, that allows the formulation of roadmap plans to improve the system.

Keywords

Errors and Human Factors; Security Culture; Airport Screening Checkpoints; Brazilian Airports

Errors and human factors in the passengers screening checkpoints of Brazilian airports from a security culture perspective

1. INTRODUCTION

An airport operator has the primary objective of ensuring the provision of airport services that allow the transportation of persons and goods by air. This primary objective corresponds to a practical goal associated with the production purpose of the organization. However, as in other complex systems, guaranteeing the safety and security of air transport operations is a fundamental condition for achieving this primary objective.

Thus, safety and security assurance allows airport organizations to achieve their production objectives, under a condition of lowest cost possible to infrastructure, human resources and users of air transport. It is known that the level of safety expected by the organization can be affected by the incidence of human error in operations that, in turn, becomes a problem that needs to be managed. That is, the error effect becomes a relevant component to be evaluated in order to reach the primary results of an airport organization [1].

The control of human error in airport security screening checkpoints may be intrinsically linked to the results derived from the security culture perceived by the individual. For this reason, the apprehension of a security culture at an individual level may be essential to mitigate the incidence of error in the airport system.

In this article, concepts and approaches derived from the organizational and safety culture were used as subsidies for the construction and understanding of the security culture concept. With this we hope to enrich and broaden the spectrum of theoretical and technical discussion about the subject.

The purpose of this article is to provide a more in-depth analysis of the errors occurring in Brazilian airport screening checkpoints that are predominantly determined by human factors associated with Security Culture.

As a pioneering study in Brazilian reality, the findings of this study bring the possibility to discuss and demonstrate the impact of the security culture as an elementary variable in the screeners' activities.

2. THEORETICAL REFERENCE

2.1 Organizational and Security Cultures

Organizational culture refers to shared values, beliefs, and behaviors by members of a particular organization and it comes from an interactive process among employees [3].

In this sense, according to the literature [3], the context of an organization is permeated by the schemes related to individual knowledge and cultural meanings, so that, when activated through interaction in the social context of the organization, a cultural experience for individuals is created.

From this perspective, organizational and social cultures are constructed by shared realities [3]. Once constructed, these cultures may have a certain deterministic function in relation to behavioral choices as a function of shared reality.

The authors [3] identified three important characteristics to understand the effect of culture on human behaviour, namely: (i) limited rationality (the available information is full of meanings constructed) affects how decisions are made - employees can make decisions based on their own goals; (ii) social and organizational cultures restrict individuals' potential choices, as they are filled with prohibitions, rules and norms that limit the options available; and (iii) constraints on behavioral choices imposed by cultures are ideally designed to influence individual choices with the intention of maximizing the likelihood that they are done congruently for the good of the collective.

The security (or safety) culture refers to the value or importance that the company and its members attach to safety [4]. If security is really important, it is expected that the organization's performance (decision-making, resource allocation, formal and informal rewards systems) will reflect such importance.

The authors mentioned here mention three constructs pertaining to the security culture: (i) Company security climate: refers to shared perceptions among company members about how security is managed. (ii) Team security climate: shared perceptions among members of the organizational unit about how security is managed; (iii) Security Conduct: The degree to which each individual behaves safely at his or her workplace or commits risk.

The assignment of these constructs in the literature on security culture denotes its complexity and the detailed form in which each variable must be studied, at the organizational, team or individual level.

2.2 Security Culture and Human Factors

The evaluation of safety culture has become a habitual practice of high reliability organizations, since culture is a determining factor of organizational factors and individual and collective behaviour [4].

From the perspective of the technical literature, the organizational security culture shapes the behaviour and structure of an individual's world perception, therefore, its relevance to the study of human factors incident to safety operating systems. In this direction, culture is constituted as a collective mental programming that distinguishes one group from another, predisposes certain attitudes and influences on the behaviour of individuals [5].

As far as standards are concerned, security culture constitutes an acceptable standard of values, attitudes and behavior. The energetic way in which the culture outcasts those who violate the norm denotes the degree of importance relevant to it. Thus, organizational culture can allow or prevent violations of a given norm, since situations can occur where the common values of individuals and the group favor certain types of behaviours and attitudes [1].

If there are no interventions to deviations from the established norm, behaviors that put at risk or that bring vulnerabilities to the system can be recurrent and can become over time a collective mental programming, in other words, they become part of the organizational culture.

2.3 Errors and Human Factors in the Airports Screening Checkpoints

The control of human error in airport screening checkpoints may be intrinsically linked to the results derived from the security culture perceived by the individual. For this reason, the apprehension of a security culture at an individual level may be essential to mitigate the incidence of error in the airport system.

Considering the human factors that are decisive for the incidence of errors, the document DOC 9808 [6] was developed to seek the application of standards in security operations. Therefore, this document presents a framework of four thematic axes, according to Figure 1.

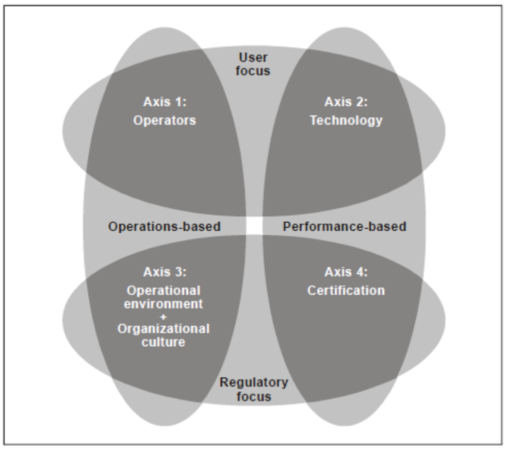

Figure 1 – Schematic representation of ICAO framework
Source: [6]

The fundamental premise of DOC 9808 [6] is that a comprehensive and systemic framework is needed to address a number of human factor issues in operations related to aviation security. The establishment of such a framework can contribute to improving the performance of the entire aviation security system.

Previous researches began the design of studies on the errors and human factors incident in the screening checkpoints of Brazilian airports [2], [7]. In these researches, the results indicated the individual perception about the influence of ten human factors that determine the incidence of errors in the Brazilian airports´ screening checkpoints. The factors covered by the Operational Environment and Organizational Culture (Axes 3) were those reported to be the ones that most influence the degree of occurrence of errors in passenger screening checkpoint in Brazilian airports.

The organizational culture in the airport passenger screening checkpoint, strictly speaking, refers to the working conditions offered to these professionals, the quality of the security equipment and other resources that might be required to perform their duties, how they are managed, the qualification of the professionals and the income perceived.

In light of the literature on error management, the way how errors are managed within a unit of work can influence the perceived costs or benefits by employees associated with leadership. Thus, punitive environments can make employees more reluctant to learn and develop leadership skills [8].

2. Passenger´s Screening Checkpoints Operations

The nature of screening process is fundamentally collective. Thus, to understand the activity performed in the screening checkpoints, the integration of security functions has fundamental importance. Each security professional performs certain functions and the sequence of actions creates a cycle. In this way, the accuracy of each individual's performance can result in the success or failure of the screening process. The team is responsible for detecting and recognizing threats, making decisions, solving problems, planning the daily work routine and designing solutions in an integrated way.

The duties performed by security professionals are based on previously established codes, either by means of standards, procedures or work instructions. Each professional is engaged in a certain task and must interpret the information received and take decisions. For example, in some situations one security professional has to inform the passenger about the need of a manual search based on the decision made by another member of the work team on the screening checkpoint.

The collective work also has knowledge and representations that are distributed among the team members. The collective dimension of the work constitutes a common base of information regarding the different tasks and actions, besides being formed by the coexistence and experience of the professionals, by the codification of information about a given situation that makes possible to anticipate the actions of the other members of the team and restructure their own actions [9].

This common base of information, which structures actions and interaction among team members, forms shared cognition, which should be considered in studies of complex systems. This is because operators are confronted with diversified tasks that require different skills, but whose articulation between tasks (tasks and competences) is essential for achieving organizational objectives and goals.

It is therefore assumed that the integration of competencies, which allow and favor the coordination of joint actions in the screening checkpoint, contributes to the resolution of problems, decision making, that is, they emphasize the role of the collective and the importance of the sharing of information for the success of the work performed.

Knowing that teamwork reflects the interaction between people, it requires, therefore, interaction between different personalities, leadership and sense of cooperation. As a group, a team can acquire its own characteristics that can influence and determine the behaviour and performance of professionals [5].

In this interaction, the relationship between professionals and the administrative area is still included, since the pressures from the administrative sector regarding the requirements of best practices and higher levels of performance, depending on the way in which they are conducted, can significantly affect human behaviour.

It adds to the fact that they are embedded in a given organizational culture, that security professionals are also embedded in an operating environment that demands a high level of accuracy in their work. In addition to being subjected to pressure from passengers, other members of their workforce, their supervisors, and the police authority, security professionals tend to feel pressured to expedite the analysis of the screened objects. For example, the pressure from both the airport operation department and the airlines against any delays caused by the passenger screening process was detected by study [14].

In general, professionals who specialize in the interpretation of images generated by X-ray equipment must perform the task for a continuous period of time not exceeding the minutes established by the authority, so that this activity is rotated among other members of the team [6], [17], [18]. Thus, the number of cabin baggage and passenger belongings to be evaluated, which require the analysis and the decision by the security professional specialized in x-rays images, is high in the hours of greater movement of passengers. The need for speedy passenger and baggage processing is in line with the nature of air transport service and international best practices [19].

In view of the factors mentioned, it is noted that the activities carried out in the screening checkpoint are influenced by variables such as: the volume of passengers processed, the experience of the security professionals, the supervision of the police authority, the own airport operator and the technologies used.

Finally, regarding the way of hiring the labor force to screening checkpoints, in the Brazilian case, it is quite common for the airport operator to use outsourcing, that is, the screening checkpoints ends up being operated by professionals who are directly linked to aviation security organization or company, rather than directly linked to the airport operator.

3. METHODS

In an earlier study [2], the authors have employed the Theory of Generic Error Modelling System (GEMS) [10] and the Framework of four principal axes on human factors recommended by the International Civil Aviation Organization [6] to elaborate a self-observation questionnaire, composed by 60 (sixty) items (assertive or issues) associated with errors or human factors that may affect the operations of passenger screening checkpoints.

Among the 60 questions of the questionnaire, 46 of them were categorized into seven principal components (PC) by Principal Component Analysis (PCA). These PC represented 42.04% of the total proportion explained by the variance of the data, in other words, the human factors and errors that were searched.

The survey respondents could assess, by means of a Likert-type scale, the level of frequency, intensity, or agreement with the statements or questions presented in the questionnaire. The evaluation options on the Likert scale are shown in Table 1.

Table 1 - Options of evaluation from the Likert scale
Source: Adapted from [2]

Items (Type of evaluation)	*Likert* Scale (Options of evaluation)				
Level of frequency	Never (N)	Sometines (S)	Often (O)	Mostly (M)	Always (A)
Level of intensity	None (N)	Low (L)	Medium (M)	High (H)	Total (T)
Level of agreement	Totally Disagree (TD)	Disagree (D)	Indiferent (I)	Agree (A)	Totally Agree (TA)

The questionnaire was applied to a representative sample of the universe of professionals working in the passenger screening checkpoint at Brazilian airports, in the period of 2013 and 2014. The participants of the survey totaled 602 professionals, distributed in 18 Brazilian airports, as shown in Figure 2.

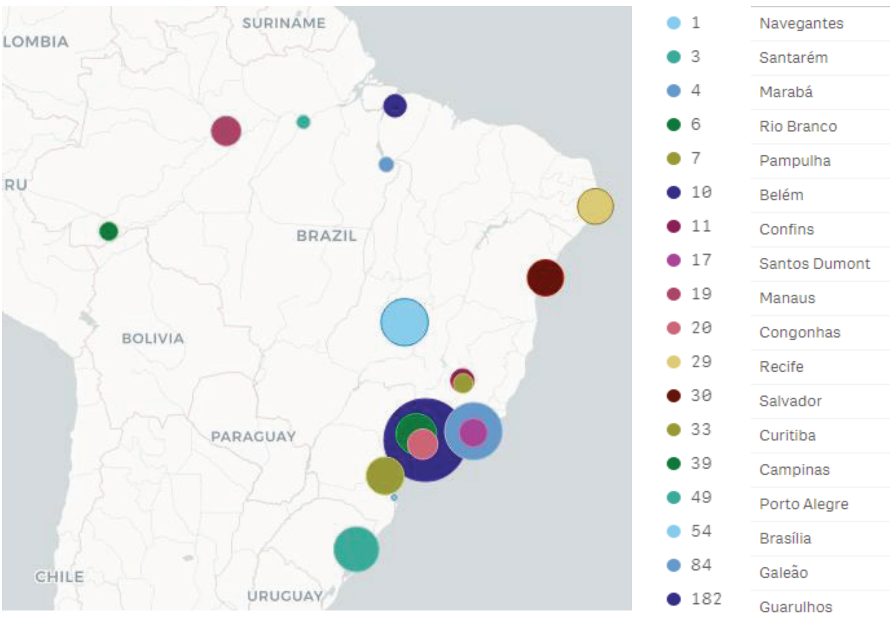

Figure 2 – Distribution of survey participants on Brazilian airports.
Source: [6]

The workers interviewed (universe in study) complies with the rules of specific training for staff performing aviation security functions and the training is according with the requirements of the Brazil´s National Civil Aviation Security Training Program (NCASTP). This Program establishes the certification process, which includes the training phase, applicable to all professionals who will perform security duties at Brazilian airports, in particular duties related to the screening of persons and objects.

For the current study, it was performed the exploratory analysis of the data obtained through self-observation questionnaire items directly linked to the security culture. In the universe of 60 (sixty) questionnaire items, there were 10 (ten) items (assertive or questions) related to the security culture, as indicated in Table 2. The identification numbers shown in Table 2 correspond to the question's number in the applied questionnaire.

Table 2-List of questions related of Security Culture
Source: Adapted from [2]

Items ID	Items Description	Types of Error or Human Factors
Q05	If I am working with flow control in hours of great flow of passengers, how often do I advise a coworker who is operating the X-ray equipment about the situation of the queues?	Human factor: security culture and operating environment Error: skills - omission by interruption
Q32	The work that I do is important to the society.	Human factor: security culture
Q33	The work that I do is valued by the organization.	Human factor: security culture and operating environment - retention of staff
Q46	Most of the errors that occur in the screening checkpoint are due to the fact that professionals are not correctly supervised, by airport´s operator, and/or by police department responsible for AVSEC in the airport.	Human factor: security culture and operating environment
Q48	Most of the errors that occur in the screening checkpoint are due to the managers who do not transmit objective job´s instructions.	Human factor: security culture and operating environment
Q50	It is fundamental to report failures and errors that occur in the screening checkpoint through non-punitive ways, in order to orient the AVSEC professionals how to avoid them.	Human factor: security culture
Q51	I feel comfortable to report failures or errors that occur in the screening checkpoint.	Human factor: security culture
Q54	To do my work at the screening checkpoint, I feel supported either by the police department responsible for AVSEC in the airport, or by the airport´s operator.	Human factor: security culture and operating environment
Q57	When my physical conditions do not allow the adequate performance of my functions as Aviation Security Agent, I am temporarily removed from my activities, or I have the option of working in another function.	Human factor: security culture and operating environment
Q58	The available place for resting and/or feeding is not feasible to use during the interval time of working days.	Human factor: security culture and operating environment

4. RESULTS AND DISCUSSIONS

The following are the results and discussions on the ten items regarding on security culture.

Considering the moments of great movement of passengers (Q05, Fig. 3), it is observed that almost 60% of the interviewers affirm that "never" or only "sometimes" decide to alert the X-ray screener about the situation of the queues. However, there are still a significant number of professionals, approximately 40%, who say they alert the operator "frequently" or "mostly" or even "always" at times of great movement of passengers.

This result suggests that the need for speedy in processing of passengers to maintain queue size at a level considered acceptable influences, to some extent, the work process of the professionals, in a negative way, that is, may cause involuntary suppression of some stage of the procedures due to interruptions (error: omission by interruption). A more robust security culture coupled with a more balanced operating environment in relation to the capacity to serve the users can be elements that help prevent this type of error.

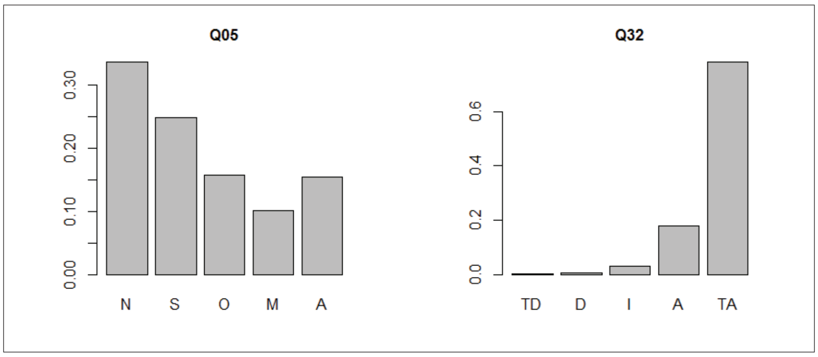

Figure 3 – Results of Questions 05 (advise about the situation of the queues) and Question 32 (importance of the job to the society)
Source: Authors

Regarding the importance of performance of screening work for society (Q32, Fig. 3) the result indicated almost 80% of total agreement by the research´s participants. Thus, there is an important degree of awareness among screening professionals regarding the relevance of their activity to protect society against intentional threats to air transportation. However, we dare to say that full agreement with the affirmative of question 32 should have reached the entire population surveyed, given the criticality of the activity to ensure the protection of air transport.

On this level of awareness, as explained by Salter [12], besides the technical competence, the perception of the value of the organization's mission must be aligned with the responsibility and recognition of the professional about their real contribution to security. This is because the technical competence to evaluate prohibited items or perform screening procedures can be trained and evaluated. But valuation of the mission or commitment to the organization and values of security is more difficult to grasp and evaluate.

When we refer to the appreciation of work by the contracting organization (Q33, Fig. 4), approximately 35% said they agree or totally agree with the appreciation given by their organization. On the other hand, a greater proportion of professionals, almost 45%, indicated that they did not agree with the existence of a valorization by the contracting organization.

It is important to analyze this result considering the way of hiring the majority of security professionals who work in the passenger screening checkpoints in Brazilian airports. The model most commonly used by airport operators is the outsourcing of this activity to companies specializing in providing civil aviation protection services, that is, security

professionals are not directly related to the airport operator, who is the primary responsible for ensuring the effectiveness of the passenger screening process.

Regarding this type of hiring, Salter [12] emphasizes that a common result it is a practice of reduced wages and a high turnover of employees, which indirectly is a measure of low valorization of the organizational mission. Consequently, the professionalization of security agents got impaired, that is, it reduces the possibility of advancement in the professional career, under the aspects of salary differentiation, their technical specialization and attribution of responsibilities.

Other studies reached similar conclusions [13], [14], [15], where they showed that high turnover, low remuneration and inadequate training among security agents are largely responsible for poor security screening. These factors lead to low professionalization in the workplace. In short, there are insufficient rewards for highly regulated and rigorous labor, with little opportunity for career advancement or long-term job stability.

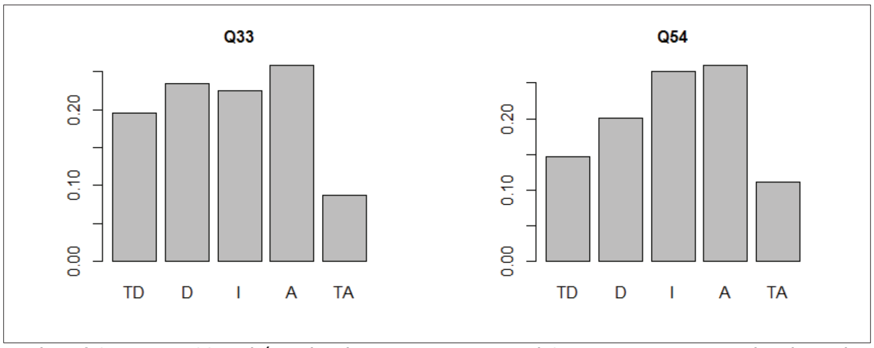

Figure 4 – Results of Questions 33 (job´s value by organization) and Question 54 (support by the police department or by airport operator)
Source: Authors

Still within the scope of institutional support given to the activity performed by screeners (Q54, Fig. 4), the results show that a considerable proportion of 35% of those interviewed do not feel supported by the police authority responsible for security oversight activities at the airport or even by the airport operator himself, who is directly responsible for airport security.

It can be seen that although the professionals have a very reasonable understanding of the importance of their activity, a significant part of them do not feel valued or adequately supported by their direct contractors, the airport operator or the airport police authority. This type of perception is critical, which may impair the effectiveness of the security measures applied in the screening checkpoint and would require the adoption of immediate corrective actions at the management level. The appreciation of the contractors and the airport operator and the support of the police authority to the activity carried out in the screening checkpoint are fundamental to legitimize the decision making of these professionals towards the users of the air transport [12], [16].

Regarding those more determinant factors in the incidence of misconceptions (Q46, Fig. 5), the results indicate that the majority of the respondents, 56%, do not agree (disagree or totally disagree), with the statement that most misunderstandings in the screening checkpoint come from a lack of proper supervision by the airport operator or the police authority. A little less than 30% of those interviewed agree with this statement.

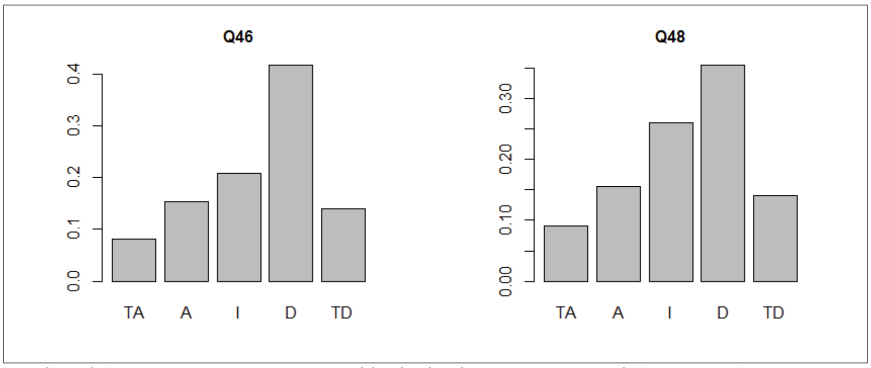

Figure 5 – Results of Questions 46 (errors caused by lack of supervision) and Question 48 (errors caused by lack of objective´s instructions)
Source: Authors

Still in relation to most of the misunderstandings that occur in the screening checkpoint (Q48, Fig. 5), it is observed that approximately 50% of the research participants also do not believe that it stems from the lack of objective work instructions by their managers.

It is verified that, despite the perception of lack of appreciation or adequate support for the screening activity by the responsible parties, it can be stated that a large number of professionals do not consider that most of the misconceptions committed in the screening checkpoint come from lack of supervision or lack of objective work instructions.

This result may confirm that most of the errors are more associated with the human condition [10] and can also guide us to reduce, relative to other factors, the weight given the lack of supervision as a determining factor in the occurrence of errors in the screening checkpoints of Brazilian airports.

Regarding the use of a system of failures and misconceptions´ reports, it is observed that 58% of the respondents stated that they agree (agree or agree totally) to report misconceptions or failures that occur in the screening checkpoint, using a non-punitive means, is fundamental to guide security professionals on how to avoid such misunderstandings/failures (Q50, Fig. 6). On the other hand, almost 55% of respondents did not say that they feel comfortable reporting failures or misunderstandings that occur in the screening checkpoints (Q51, Fig. 6).

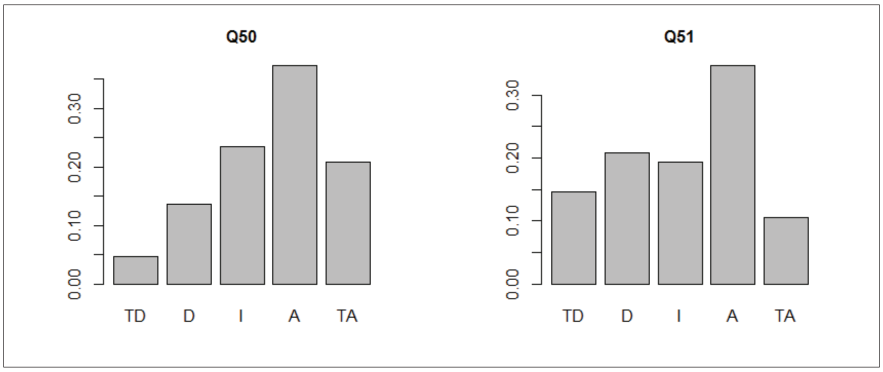

Figure 6 – Results of Questions 50 (importance of the failures report system) and Question 51 (feeling comfortable to use the failures report system)
Source: Authors

It can be seen that despite a predominant understanding of the importance of voluntary reporting of occurrences, which is in line with the theoretical argument [6], there seems to be no consolidated practice in the work routine of professionals or the availability of a system or mechanism that enables this practice.

Thus, responsible managers should adopt actions that would enable their full application, taking advantage of the existing awareness among the professionals themselves and, fundamentally, to know and map the errors involved in the operation of the screening checkpoint and the possible determinants factors of reality demonstrated in the reports.

In situations where the professional's physical conditions do not allow the proper performance of the security functions (Q57, Fig. 7), only 30% of the respondents agree (agree or totally agree) with the assertion that they are removed from their activities or have the option of working in another role.

This claim assumes that the organizational culture needs to be attentive to the issues related to the physical well-being of professionals, either through quality of life programs at work or those related to the ergonomics of the activity [11]. These measures favor and provide the necessary conditions to obtain higher indices of in-service performance and decrease of absenteeism rates.

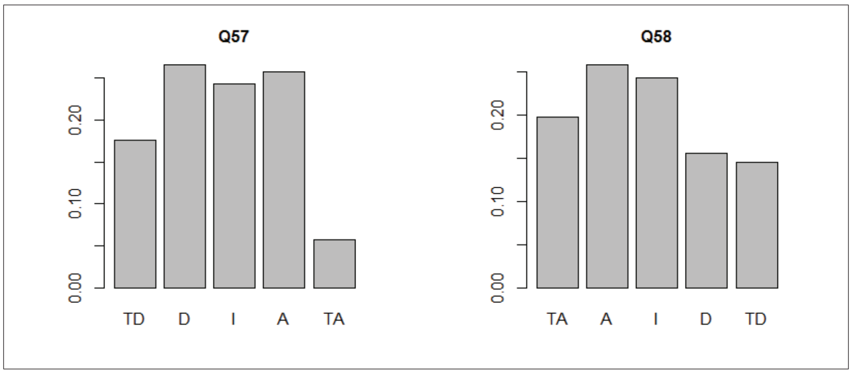

Figure 7 – Results of Questions 57 (physical conditions that not allow adequate performance) and Question 58 (available place for resting or feeding)
Source: Authors

Regarding the last evaluated aspect, concerning the quality of the feeding and resting places (Q58, Fig. 7), it is verified that almost 50% of the professionals agree (agree or totally agree) that these environments make it impossible to proper use the interval time of the working day.

Although it has not been stated under which aspects these places create difficult to enjoy the interval time (whether due to the distance between the screening checkpoint and the feeding/resting places, whether due to lack of light or insufficient space to welcome the team of professionals, if due to other deficient environmental factors), it is known that the airport environment is a rather complex place. In this sense, it is necessary to seek to identify the characteristics that can improve the benefits that the rest and feeding places can offer the security professionals.

4. CONCLUSIONS

The exploratory analysis of the data considered in this study indicated the presence of fundamental elements for the development of an adequate security culture among the professionals who work in the passenger screening checkpoint of the Brazilian airports.

The awareness of the majority of professionals regarding the relevance of their screening activity to protect society against intentional threats to air transport and the predominant understanding of the importance of voluntary reporting of errors and misunderstandings in the screening checkpoint are examples that demonstrate the presence of important elements for the formation and consolidation of an organizational culture that effectively contributes to the quality of the work of passenger screening applied in the airport environment.

On the other hand, the data also indicate the presence of human factors associated to the security culture with the potential of negatively influencing the performance of the passenger screening activity.

The concern to increase the processing of passengers, in order to keep the queues in size judged acceptable, generates the behavior of one professional to alert the other professional who is performing the interpretation of X-ray images. This behaviour may cause errors of the type "omission by interruption". The findings related to the professionals in not feeling valued or adequately supported by their direct contractors, the airport operator or the airport police authority, and the lack of a consolidated practice of reporting occurrences in the work routine of the professionals or the provision of a system or mechanism that makes this practice feasible are two other examples of factors that demonstrate deficiencies in the security culture that permeates the work environment of screeners at Brazilian airports.

Thus, it seems evident the need for actions to improve the security culture experienced by screening professionals at Brazilian airports. The management of errors and human factors that could affect the passenger screening checkpoint requires management decision-making, a change in the way of assessing operational reality and knowledge management, in order to propagate a security culture throughout the organization [12].

As raised by Yoo and Choi [14], interventions to improve the security culture may involve measures that include a rigorous recruitment and selection policy, professional enhancement policy, promotion of a suitable, comfortable, pleasant and safe working environment, as well as continuous training of the work team.

Lastly, the improvement of the security culture can also be sought through simple measures and without the need for expensive financial resources, such as the effective implementation of an occurrence reporting system. Security managers can take actions that make possible a full application of this system taking advantage of the existing awareness among the professionals themselves and, fundamentally, with the objective of knowing and mapping the errors incident to the operation of the screening checkpoints and the potential factors that determines the reality demonstrated in the reports.

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Potencial del Aeropuerto Intercontinental de Querétaro (AIQ) como alternativa para el manejo de carga aérea, ante la saturación del Aeropuerto Internacional de la Ciudad de México (AICM)

Alfonso Herrera García - aherrera@imt.mx
Instituto Mexicano del Transporte
José Arturo Pérez Sánchez - japerez@imt.mx
Instituto Mexicano del Transporte

Abstract

El propósito de esta investigación es determinar el potencial que tendría el AIQ para manejar parte de la carga aérea del AICM, ante la saturación de este último y para evitar que el crecimiento de estos flujos se estanque.
La investigación utilizará información estadística para determinar las tendencias de los flujos de carga (domésticos y de comercio exterior) con objeto de determinar su preponderancia. Además, se cuantificará la carga atendida en los vuelos exclusivos de carga y en los vuelos mixtos (pasajeros y carga). La hipótesis de trabajo es que los vuelos exclusivos de carga son los que tendrían mayor potencial para trasladarse del AIQ hacia el AICM.
Se espera que se determinen los volúmenes de carga aérea con potencial que pueden ser cambiados del AICM al AIQ, considerando los vuelos exclusivos de carga, pero también los orígenes y destinos comunes de la carga y su tipo (por fracción arancelaria).
La estimación de los volúmenes de carga a manejar en el AIQ ayudará a determinar los requerimientos de infraestructura necesaria para su atención; y además, se determinará si hay la necesidad de la colaboración de otros aeropuertos cercanos al AICM para atender la demanda no cubierta, mientras se construye el nuevo Aeropuerto Internacional de Santa Lucía. Hasta ahora, no hay estudios de este tipo por lo que este análisis es de gran importancia.

Keywords

aeropuerto; carga aérea; saturación

Potencial del Aeropuerto Intercontinental de Querétaro (AIQ) como alternativa para el manejo de carga aérea, ante la saturación del Aeropuerto Internacional de la Ciudad de México (AICM)

Introducción

El transporte aéreo más que cualquier otro modo de transporte ha crecido a escala mundial tanto en términos de pasajeros como de carga, lo que es esencial para la operación de la economía internacional. De acuerdo con la Asociación de Transporte Aéreo Internacional (IATA), la carga aérea representa en términos económicos más de un tercio del total de carga movilizada globalmente. En particular, en México el transporte aéreo de carga contribuye con el 4.7% de las exportaciones y el 9% de las importaciones, es decir con el 6.9% global de su comercio exterior [1].

Las cifras de la IATA también señalan que, durante 2018, en el ámbito mundial se atendieron cuatro mil trescientos millones de pasajeros [2]. Por su parte, en México durante ese mismo año, se atendieron 97.2 millones de usuarios [3]. Por lo anterior, la aviación es una herramienta indispensable para la integración nacional, el turismo, la creación de negocios y el comercio nacional e internacional de mercancías; es un factor determinante de la competitividad y el desarrollo. Los aeropuertos son un recurso nacional vital, dado que constituyen un papel clave en el transporte de personas y mercancías [4].

Como antecedente y justificación para esta esta investigación, cabe señalar que el objetivo 3.6 del Plan Nacional de Desarrollo 2019-20124 de México [5] establece la necesidad de "*desarrollar de manera transparente, una red de transportes accesible, segura, eficiente, sostenible, incluyente y moderna, con visión de desarrollo regional y de redes logísticas que conecte a todas las personas, y facilite el traslado de bienes y servicios,*"; además, señala que "*la infraestructura pública es un elemento fundamental para detonar el potencial económico de un país*". También, puntualiza que "*en algunas regiones, la infraestructura de transporte es precaria o inexistente, mientras que en otras se presentan problemas de capacidad, reflejo de la insuficiencia de la infraestructura disponible para cubrir las necesidades de la población*". Para lograr este objetivo, el Gobierno de México "*promoverá una visión de conectividad y logística multimodal que impulse el desarrollo regional de largo plazo*". Además, destaca en cuanto a infraestructura aeroportuaria, "*la necesidad por atender el problema de saturación existente en el Aeropuerto Internacional de la Ciudad de México (AICM)*".

El AICM fue declarado como saturado en 2014 [6], debido a ello y ante la falta de un nuevo aeropuerto que soporte las actuales tasas de crecimiento en el manejo de carga aérea (9% anual), se abre la posibilidad de que un aeropuerto relativamente cercano, el AIQ, que está situado en línea recta a 175 km al noroeste del AICM, sirva de apoyo para estos flujos crecientes. En 2018, el AICM atendió 585 mil 320 toneladas de carga aérea nacional e internacional, lo que representó el 54.1% del total mexicano, por lo que esta terminal aérea representa el principal centro concentrador y distribuidor (*hub*) de estos flujos en México. De hecho, el 80% de la carga aérea en México se maneja en sólo cuatro terminales aeroportuarias [4]. Por otra parte, en 2003, el Aeropuerto Intercontinental de Querétaro (AIQ) ocupó la posición 44 de los 62 aeropuertos mexicanos que tuvieron actividad de carga aérea [7], en cambio, el año pasado, ocupó la cuarta posición sólo por debajo del AICM, Guadalajara y Monterrey [4]. En 2018, el AIQ manejó un monto de carga aérea igual a 38 mil 303 toneladas, estableciendo su mejor registro de carga aérea hasta esa fecha. Este resultado significó un alza de 63.2% respecto de las 23 mil 465 toneladas acumuladas en 2017 [8].

El AIQ es un aeropuerto en sociedad del Gobierno del Estado de Querétaro (75% de participación) y Aeropuertos y Servicios Auxiliares (25% de participación), en su actual ubicación inició operaciones en noviembre de 2004 [9] y [10].

Actualmente, se trabaja en adecuaciones para que el AIQ continúe brindando mejor servicio. Entre ellas resalta la construcción de bodegas de almacenamiento y una instalación para mercancías de temperatura controlada. En 2019, se espera que dos de las actuales aerolíneas cargueras incrementen sus frecuencias y que se sumen tres aerolíneas cargueras más, para finales de 2019 [11].

En este trabajo se realiza una revisión de cómo ha sido la evolución de la carga total mexicana, y en particular del AICM y del AIQ; considerando los flujos domésticos y de comercio exterior, pero también revisando la diferencia entre las operaciones exclusivas de carga y las mixtas. Además, se realiza un análisis de los principales orígenes y destinos, nacionales e internacionales de la carga aérea en estos dos aeropuertos. En particular para el año 2018 se determinan sus principales flujos de comercio exterior, en términos de fracción arancelaria.

La hipótesis de trabajo es que los vuelos exclusivos de carga son los más susceptibles de cambiarse del AICM al AIQ, dado que la carga es más fácil de transporta y consolidar, en comparación con el manejo de personas, que son más renuentes a cambiar de aeropuerto y prefieren horarios diurnos, en cambio la carga se puede transportar en cualquier horario. Los costos adicionales se relacionan con el traslado de la carga entre estos dos aeropuertos (costo de traslado, peaje y tiempo requerido).

Para estimar el costo de traslado, con base en [12] se estimaron los costos de operación vehicular de diferentes vehículos de carga, considerando la distancia terrestre entre el AICM y el AIQ (214 kilómetros), las características de la carretera (terreno plano con un índice internacional de rugosidad igual a 2.5 m/km), y las características de los vehículos; además se estimaron las tarifas de peaje para los mismos [13], con lo que finalmente se determinó el costo de transporte adicional que se require para trasladar cada tonelada de carga del AICM hacia el AIQ. Este es el costo adicional que se tendría que pagar para tener acceso al servicio de transporte aéreo.

Tabla 1 - Costos de operación vehicular y peaje por unidad de carga
Fuente: Elaboración propia con base en [12] y [13]

Tipo de vehículo	Costo unitario por tonelada de carga transportada	
	Pesos mexicanos	Dólares
T3-S2-R4	151.68	7.58
T3-S3	167.97	8.40
T3-S2	197.97	9.90
Camión de 3 ejes	204.39	10.22
Camión de 2 ejes	267.22	13.36

Por lo tanto, para los diferentes tipos de vehículos considerados, el costo adicional de transportar cada kilogramo de carga entre el AICM y el AIQ sería de entre 0.00758 y 0.01336 dólares; los cuales no son montos considerables, ya que regularmente la carga aérea está constituida por productos de alta densidad económica. Es decir, sí tendría sentido mover estas cargas hacia el AIQ con objeto de disponer del servicio de transporte aéreo, que ya no puede brindar el AICM debido a su saturación. Además, en cuanto el nivel de calidad de los servicios de carga aérea, es indudable que el AICM presenta desventajas, principalmente debido a la falta de espacio físico y a la creciente demanda de operaciones [14]; por el contrario, en el AIQ se tiene una gran disponibilidad de espacio y muy pocas operaciones.

En cuanto al tiempo requerido para trasladar por vía terrestre la carga entre estos dos aeropuertos, su magnitud varía entre dos horas siete minutos, y dos horas treinta y cinco minutos, dependiendo de la hora del día y del sentido del viaje. En particular, en el sentido AIQ-AICM el tiempo promedio es de dos horas y dieciocho minutos, y en el sentido AICM-AIQ, es de dos horas catorce minutos. Estos tiempos corresponden a la ruta más rápida utilizando la Carretera Federal 57, 57D y el Circuito Exterior Mexiquense. Valores estimados con base en [15].

Datos geográficos y administrativos del AICM [16]:

- Coordenadas del punto de referencia de aeródromo (ARP) y emplazamiento en el aeródromo: 19° 26′ 11.027″ N y 099° 04′ 19.098″ W, entre pistas 05L/23R y 05R/23L
- Elevación/temperatura de referencia: 2,230 m (7,316 pies) / 27° C
- Tipo de tránsito permitido: IFR
- Servicio de aduanas e inmigración y de abastecimiento de combustible las 24 horas
- Instalaciones de manipulación de la carga: Si
- Avión máximo operable: A380-800

Datos geográficos y administrativos del AIQ [16]:

- Coordenadas del punto de referencia de aeródromo (ARP) y emplazamiento en el aeródromo: 20° 37′ 02.56276″ N y 100° 11′ 08.49871″ W, al centro de la pista
- Elevación/temperatura de referencia: 1,919 m (6,296 pies) / 22° C
- Tipo de tránsito permitido: IFR / VFR
- Servicio de aduanas e inmigración y de abastecimiento de combustible las 24 horas
- Instalaciones de manipulación de la carga: Se cuenta con instalaciones modernas y equipo suficiente que permite manipular cargas de las aeronaves, se cuenta con un área de 35,000 m^2 de plataforma de carga.
- Avión máximo operable: B747-8
- Superficie y resistencia de las plataformas: Comercial 125,000 m^2, concreto hidráulico, PCN 108/R/A/W/T. Aviación general 14,400 m^2, concreto hidráulico, PCN 35/R/A/W/T. MRO 25,560 m^2 concreto hidráulico, PCN 145 R/A/W/T. Carga 35,000 m^2, concreto hidráulico, PCN 78/R/A/W/T.

Para esta investigación se utilizó inicialmente el método cuantitativo, mediante el análisis de información detallada de la carga aérea manejada en los últimos años en los aeropuertos de México y Querétaro; posteriormente, mediante búsqueda de similitudes y comparaciones sistemáticas (método comparativo) se determinaron las coincidencias en los flujos de carga, en cuanto a orígenes y destinos y tipos de carga, para delimitar aquellos con potencial de ser transferidos del AICM hacia el AIQ. Además, se utilizaron herramientas estadísticas para realizar los análisis requeridos.

Análisis de la información

La Figura 1 muestra la carga total manejada en los 58 aeropuertos mexicanos que atendieron a estos flujos durante 2018. Debido a la gran concentración de esta actividad en muy pocos aeropuertos, en la Figura 2 se presentan más detalles relacionados con los flujos domésticos (nacionales) y de comercio exterior (internacionales), para los cinco principales aeropuertos que en conjunto acumularon el 83.3% del total de carga aérea en México durante 2018.

En las figuras 3 a 6 se muestra en particular la distribución histórica de los flujos de carga aérea para los aeropuertos de la Ciudad de México y Querétaro, para el periodo del 2009 al 2018, desagregando los vuelos nacionales e internacionales; y los mixtos (pasajeros y carga) y exclusivos de carga.

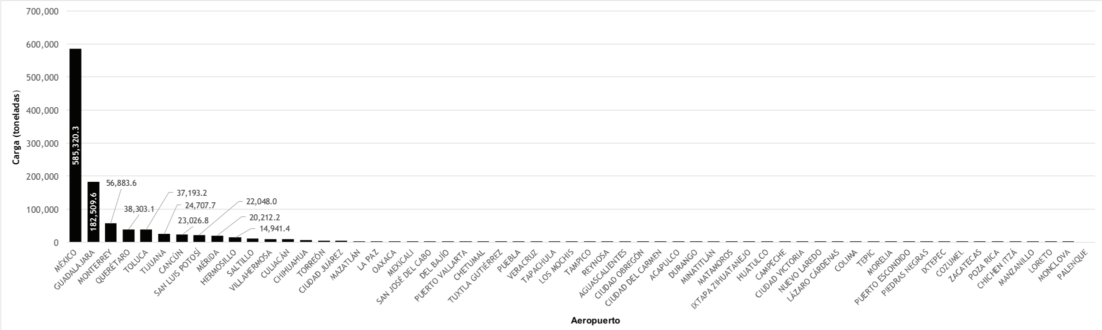

Figura 1 - Carga total atendida durante 2018 en los aeropuertos mexicanos
Fuente: Elaboración propia con base en [4]

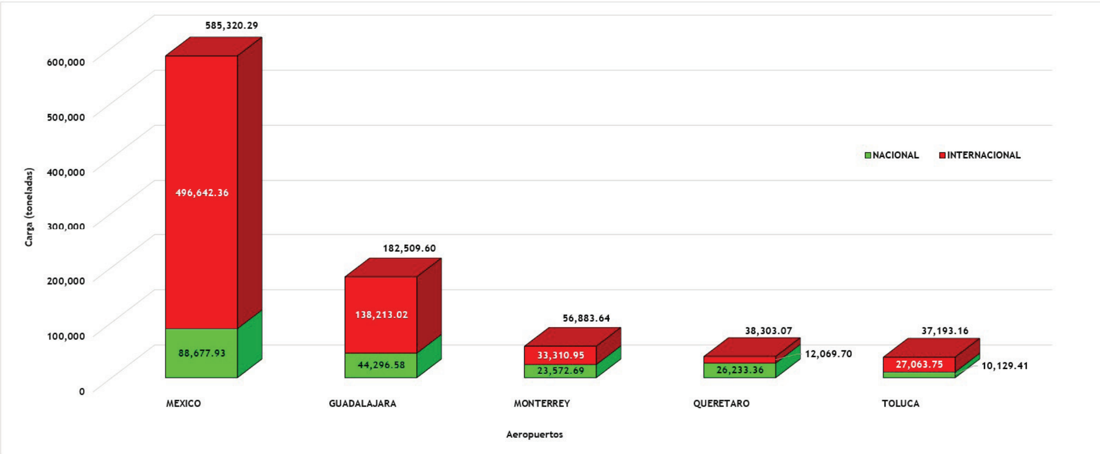

Figura 2 - Carga total atendida durante 2018 en los principales cinco aeropuertos mexicanos
Fuente: Elaboración propia con base en [4]

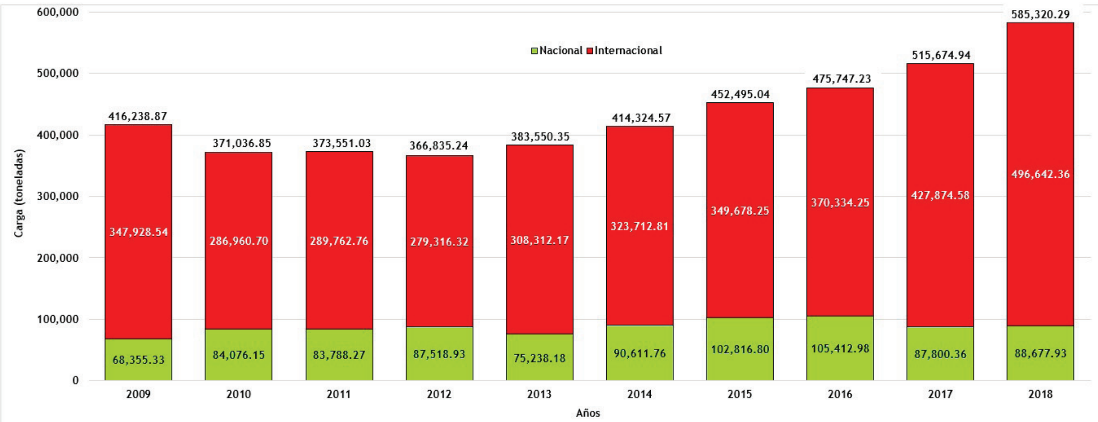

Figura 3 - Evolución de la carga aérea en el AICM, dividida en vuelos nacionales e internacionales
Fuente: Elaboración propia con base en [8]

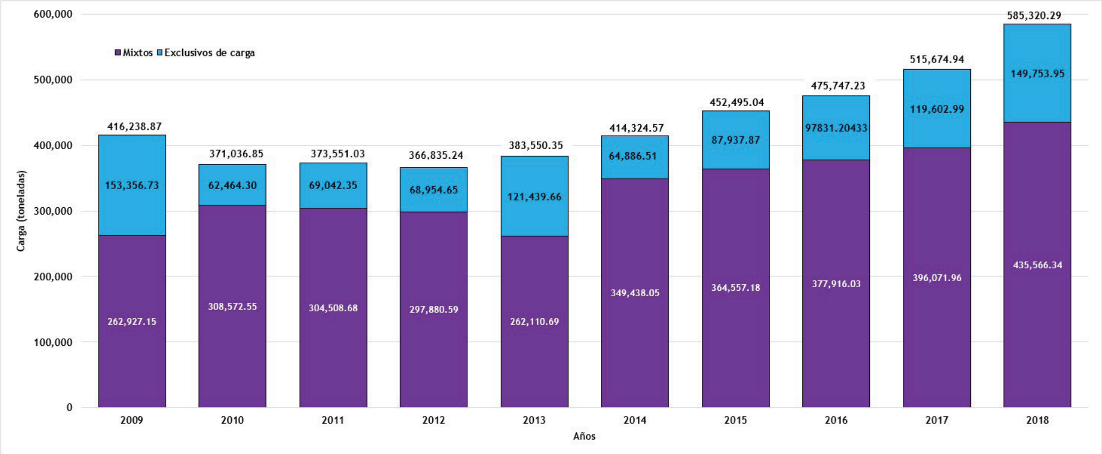

Figura 4 - Evolución de la carga aérea en el AICM, dividida en vuelos mixtos y exclusivos de carga
Fuente: Elaboración propia con base en [8]

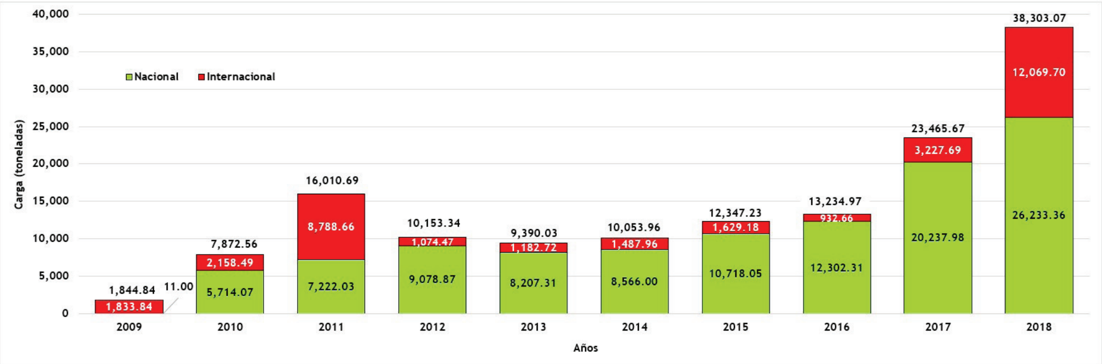

Figura 5 - Evolución de la carga aérea en el AIQ, dividida en vuelos nacionales e internacionales
Fuente: Elaboración propia con base en [8]

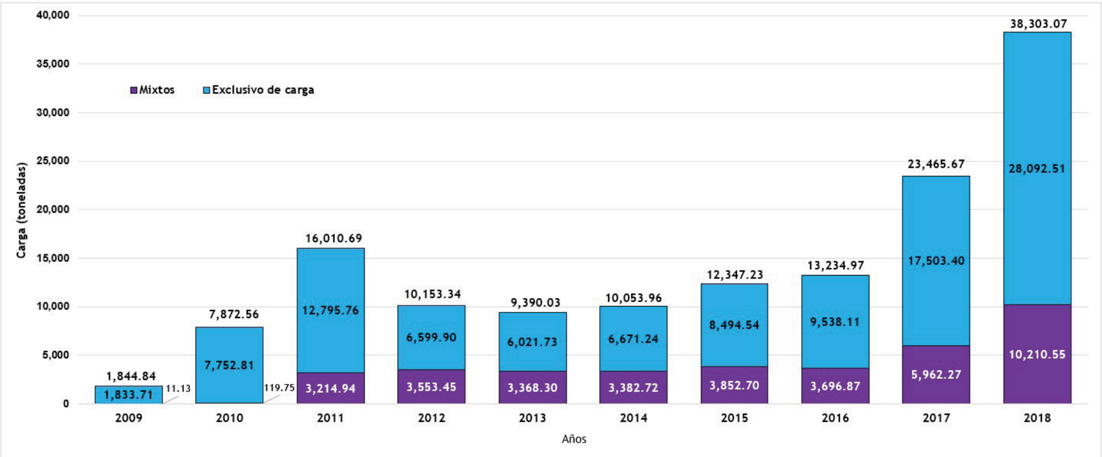

Figura 6 - Evolución de la carga aérea en el AIQ, dividida en vuelos mixtos y exclusivos de carga
Fuente: Elaboración propia con base en [8]

En la Figura 7 se muestra la distribución de la carga aérea en el AICM y el AIQ, separada en vuelos nacionales e internacionales; y además, su subdivisión en vuelos mixtos y exclusivos de carga. También, se indican las magnitudes de la carga que sale de dichos aeropuertos y la que llega.

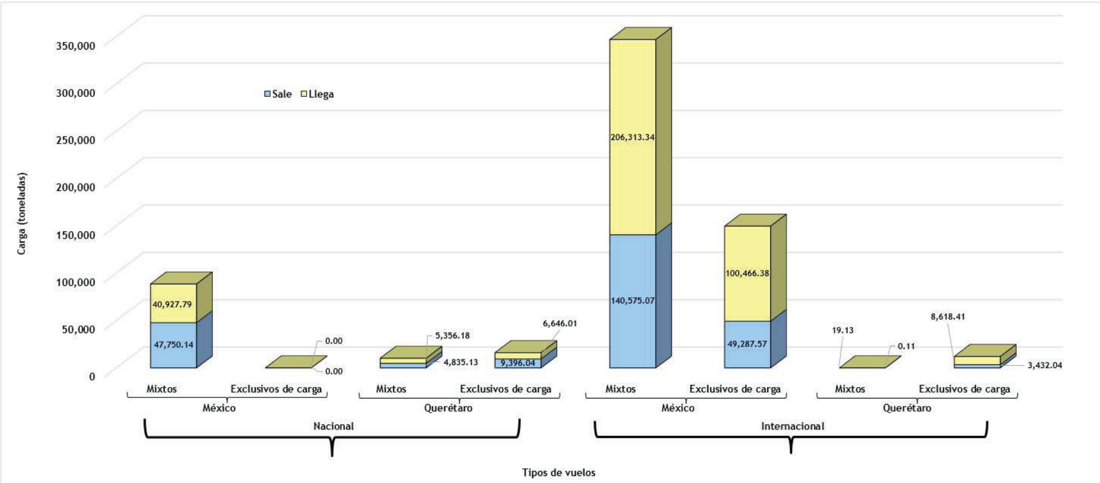

Figura 7 - Panorama general de la distribución de la carga aérea en los distintos tipos de vuelos, en el AICM y el AIQ, durante 2018
Fuente: Elaboración propia con base en [8]

Retomando los supuestos de este análisis, en la Tabla 2, se determinan los aeropuertos que son comunes para ambos aeropuertos en los vuelos exclusivos de carga, que como se observa en la Figura 8 corresponden a los vuelos internacionales. Estos serían los vuelos con mayor probabilidad de trasladarse del AICM hacia el AIQ, a estos vuelos se les denomina aquí como vuelos nivel A (marcados con color verde en la tabla); después se ubicarían aquellos vuelos que no tienen orígenes o destinos comunes y que, por lo tanto, tienen menor probabilidad de cambiarse del AICM hacia el AIQ, vuelos nivel B (marcados con color amarillo en la tabla).

Dado que la carga con potencial para ser trasladada del AICM hacia el AIQ se concentra en los flujos internacionales, es conveniente identificar algunas características de la carga aérea de comercio exterior en estos dos aeropuertos.

En relación con el valor de las mercancías de exportación por vía aérea, las aduanas en los aeropuertos del AICM y AIQ se ubicaron en el segundo y tercer lugar, respectivamente, de las aduanas mexicanas. En cambio, en el sentido opuesto, el valor de las mercancías de importación por vía aérea, ocuparon el primer y cuarto lugar, respectivamente.

Así, las aduanas del AICM y AIQ concentraron el 35.7% (7,747 millones de dólares) y 5.1% (1,105 millones de dólares), respectivamente, del valor total de las exportaciones de México por vía aérea. En cambio, en el sentido opuesto, estos aeropuertos concentraron el 51% (alrededor de 22 mil millones de dólares) y 3.92% (1,689 millones de dólares), respectivamente, del valor total de las importaciones.

En cuanto al origen y destino del valor de las mercancías de comercio exterior durante 2018 (Tabla 3), el AIQ tuvo como principales orígenes y destinos los aeropuertos de los Estados Unidos de América, donde las exportaciones a los aeropuertos de dicho país concentraron el 74.19% (820 millones de dólares) y, en el sentido de las importaciones, los aeropuertos de dicho país concentraron el 38.79% (655 millones de dólares). En tanto, agrupados por región continental los principales países de origen y destino, la Región de Norteamérica concentró el 81.5% (900 millones de dólares) del valor total de las exportaciones por el AIQ y, las regiones de Europa y Asía concentraron el 13.5% (149 millones) y el 2.2% (24 millones), respectivamente; en el sentido opuesto, la Región de Norteamérica concentró el 45.9% (775 millones de dólares) del valor total de las importaciones del AIQ y, las regiones de Asía y Europa concentraron el 21.1% (357 millones) y 18.7% (316 millones), respectivamente.

Tabla 2 - Aeropuertos con potencial para trasladar sus operaciones o crecer en el AIQ (2018)
Fuente: Elaboración propia con base en [8]

AEROPUERTO	CARGA AÉREA (TONELADAS)		
	DESDE MÉXICO	HACIA MÉXICO	TOTAL
COVINGTON,EUA	8,234.79	9,840.33	18,075.12
LOUISVILLE, EUA	7,500.92	9,286.72	16,787.64
HUNTSVILLE, EUA	1,661.75	5,876.51	7,538.26
MIAMI, EUA	794.90	739.81	1,534.71
CAMPINAS, BRASIL	548.70	491.94	1,040.64
LIMA, PERÚ	232.37	0.00	232.37
SANTIAGO DE CHILE, CHILE	0.00	200.24	200.24
NUEVA YORK, EUA	0.00	134.49	134.49
DETROIT, EUA	7.55	39.66	47.21
DOVER, INGLATERRA	2.80	30.49	33.28
SUBTOTALES	**18,983.77**	**26,640.18**	**45,623.95**
DOHA, CATAR	9,271.05	18,244.87	27,515.92
HONG KONG, CHINA	7,531.12	18,373.29	25,904.41
LUXEMBURGO, LUXEMBURGO	3,347.73	17,816.22	21,163.95
ZARAGOZA, ESPAÑA	2,852.02	6,964.40	9,816.42
JEBEL ALI, EMIRATOS ÁRABES UNIDOS	2,963.65	6,196.46	9,160.11
TEL AVIV, ISRAEL	3,493.06	4,551.39	8,044.45
ESTAMBUL, TURQUÍA	396.65	1,051.41	1,448.07
ANCHORAGE, EUA	0.00	407.97	407.97
MAASTRICH, PAÍSES BAJOS	329.59	0.00	329.59
SAN JOSÉ, COSTA RICA	0.00	134.49	134.49
MEDELLÍN, COLOMBIA	69.00	0.00	69.00
OSCADA, EUA	2.64	56.73	59.37
PALM SPRINGS, EUA	0.00	28.96	28.96
KUWAIT, KUWAIT	27.29	0.00	27.29
PUERTO ESPAÑA, TRINIDAD Y TOBAGO	17.51	0.00	17.51
FAIRFIELD, EUA	2.46	0.00	2.46
COPENHAGE, DINAMARCA	0.03	0.00	0.03
SUBTOTALES	**30,303.80**	**73,826.19**	**104,129.99**
TOTALES	**49,287.57**	**100,466.38**	**149,753.95**

Tabla 3 - Distribución porcentual del valor del origen/destino del comercio exterior en las aduanas del AIQ y AICM (2018)
Fuente: Elaboración propia con base en [17]

Exportaciones				Importaciones			
AIQ		AICM		AIQ		AICM	
PAIS	PORCENTAJE	PAIS	PORCENTAJE	PAIS	PORCENTAJE	PAIS	PORCENTAJE
Estados Unidos	74.19%	Estados Unidos	38.34%	Estados Unidos	38.79%	China	29.35%
Canadá	7.29%	Reino Unido	11.41%	Francia	11.83%	Alemania	12.48%
Francia	5.60%	Alemania	10.35%	China	8.18%	Estados Unidos	11.06%
Reino Unido	2.88%	Suiza	5.80%	Canadá	7.10%	Francia	5.48%
Alemania	2.22%	Francia	4.15%	Alemania	6.89%	Italia	5.08%
Turquía	1.59%	Brasil	3.41%	Taiwán	6.70%	Suiza	2.90%
Singapur	1.45%	Colombia	2.11%	Japón	3.09%	Japón	2.54%
España	1.20%	China	2.00%	Malasia	1.75%	España	2.40%
China	0.75%	Panamá	1.45%	Filipinas	1.40%	Brasil	2.18%
Resto de países	2.82%	Resto de países	20.99%	Resto de países	14.27%	Resto de países	26.52%
Total en millones de dólares	1,105 100.00%	Total en millones de dólares	7,747 100.00%	Total en millones de dólares	1,689 100.00%	Total en millones de dólares	21,999 100.00%

En el AICM, el valor del comercio exterior presentó un considerable desbalance direccional, donde las exportaciones representaron un tercio del valor de las importaciones. De esta forma, los tres principales destinos del valor de las mercancías concentran el 60.1% del total de las exportaciones, siendo los Estados Unidos (38.34%; 2,970 millones dólares), Reino Unido (11.41%; 884 millones) y Alemania (10.35%; 802 millones). En cambio, en el sentido opuesto, los tres principales orígenes concentraron el 52.9% del valor total de las importaciones por el AICM, siendo China (29.35%; 6,457 millones de dólares), Alemania (12.48%; 2,745 millones) y los Estados Unidos (11.06%; 2,432 millones).

Agrupados por región continental, los principales países origen-destino del valor de las mercancías para el AICM, la Región de Norteamérica concentró el 38.3% (2,970 millones de dólares) del valor total de las exportaciones y, las regiones de Europa y Centro-Sudamérica el 31.7% (2,456 millones) y 6.9% (539 millones), respectivamente. En el sentido opuesto, la Región de Asía concentró el 31.9% (7,016 millones de dólares) del valor total de las importaciones y, las regiones de Europa y Norteamérica concentraron el 28.4% (6,236 millones) y el 11.1% (2,432 millones), respectivamente.

Con respecto a las características de las mercancías del comercio exterior, durante 2018 (Tabla 4), las diez principales mercancías de exportación agrupadas por capítulo arancelario en el AIQ concentraron el 97.8% (1,081 millones de dólares) del valor total de las exportaciones por dicha aduana. Observe que, los primeros tres capítulos representaron el 79.3% (876 millones) de este total, el capítulo 84 contribuyó con el 40.7%, el capítulo 98 con el 21.7% y el capítulo 85 con el 16.9% del total de los movimientos referidos. Por otra parte, en el sentido de las importaciones en el AIQ, los diez principales capítulos concentraron el 97.4% (1,646 millones de dólares) del valor total de las importaciones por dicha aduana; y los primeros tres capítulos representaron el 85.6% (1,446 millones) del este total, siendo el capítulo principal el 98 (51.5%), seguido del capítulo 85 (23.8%), y del capítulo 84, con el 10.1% del total de los movimientos referidos.

Tabla 4 - Distribución porcentual del valor del comercio exterior de mercancías, agrupadas por capítulos arancelarios en las aduanas del AIQ y AICM (2018)
Fuente: Elaboración propia con base en [17]

Exportaciones				Importaciones			
AIQ		AICM		AIQ		AICM	
Cap. Arancelario	PORCENTAJE	Cap. Arancelario	PORCENTAJE	Cap. Arancelario	PORCENTAJE	Cap. Arancelario	PORCENTAJE
Capítulo 84	40.70%	Capítulo 71	40.42%	Capítulo 98	51.59%	Capítulo 85	31.77%
Capítulo 98	21.70%	Capítulo 84	17.05%	Capítulo 85	23.85%	Capítulo 84	17.25%
Capítulo 85	16.91%	Capítulo 85	7.97%	Capítulo 84	10.15%	Capítulo 30	14.18%
Capítulo 99	8.26%	Capítulo 98	7.34%	Capítulo 82	3.71%	Capítulo 90	7.34%
Capítulo 87	3.70%	Capítulo 30	6.19%	Capítulo 90	2.07%	Capítulo 98	3.95%
Capítulo 88	2.65%	Capítulo 90	3.92%	Capítulo 87	1.88%	Capítulo 29	3.54%
Capítulo 90	2.33%	Capítulo 29	3.51%	Capítulo 99	1.60%	Capítulo 62	2.50%
Capítulo 39	0.70%	Capítulo 87	2.48%	Capítulo 39	1.25%	Capítulo 71	1.75%
Capítulo 40	0.44%	Capítulo 88	1.75%	Capítulo 73	0.82%	Capítulo 87	1.67%
Capítulo 70	0.41%	Capítulo 8	1.05%	Capítulo 40	0.51%	Capítulo 61	1.48%
Resto Capítulos	2.21%	Resto Capítulos	8.33%	Resto Capítulos	2.57%	Resto Capítulos	14.59%
Total en millones de dólares	**1,105** 100.00%	**Total en millones de dólares**	**7,746** 100.00%	**Total en millones de dólares**	**1,689** 100.00%	**Total en millones de dólares**	**21,999** 100.00%

Notas:

Capítulo 8	Frutas y frutos comestibles; cortezas de agrios (cítricos), melones o sandías.
Capítulo 29	Productos químicos orgánicos.
Capítulo 30	Productos farmacéuticos.
Capítulo 39	Plástico y sus manufacturas.
Capítulo 40	Caucho y sus manufacturas.
Capítulo 61	Prendas y complementos (accesorios), de vestir, de punto.
Capítulo 62	Prendas y complementos (accesorios), de vestir, excepto los de punto.
Capítulo 70	Vidrio y sus manufacturas.
Capítulo 71	Perlas, piedras preciosas, metales preciosos, chapados de metal precioso y manufacturas de estas materias; bisutería; monedas.
Capítulo 73	Manufacturas de fundición, hierro o acero.
Capítulo 82	Herramientas y útiles, artículos de cuchillería y cubiertos de mesa, de metal común; partes de estos artículos, de metal común.
Capítulo 84	Máquinas, aparatos y artefactos mecánicos; partes de estas máquinas o aparatos.
Capítulo 85	Máquinas, aparatos y material eléctrico; aparatos de grabación o reproducción de sonido, de imagen y sonido en televisión, y las partes y accesorios de estos aparatos.
Capítulo 87	Vehículos automóviles, tractores, velocípedos y demás vehículos terrestres; sus partes y accesorios.
Capítulo 88	Aeronaves, vehículos espaciales, y sus partes.
Capítulo 90	Instrumentos y aparatos de óptica, fotografía o cinematografía, de medida, control o precisión, medico quirúrgicos; partes y accesorios de estos instrumentos o aparatos.
Capítulo 98	Operaciones especiales.
Capítulo 99	Códigos arancelarios no catalogados en la tarifa.

Cabe mencionar que, las principales mercancías del comercio exterior en el AIQ correspondieron al sector aeronáutico, que en el sentido de las exportaciones representaron el 59.9% del valor total de las exportaciones por dicho aeropuerto (38.2% turborreactores o turbopropulsores del Capítulo 84 y, 21.7% a las destinadas a la reparación/mantenimiento y ensamblaje/fabricación de aeronaves, comprendidas en el Capítulo 98). En el sentido de las importaciones, las principales mercancías fueron las mismas que en las exportaciones (56.6%), pero ahora las comprendidas en el capítulo 98 concentraron el 37.9% y las del capítulo 84 el 2.5%, del valor total de las importaciones en dicho aeropuerto.

En el AICM, las diez principales mercancías de exportación agrupadas por capítulo arancelario concentraron el 91.7% (7,101 millones de dólares) del valor total de las exportaciones, por dicha aduana y, los primeros cuatro capítulos representaron el 72.8% (5,637 millones) de este total, correspondiendo al capítulo 71 el 40.4%, al capítulo 84 el 17%, al capítulo 85 el 7.9% y al capítulo 98 el 7.3% del total de los movimientos referidos.

En tanto en el sentido de las importaciones en el AICM, los diez principales capítulos concentraron el 85.4% (18,790 millones de dólares) del valor total de las importaciones por dicha aduana y, los primeros cuatro capítulos representaron el 70.5% (15,515 millones de dólares) del este total, siendo los principales el capítulo 85 con el 31.7%, el capítulo 84 con el 17.2%, el capítulo 30 con el 14.1% y el capítulo 90 con el 7.3%, del total de los flujos referidos.

Por último, en relación con las principales mercancías del comercio exterior en el AICM, el oro en bruto (incluido el oro platinado), semilabrado o en polvo, comprendido en el capítulo 71, concentró el 39.3% del valor total de las mercancías de exportación por dicho aeropuerto. En cambio, en el sentido opuesto, los productos farmacéuticos concentraron el 9.8% del total del valor de las importaciones del AICM.

Discusión de los resultados

Durante 2018, cincuenta y ocho aeropuertos mexicanos atendieron carga aérea, sin embargo, los aeropuertos de la Ciudad de México, Guadalajara, Monterrey y Querétaro concentraron casi el 80% de estos flujos. El AICM destacó con mucho al resto de los aeropuertos mexicanos, manejando poco más del 54% del total de la carga aérea, también sobresale el aeropuerto de Guadalajara que individualmente atendió el 16.8% del total de estos flujos.

Los principales volúmenes de carga aérea en el AICM provienen de los vuelos internacionales (el 84.8%, en 2018); en cambio, en el AIQ sucede lo opuesto (sólo el 31.5% provino de estos vuelos en 2018). Por otra parte, en el AICM la mayor parte de la carga (74.4%, durante 2018) se atendió en los compartimientos inferiores de las aeronaves de pasajeros (vuelos mixtos), por el contrario, en el AIQ la mayor parte provino de las aeronaves exclusivas de carga (el 73.3%, en 2018).

En el caso de los vuelos nacionales del AICM, la carga aérea se concentra en los vuelos mixtos, en cambio en el AIQ se concentra en los vuelos exclusivos de carga (61.1%), por lo que en este caso se tienen pocas probabilidades de cambiar estos flujos del AICM hacia el AIQ. Por su parte, en los vuelos internacionales, la mayor parte de la carga del AICM (346,888.4 toneladas) se transporta en aeronaves mixtas (69.8%), las cuales son muy poco susceptibles de trasladarse hacia el AIQ; sin embargo, también existe una porción importante de carga que se mueve en aeronaves exclusivas de carga (149,753.9 toneladas) que podría atender el AIQ, sobre todo en aquellos vuelos que tuvieran orígenes y destinos comunes para ambos aeropuertos.

Los resultados indican que habría una cantidad significativa de carga aérea que podría ser cambiada del AICM hacia el AIQ, más de 149 mil toneladas; sin embargo, la magnitud más probable corresponde a aquellos flujos que tienen orígenes y destinos comunes entre el AICM y el AIQ (nivel A), el monto de esta carga es un poco mayor a las 45 mil toneladas anuales. La carga menos probable o nivel B corresponde a vuelos que no tiene orígenes y destinos comunes entre los dos aeropuertos, por lo que sería necesario implementarlos.

La mayor parte de la carga nivel A (96.7%) está conformada por orígenes y destinos en los Estados Unidos.

Aunque los resultados presentados en la Tabla 2, sirven para orientar las decisiones de aquellos vuelos de carga aérea que podrían cambiarse del AICM al AIQ, también sirven para señalar que vuelos podrían empezar a crecer en el AIQ, ante la saturación del AICM; en caso de que se optara por atender a estos flujos en ambos aeropuertos. La ventaja de mover los flujos de carga nivel A en el AIQ, radica en que se liberaría capacidad en el AICM, la cual podría ofrecerse para otros vuelos, permitiendo su crecimiento.

Conclusiones y recomendaciones

Las vocaciones del AICM y el AIQ son distintas, el AICM maneja los mayores volúmenes de carga provenientes del comercio exterior y en aeronaves de pasajeros; en cambio, el AIQ atiende principalmente cargas domésticas en aeronaves exclusivas de carga. No obstante, dado los grandes volúmenes de carga aérea atendidos en el AICM, parte de sus flujos podrían captarse en el AIQ.

Existe una cantidad significativa de carga aérea, del orden de 149 mil toneladas anuales, que podría ser cambiada del AICM hacia el AIQ.

Parte de esta carga, más de 45 mil toneladas anuales, corresponde a flujos que tienen una alta probabilidad de cambiarse del AICM al AIQ, debido a que los orígenes y destinos de esta carga son comunes entre estos dos aeropuertos y a que se realizan en aeronaves exclusivas de carga. La mayor parte de estos vuelos son desde y hacia aeropuertos de los Estados Unidos.

La carga nivel B, entre el AICM y el AIQ, corresponde a vuelos exclusivos de carga que no tiene orígenes y destinos comunes entre ambos, por lo que sería conveniente tomar las medidas requeridas para promoverlos e implementarlos. Esta carga es muy significativa, del orden de 104 mil toneladas anuales.

Además, sería conveniente que se generaran más vuelos mixtos (de carga y pasajeros) en el AIQ, para empezar a atraer la carga de estos; la carga aérea de estos vuelos en el AICM es muy significativa (más de 435 mil toneladas, en 2018).

Los principales productos transportados en el AICM y el AIQ tienen semejanza en su clasificación por capítulo arancelario, en particular en el 84, 85 y 98.

El AIQ debe ofrecer ventajas competitivas para mantener a las aerolíneas, empresas de carga aérea y clientes después de que entre en operación el AISL. Por ejemplo, mediante tarifas atractivas, espacios para crecimiento, y tiempos de atención y procesamiento competitivos.

En cuanto a otros aeropuertos cercanos al AICM que podrían ser alternativas para contribuir a disminuir el problema de su saturación en carga aérea, mientras se construye un nuevo aeropuerto que resolvería el problema, se tiene a los aeropuertos de Cuernavaca, Pachuca, Puebla y Toluca. Sin embargo, los aeropuertos de Cuernavaca y Pachuca ni siquiera presentan registro de atención de carga aérea; Puebla sí lo tiene, pero con magnitudes bajísimas (ver Figura 1, ocupa el lugar 26); por lo que la otra alternativa real sería el aeropuerto de Toluca (que aparece en quinto lugar de los aeropuertos mexicanos en la Figura 1), en este caso su principal restricción es su elevación (2,580 msnm).

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Alternatives for the operational redistribution of airlines between the Mexico City International Airport (AICM) and the future Santa Lucia International Airport (AISL)

Alfonso Herrera García - aherrera@imt.mx
Instituto Mexicano del Transporte

Abstract
In this paper diverse alternatives are considered and explored in order to have an overview that helps to guide the decisions to establish the future operational arrangement of the airlines at the AICM and the AISL.
Due to the cancellation of the New Mexico City International Airport (NAIM) and the decision to build a new one, the AISL, which will operate in conjunction with the AICM, it arises the challenge of determining how it could be the operational redistribution of airlines in both airports. For this analysis is carried out a review of the airlines features that currently operate in the AICM, and based on these some alternatives are established.
It is expected to establish the alternatives with the greatest potential, along with their pros and cons, both in qualitative and quantitative terms. Among the factors to consider are the passengers origin or destination (domestic and international), the number of takeoffs or landings carried out by the airlines, the different aircraft types, the airline alliances and the connecting flights.
Considering that there are no studies about the operational redistribution of the airlines in the binomial AICM-AISL, the results are of great practical importance. The contribution focus on reduce the negative impacts to passengers and airlines; and in order to support efficiently the growth of air transport demand in Mexico City.

Keywords
airline; airport; connecting flight; operation

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Theoretical foundation

Air transport more than any other mode of transportation has grown worldwide, both in terms of passengers and cargo, which is essential for the operation of the international economy. According to the International Air Transport Association (IATA), in 2018, at the global level 4.3 billion passengers were attended. In particular, in Mexico that year, 97.2 million passengers were attended, of which 49.6 million corresponded to domestic flights and 47.6 million to international flights [1]. In economic terms, the Mexican air transport contributes with 6.9% of its global foreign trade [2]. Thus, aviation is an indispensable tool for national integration, tourism, creation of businesses, and domestic and foreign trade; It is an important determinant of competitiveness and development. Airports are vital national resources, because they serve a key role in transportation of people and goods.

In the Nation Project 2018-2024 of the Mexican Government [3] was established that in order to boost the economy and job creation, it is essential to revive infrastructure investment. Since this is the most effective lever to spur economic development, considering its multiplier effect in different economic sectors. Also, it was established that without infrastructure there is no progress. Among the infrastructure projects considered about air transport, the Airport System of the Mexico Valley Metropolitan Area was established. It is proposed to form a complementary system of airports, in order to coordinate the management of domestic and international commercial flights as well as cargo flights.

Also it has been established that, it will be built an airport system made up of the Mexico City International Airport, the Toluca International Airport and the new International Airport in the grounds of the Military Airbase of Santa Lucia [4].

In addition, the National Development Plan (PND) 2019-2024 [5] establishes that the International Airport of Santa Lucia (AISL) "Felipe Angeles" will be added to the Mexican airport infrastructure. This airport will have three runways, two civilian and one for military use. The AISL will have a capacity to perform 190 thousand annual air operations and to attend 20 million passengers per year. Additionally, it will build a third passenger terminal at the International Airport of Mexico City (AICM).

Moreover, the objective 3.6 of the PND 2019-2024 pointed out that "*public infrastructure is a key element to detonate a country's economic potential*"; and in terms of airport infrastructure, highlights the importance of resolving the problem of saturation at the AICM.

In 2018, the AICM attended 47.8 million passengers and more than 585 thousand tonnes of air cargo, so it is the main Mexican hub of these flows. These values represented the 32.5% and 54.1%, respectively, of the total Mexican air transport flows. In terms of air transport movements (ATMs), the AICM also occupies the first place in Mexico, in 2018 attended 423,980 takeoffs and landings [1].

Due to the cancellation of the New International Airport of Mexico (NAIM) in Texcoco, and the decision of building a new one at Santa Lucia (AISL) working in conjunction with the AICM, it arises the challenge of determining how would be the operation of the airlines in these two airports, to ensure its functioning with minor affectations to the airlines and passengers; to satisfy the demand of air transportation in the Mexico City Metropolitan Area; and to solve the congestion problem of the current AICM.

Figure 1 –AISL lay out
Source: Adapted from [6]

There are very few recent references from specialized publications about multiple airports. Some of them are about multiairport choice models [7], or for applications in air traffic control [8], or forecasting air passengers [9]; and one paper presents an analysis of the dynamics of evolution of multiairport systems worldwide that can help to guide their effective development in the future [10]. This analysis showed significant differences in the evolution of multiairport systems across world regions. However, the article does not specify how to establish the airlines that must operate in each airport.

The objective of this paper is to explore diverse alternatives in order to have an overview that helps to guide the decisions to establish the future operational arrangement of the airlines at the AICM and the AISL.

The contribution focus on reduce the negative impacts to passengers and airlines, to support efficiently the growth of air transport demand in Mexico City.

Methodology

For this research was initially performed an analysis of detailed information about the airlines characteristics that currently operate at the AICM. Subsequently, the particular operational characteristics of the airlines were reviewed, looking for regularities in the operational variables of the airlines in order to set up general conclusions. Finally, using the analytical method were established the alternatives, these considered the different operational variables and their relationships, to determine in more detail their nature. In addition, statistical tools were used to obtain averages, maximums, minimums, growth rates, trends, coefficients and forecasts.

The alternatives with the greatest potential were established, along with their pros and cons, both in qualitative and quantitative terms. The origin or destination of passengers (domestic and international), the number of takeoffs or landings carried out by the airlines, the different types of aircraft, the airline alliances and the connecting flights were the main factors considered.

The paper emerges from the hypothesis that there is not an infinite amount of options in order to the airlines can operate, since the characteristics of each airline (for example, number of passengers and flights attended) and airport (for example, capabilities in the passenger terminal and on the runways) defined in which of the two airports could operate.

Research data

The AICM was declared saturated in most of their operational time (between 07:00 and 22:59 hours) since September 2014 [11]; thus, since 2016 the average annual growth rate (AAGR) of total passengers attended at the AICM has been declining. During 2015, the AAGR was just like 12.19%; in 2016, 8.52%; in 2017, 7.24%; and in 2018, 6.63%. Based on a liner trend of these values (R^2 = 0.866) the following rates could be expected in the future: 2019, 4.11%; 2020, 2.32% and 2021, 0.52%.

Applying these rates to the figures of passengers attended in 2018, a total of 51.18 million passengers to be attend was estimated for the year 2021, when it is supposed that the AISL will start operations.

The master plan assumed that, in the initial stage of AISL, at the end of 2021, it will have a maximum capacity of 20 million passengers. However, it is not recommended that starts to function at full capacity because it would be operating under the condition of a congested airport, and it would have no room for growth. It is known that when the airports have reached 80% of its maximum capacity, begin to present a rapid and significant deterioration in the service they offer [12] and [13]. Therefore, it shall be deemed that the AISL will begin operations to 80% of its maximum capacity, that means, with a capacity of 16 million passengers.

Under the abovementioned conditions, the following scenarios are established, where the AISL initially would attend 16 million passengers, and the AICM 35.18 million passengers, making as a hole to meet the total demand estimated for the year 2021 (51.18 million passengers).

Scenarios considered:

Scenario 1. Status quo. In this case, the operation of the AICM remain unchanged, in other words the AICM would attend 51.18 million passengers in year 2021 and all future growth would be presented in the AISL.

Scenario 2. Major alliances. Under this condition, the airlines that move the greatest number of passengers together with their alliances remain in the AICM. The purpose is that the passengers with a connecting flight of these airlines do not need to move between the two airports.

For this scenario, it was determined the current passenger proportions for the different airlines, and then, it was assumed that in the future this ratio is kept, but with the predicted passenger volumes.

Figure 2 shows the proportions of passengers per airline, for a typical day of operation at the AICM; and Table 1 shows the predicted values of passengers to be attended in the year 2021, for the different airlines, based on Figure 2.

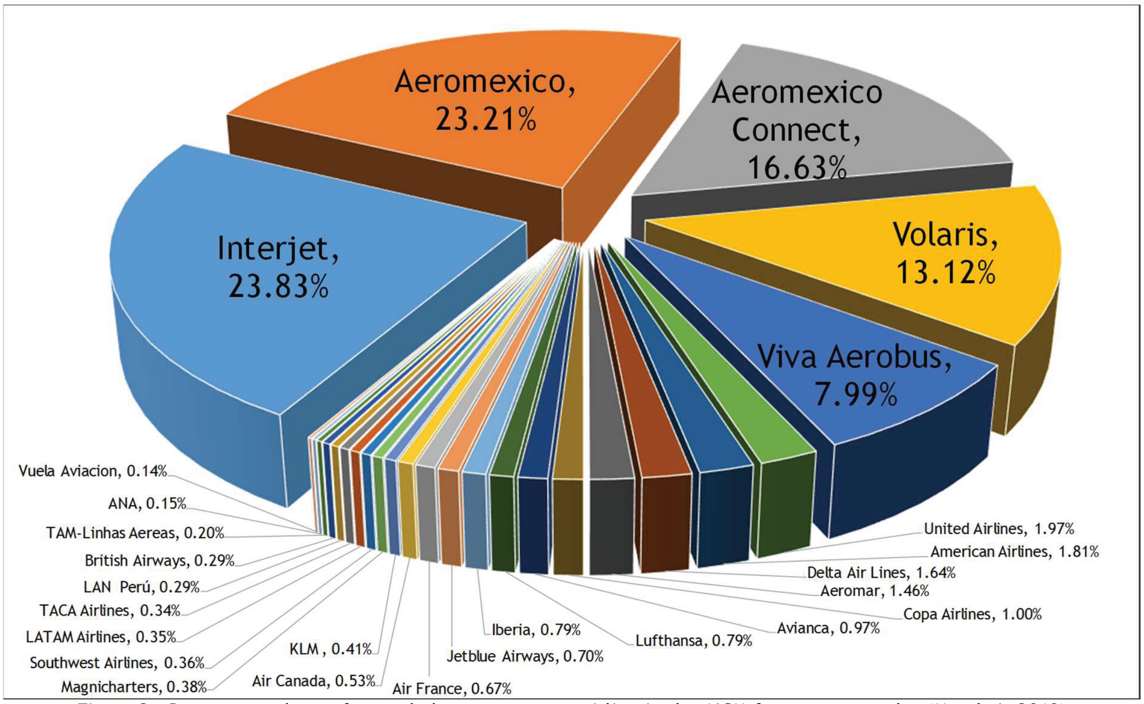

Figure 2 - Percentage share of attended passengers per airline in the AICM for an average day (March 6, 2019)
Source: Own elaboration based on information provided by the AICM

As can be seen from Table 1, the airlines Interjet, Aeromexico and Aeromexico Connect would build up 32.5 million passengers in 2021; this figure is close to 35.18 million passengers, which is the recommended capacity mentioned before to meet the demand in the AICM for that year. Consequently, the scenario 2 proposed considers to these three airlines as the ideal candidates to continue operating at AICM; but also the airlines related to their alliances are included. American Airlines, Lufthansa, Iberia, Air Canada, LATAM, LAN, British Airways, TAM and ANA correspond to Interjet [14]; and in the case of Aeromexico the airlines of its alliance (SkyTeam) that operate in the AICM are Air France, Delta Airlines and KLM [15].

The other airlines, Mexican and foreign, would move to the AISL. As a whole, the airlines at the AICM would be attending approximately 36.633 million passengers (to 71.5% of the maximum capacity of passenger terminal); and the other airlines would attend around 14.547 million passengers at the AISL (to 72.7% of the maximum capacity of passenger terminal). Under this scenario the Table 1 shows in the colours green and blue the airlines that would operate in the AICM and AISL, respectively.

Considering the growth trend of operations at the AICM for the year 2021, it was estimated a value of 474,062 operations. Performing the respective estimations for the airlines that operate at the two airports were determined 342,671 operations per year at the AICM and 131,391 operations at the AISL; so in this scenario their runways would be operating to 72.2% and 69.1% of their maximum capacity, respectively.

Subsequently, considering a moderate growth of the attended passengers (AAGR = 4%) at the two airports, it was estimated that both infrastructures would be working to nearly 100 percent of their capacities in the year 2029 (AICM would attend 50.14 million passengers and the AISL 19.9 million); and definitely in 2030, they would not be able to meet all the demand; so the expansion of the AISL should start before 2027.

Table 1 - Predicted passengers to be attended in the year 2021, for the different airlines that currently operate in the AICM
Source: Own forecast based on information provided by the AICM

Airline	Passengers per airline by the end of 2021 (millions)	Passengers accumulated (millions)
INTERJET	12.195	12.195
AEROMEXICO	11.878	24.073
AEROMEXICO CONNECT	8.509	32.582
VOLARIS	6.713	39.295
VIVA AEROBUS	4.089	43.384
UNITED AIRLINES	1.007	44.392
AMERICAN AIRLINES	0.926	45.318
DELTA AIR LINES	0.839	46.157
AEROMAR	0.749	46.907
COPA AIRLINES	0.511	47.418
AVIANCA	0.497	47.915
LUFTHANSA	0.407	48.322
IBERIA	0.403	48.725
JETBLUE AIRWAYS	0.357	49.082
AIR FRANCE	0.341	49.424
AIR CANADA	0.270	49.694
KLM	0.208	49.902
MAGNICHARTERS	0.194	50.096
SOUTHWEST AIRLINES	0.183	50.279
LATAM AIRLINES	0.180	50.459
TACA AIRLINES	0.176	50.635
LAN PERU	0.149	50.784
BRITISH AIRWAYS	0.147	50.930
TAM-LINHAS AEREAS	0.103	51.033
ANA	0.077	51.111
VUELA AVIACION	0.069	51.180
Total	51.180	

Scenario 3. Domestic flights in the AICM and international flights in the AISL. Under this scenario it is assumed that the AICM concentrated the domestic flights and the AISL the International flights. Due to the domestic flights make up the highest proportion of passengers (68.9%) and operations (72.1%), these would be located at the AICM, because it has greater capacity than the AISL; and all the international flights would be attended in the latter.

Table 2 presents the distribution of the airlines in these airports, considering the passenger forecast for 2021.

Scenario 4. T1 airlines at AICM and T2 airlines at AISL. Under this scenario the airlines currently operating at AICM Terminal 1 (T1) would remain in this airport, and the airlines that currently offer service at AICM Terminal 2 (T2) would move to the AISL.

The correspondence between the T1 and AICM is because the Terminal 1 attends currently more passengers than the T2, and the capacity of the AICM in 2021 would be greater than the AISL.

Table 3 presents the results of the passengers and operations forecasts for this scenario by the year 2021.

Finally, in relation to the four scenarios above mentioned, it is important to note that all these analyses considered forecasts based on an average day, corresponding to Wednesday, 6 March 2019. After review the other days of the week (from 3 to 9 March 2019) only marginal changes in the percentage share of passengers were observed; the most significant difference found was the participation of other four airlines (China Southern Air, Hainan Airlines, Copa Airlines Colombia and Trans American Airlines), that there were not presented at the average day; however, the percentage shares of these airlines were minimal, for instance, their average share in flights was equal to 0.09% or approximately one flight per day.

Table 2 - Passengers and operations at the AICM (domestic flights) and AISL (international flights) for year 2021
Source: Own forecast based on information provided by the AICM

AIRPORT	AIRLINE	PASSENGERS TO BE ATTENDED (MILLIONS)	FLIGHTS TO BE ATTENDED
AICM DOMESTIC FLIGHTS	INTERJET	9.90	89,622
	AEROMEXICO CONNECT	7.88	103,410
	AEROMEXICO	6.31	49,880
	VOLARIS	6.17	40,958
	VIVA AEROBUS	4.09	27,576
	AEROMAR	0.73	27,170
	MAGNICHARTERS	0.19	3,244
	SUBTOTAL	**35.27**	**341,860**
AISL INTERNATIONAL FLIGHTS	AEROMEXICO	5.57	40,958
	INTERJET	2.30	21,899
	UNITED AIRLINES	1.01	10,544
	AMERICAN AIRLINES	0.93	8,516
	DELTA AIR LINES	0.84	7,300
	AEROMEXICO CONNECT	0.63	9,733
	VOLARIS	0.54	5,272
	COPA ARLINES	0.51	4,055
	AVIANCA	0.44	2,433
	LUFTHANSA	0.41	1,622
	IBERIA	0.40	1,622
	JETBLUE AIRWAYS	0.36	4,866
	AIR FRANCE	0.34	811
	AIR CANADA	0.33	2,839
	KLM	0.21	811
	SOUTHWEST AIRLINES	0.18	1,622
	LATAM AIRLINES	0.18	811
	TACA AIRLINES	0.18	1,622
	LAN PERU	0.15	811
	BRITISH AIRWAYS	0.15	811
	TAM-LINHAS AEREAS	0.10	811
	ANA	0.08	811
	VUELA AVIACION	0.07	811
	AEROMAR	0.01	811
	SUBTOTAL	**15.91**	**132,202**
	TOTAL	**51.18**	**474,062**

Table 3 - Passengers and operations at the AICM (AICM T1 current airlines) and AISL (AICM T2 current airlines) for year 2021
Source: Own forecast based on information provided by the AICM

AIRPORT	AIRLINE	PASSENGERS (MILLIONS)	FLIGHTS
AICM	INTERJET	12.19	111,520
	VOLARIS	6.71	46,230
	VIVA AEROBUS	4.09	27,576
	UNITED AIRLINES	1.01	10,544
	AMERICAN AIRLINES	0.93	8,516
	AVIANCA	0.44	2,433
	LUFTHANSA	0.41	1,622
	IBERIA	0.40	1,622
	JETBLUE AIRWAYS	0.36	4,866
	AIR FRANCE	0.34	811
	AIR CANADA	0.33	2,839
	KLM	0.21	811
	MAGNICHARTERS	0.19	3,244
	SOUTHWEST AIRLINES	0.18	1,622
	LATAM AIRLINES	0.18	811
	TACA AIRLINES	0.18	1,622
	LAN PERÚ	0.15	811
	BRITISH AIRWAYS	0.15	811
	TAM-LINHAS AEREAS	0.10	811
	ANA	0.08	811
	VUELA AVIACION	0.07	811
	SUBTOTAL	**28.69**	**230,745**
AISL	AEROMEXICO	11.88	90,838
	AEROMEXICO CONNECT	8.51	113,142
	DELTA AIR LINES	0.84	7,300
	AEROMAR	0.75	27,981
	COPA ARLINES	0.51	4,055
	SUBTOTAL	**22.49**	**243,317**
	TOTAL	**51.18**	**474,062**

Analysis and discussion of results

Then, the pros and cons for each of the alternatives are analyzed.

Scenario 1. Status quo. This is a trivial solution.

Advantages: Those airline companies that wish to grow should start operations at the new airport in Saint Lucia. Otherwise, they will stay the same.

Disadvantages: The AISL would be underutilized in the short term and the AICM would be congested, so the problem would not be solved. Under this scenario, all airlines that decide to grow need to operate at two airports, increasing their operating costs by requiring staff in both locations. This condition discourages the growth of air services due to the high initial operational costs in both facilities. In some cases, the connecting flights within a same airline would require ground transportation of passengers between the airports. Then, the worst disadvantage of this option is that the AICM would continue operating in saturation condition, which implies according to previous studies, a significant deterioration of the service, that is reflected in high or significant queues and waiting times. In addition, supposing a moderate AAGR (4%) for the passengers, in the year 2028 the AISL would reach more than 80% of its maximum capacity (16.17 million passengers) and in 2030 would exceed it (21.67 million).

Scenario 2. Major alliances. Note that in this case five airlines build up almost 85 per cent of the total passengers handled in the AICM (Interjet, Aeromexico, Aeromexico Connect, Volaris and Viva Aerobus); note too that all of them are Mexican airlines. The rest of the airlines have very small participation, less than two percent on an individual basis.

Advantages: The three main Mexican airlines remain at the AICM. The operation of the airline alliances (code-sharing) is facilitated. Most connecting flights are at the same airport (AICM or AISL); the saturation is reduced significantly; and there is capacity for supporting growth.

Disadvantage: Some airlines have to move their operations to the AISL.

Scenario 3. Domestic flights in the AICM and international flights in the AISL. Note that under this scenario, on one hand, the AISL begins operations at 79.5% of maximum capacity in its passenger terminal and at 69.5% of maximum capacity in runways; on the other hand, the AICM respective values are 68.9% and 72.1%. So both would have capacity for growth. Assuming an AAGR = 4% for the passengers, the AISL would be saturated in year 2027, and the AICM in the year 2031, since the first begins with a higher level of use at its passenger terminal.

Advantage: The level of initial use allows growth for some years.

Disadvantages: The number of passengers on connecting flights that have to move by land between the two airports is increased significantly, because all Mexican and foreign airlines with international flights arrive at an airport that does not have domestic flights, as a result of which all connection to the interior of Mexico would mean moving to another airport and vice versa; also, this alternative hinders the advantages of alliances and code-sharing. In addition, most of the Mexican airlines would require staff and facilities at both airports.

Scenario 4. T1 airlines at AICM and T2 airlines at AISL. The quantities of passengers and operations for this scenario along with the capabilities of the airports, indicate that this alternative is not viable.

Advantage: It is assumed that this scenario would reduce the number of passengers on connecting flights that have to move between these airports.

Disadvantages: This option is not viable, because although the AICM would have capacity to attend the passengers and ATMs estimated for 2021; the AISL would not have capacity for passengers (lack of capacity for 2.49 million passengers), and for operations on runways (it would exceed its capacity in over 53 thousand ATMs per year). In the case of trying that the AISL would attend the passengers of the AICM Terminal 1, there would be less capacity. Note that only Aeromexico and Aeromexico Connect airlines would exceed the capacity of the AISL.

Conclusions and recommendations

The capacity characteristics of the AICM and AISL; and the number of passengers that would be attended, and the operations that would be performed by the different airlines, delimit the possible alternatives for the operation of these airports.

The first scenario does not relieve congestion at the AICM; the third scenario is not practical because it generates more passengers moving by land between the two airports of connecting flights; and the scenario four is not viable, because it exceeds the capacity of the AISL.

Apparently, the best option is the scenario 2. In this case, it is recommended that the expansion of the AISL starts before 2027, in order to avoid the congestion problems.

It is essential to carry out consultations with the airlines to define the final operational arrangement; however, the alternatives considered in this paper serve as orientation and guidance to provide objective elements for discussions and agreements to make the final decision.

Although this analysis did not consider the Toluca International Airport (AIT), many of the conclusions remain unchanged, since this airport would continue operating and growing with its own area of influence. AIT has two disadvantages; its location favours the formation of mist, it has an annual average of 40 days under this condition; and perhaps the most important drawback is its elevation (8,466 feet), which limits the capacity to offer freight and passenger service.

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UNIVERSIDADE
BEIRA INTERIOR

Rua Marquês D'Ávila e Bolama.
6201-001 Covilhã. Portugal.

Email: geral@ubi.pt
+351 275 319 700   +351 275 329 183

GPS: 40°16'42.5", 7°30'42.2" (FEUBI)