Lisboa - Portugal
June 27-29, 2024

IX Iberoamerican Air Transportation Research Society International Congress

"The Resilience and Sustainability of Air Transportation."

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

"A Resiliência e a Sustentabilidade do Transporte Aéreo".

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

"La resiliencia y la sostenibilidad del transporte aéreo"

RIDITA 2024

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OFFICIAL LANGUAGES: English, Portuguese and Spanish.

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¬ RIDITA2024

IX IBEROAMERICAN AIR TRANSPORTATION RESEARCH SOCIETY INTERNATIONAL CONGRESS
"THE RESILIENCE AND SUSTAINABILITY OF AIR TRANSPORTATION."

¬ ORGANIZED BY

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¬ PREAMBULE

Pasión es la palabra que reúne a los que conformamos la Red Iberoamericana de Investigación en Transporte Aéreo. Quizás sea por nuestro origen latino y por este entrañable lazo que la península ibérica ha tendido con el continente americano o viceversa. El transporte aéreo es de las actividades más complejas y fascinantes con las que aún hoy cuenta la humanidad. Y eso se debe al imponente avance tecnológico, de servicio, de seguridad y de mejora en la calidad de vida. Se debe también a buscar la tan deseada sostenibilidad junto a recursos humanos altamente calificados.

Cómo investigadores, siempre debemos preguntarnos ¿Qué nos duele? Porque el dolor despierta la reacción y los deseos de superación. El mayor aporte que un investigador puede hacer a la sociedad es hacerla reflexionar. Y las hipótesis deben estar a la altura de la importancia del transporte aéreo.

La RIDITA es una sociedad de conocimiento madura que busca nuevos horizontes. Somos el mejor agente de cambio para que los sectores público y privado puedan diseñar sus estrategias, cada cual con sus propios intereses, pero a la vez articularlas por el bien común. Debemos asegurar el rigor científico para que los cambios siempre necesarios repercutan positivamente en la sociedad en general, en la sociedad en su conjunto.

Fundada en el año 2007, la RIDITA hoy cuenta con casi 300 socios en más de 25 países. En lo personal estoy orgulloso por lo conseguido y expectante por lo que vendrá, Lisboa sin duda es el lugar elegido para un nuevo protagonismo de esta Red en el escenario mundial de la aviación.

Este libro de actas contiene valiosos artículos, de gran aporte. Mis sinceras felicitaciones a cada uno de los autores por su entrega, por su pasión. Invito a todos a leer estos trabajos y que estos aportes sean adoptados para tender nuevas redes y lograr cambios.

Bienvenidos al IX Congreso.
Bienvenidos a una nueva RIDITA.

Daniel Montero Ferreiro
Presidente de la RIDITA 2019 - 2024

We are delighted to extend our warmest welcome to all participants of the IX Iberoamerican Air Transportation Research Society International Congress, jointly organized by ISEC Lisboa, UBI, and IST. This esteemed gathering, dedicated to exploring "The Resilience and Sustainability of Air Transportation," promises to be an enriching and thought-provoking event.

From June 27th to 29th, 2024, esteemed researchers, academics, and industry professionals from around the globe will converge in the vibrant city of Lisbon to engage in discussions, share insights, and foster collaborations aimed at advancing our understanding of the challenges and opportunities facing the air transportation industry.

At the heart of this congress lies a crucial theme: The Resilience and Sustainability of Air Transportation. In an era marked by unprecedented global challenges, it is imperative that we examine the resilience of air transport systems and explore strategies to ensure their long-term sustainability in the face of evolving environmental, economic, and societal factors.

Through a series of keynote speeches, panel discussions, paper presentations, and workshops, this congress seeks to facilitate meaningful dialogue and knowledge exchange on a wide range of topics, including but not limited to aviation safety, infrastructure development, regulatory frameworks, emerging technologies, and the societal impacts of air transportation.

We extend our deepest gratitude to all participants, sponsors, and partners whose contributions have made this congress possible. Together, let us embark on a journey of discovery, innovation, and collaboration as we strive to shape the future of air transportation for the benefit of society.

We look forward to welcoming you to Lisbon for what promises to be an inspiring and transformative congress.

Sincerely,

Maria Emília da Silva Baltazar
Jorge Miguel dos Reis Silva
Vasco Reis

IX Iberoamerican Air Transportation Research Society International Congress
Organizing Committee

¬ INTRODUCTION

The congress endeavours to foster the advancement and diffusion of air transport research within the Ibero-American region, encompassing its scientific, academic, technological, applied, and informative dimensions. It seeks to cultivate connections among members through scientific sessions, digital platforms, and analogous gatherings. Special emphasis is placed on nurturing cultural appreciation for air transport research and enhancing its educational aspects, thereby serving as a hub for information exchange and dissemination among stakeholders.

¬ CONGRESS TOPICS

A. Aircrafts
   - A.1. Aerospace and Aeronautical Engineering
   - A.2. Manned/Unmanned Aviation and Aerial Systems
   - A.3. Others

B. Air Industry
   - B.1. Air Transportation and Management Engineering
   - B.2. Sustainable Aviation
   - B.3. Others

C. Airports
   - C.1. Airports Operation and Management
   - C.2. Emerging Technologies
   - C.3. Others

D. Air Space
   - D.1. Aerial Mobility & Autonomous Flight Systems
   - D.2. Navigation, Guidance and Control
   - D.3. Others

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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.

¬RIDITA2024 STATISTICS

Total of 34 papers and 4 Invited Lectures 3 Keynote Speakers presented on RIDITA2024.

Figure 1 – 3672 Visitors in RIDITA2024 Website

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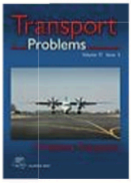
¬ SCIENTIFIC JOURNALS

JAIRM - Special Issue

Journal of Airline and Airport Management is an open access scientific journal. The aim of JAIRM is to publish theoretical and empirical articles aimed to contrast, extend and build scientific knowledge that contributes to advance our understanding of air transport from three perspectives: air transport and globalization, airline management, and airport management.

RPER - Revista Portuguesa de Estudos Regionais

A Revista é dirigida a académicos e outros profissionais para os quais são relevantes as questões do espaço e do território: economistas, urbanistas, sociólogos, engenheiros, etc. A RPER é uma revista indexada internacionalmente no EconLit (e bases associadas: JEL on CD, e-JEL e Journal of Economic Literature), na Qualis (Brasil), Latindex e na Scopus.



Transport Problems - INTERNATIONAL SCIENTIFIC JOURNAL

Journal Transport Problems is a peer-reviewed open-access scientific journal, owned by Silesian University of Technology and has more than 10 years of experience. The editorial staff includes mainly employees of the Faculty of Transport. Editorial Board performs the functions of current work related to the publication of the next issues of the journal. The International Programming Council coordinates the long-term editorial policy the journal. The Council consists of leading scientists of the world, who deal with the problems of transport. This Journal is a source of information and research results in the transportation and communications science: transport research, transport technology, transport economics, transport logistics, transport law.

¬ CONGRESS PROGRAM

Time	27 June 2024	Place
10.00 H	Registration (Until 17.30 h)	Registration Desk
11.00 – 11.30 H	OPENING CEREMONY	Auditorium
11.30 – 13.00 H	Invited Lectures	Auditorium
13.00 – 14.00 H	Lunch	My Campus
14.00 – 16.00 H	Air Transport and Airports	Auditorium
16.00 – 16.30 H	Coffee Break	My Campus
16.30 – 19.00 H	Air Traffic Management Technological Strategies	Auditorium
20.00 H	Welcome Reception	Salão Nobre da Junta de Freguesia do Lumiar

Time	28 June 2024	Place
8.30 H	Registration (Until 17.30 h)	Registration Desk
9.00 – 10.30 H	Invited Lectures	Auditorium
10.30 – 11.00 H	Coffee Break	My Campus
11.00 – 13.00 H	Airports Operational Strategies	Auditorium
13.00 – 14.00 H	Lunch	My Campus
14.00 – 16.00 H	Air Transport Operational Strategies	Auditorium
16.00 – 16.30 H	Coffee Break	My campus
16.30 – 19.00 H	Planning and Policy Economic Strategies	Auditorium
20.00 H	Congress Dinner	Lagar da Quinta de São Vicente, Telheiras

Time	29 June 2024	Place
8.30 H	Registration (Until 17.30 h)	Registration Desk
9.00 – 10.30 H	Invited Lectures	Auditorium
10.30 – 11.00 H	Coffee Break	My Campus
11.00 – 13.00 H	Decision-making Processes Economic Strategies	Auditorium
13:00 – 14.00 H	Lunch	My Campus
14.00 – 16.00 H	Air Transport Sustainable Development Social and Environmental Strategies	Auditorium
16.00 – 16.30 H	CLOSING CEREMONY	Auditorium
17.00 – 18.00 H	RIDITA General Assembly	Auditorium

¬ LISBON CITY

Lisbon is built on hills looking over the River Tagus. Modern and cosmopolitan, it is a great centre of culture and tourism, and a pleasure to discover on foot. Add to that its cultural diversity, laidback feel and architectural time warp, and you have one of the most enjoyable cities in Europe. Clean skies and the softness of its light are an integral part of the charm of this city. Seen from the river - one of the city's many great viewpoints - Lisbon is an impressionist picture of low-rise ochre and pastel, punctuated by church towers and domes.

Eating and Shopping in Lisbon

Lisbon is a melting pot of cultures, flavours and spices. Quality of food in general, and of fish in particular, are always referred as special. Several neighborhoods' offer interesting shopping areas of local flavour.

Large, modern shopping malls with wide opening hours and easy access by public transport are also very popular.

Nightlife in Lisbon

One of the traditional centres of Lisbon's nightlife is Bairro Alto, with its fado houses, restaurants and dozens of bars and clubs. After the riverside area was remodeled for Expo98, night life in Lisbon gained a new dimension both on east and west fronts.

Out of Town

People who want to get away from the city centre, however, can go with modern railways to Sintra or to Estoril and Cascais, about 30km away, with beautiful landscapes, urban settings and nice restaurants and bars.

Things to do in Lisbon.

Lisbon Cathedral

Lisbon Cathedral, better known as Sé de Lisboa, is the oldest and most important church in the city. Its construction dates from the twelfth Century. The Cathedral of Lisbon is austere in appearance with a predominantly Romanesque style, although with the alterations made over the years, different styles have been masterfully blended which give it a very special character. From the outside, the cathedral is protected by thick walls framed by two bell towers, which give it an appearance more typical of a medieval fortress than of a church. The façade still retains its 12th-century Romanesque style and its centerpiece is a central rose window. Once inside, we'll find a temple that, in the midst of its austere character, has some decorative elements such as the fountain in which Saint Anthony of Padua was baptized, some 14th-century sarcophagi, and a striking 14th-century Gothic chapel.

Jerónimos Monastery

The Jerónimos Monastery (Hieronymites Monastery) is one of the most visited tourist attractions in Lisbon. It was declared a World Heritage Site in 1983. The Jerónimos Monastery, also called Hieronymites Monastery, is along with the Tower of Belém, one of the most visited sites in Lisbon. UNESCO declared it a World Heritage Site in 1983.

This landmark is called Mosteiro dos Jerónimos in Portuguese. The religious building was designed by the Portuguese architect Diogo de Boitaca to commemorate the return of Vasco da Gama from India. The construction began on 6 January 1501 and wasn't completed until the seventeenth century. The building is predominantly Manueline style (Portuguese late Gothic). Curiously, the monastery was built on the site of the former Ermida do Restelo, the chapel where Vasco da Gama and the rest of the sailors prayed before setting sail down the African coast to India.

Belém Tower in Lisbon

Belém Tower was first built to defend Lisbon. Years later, it was transformed into a lighthouse and customs center. The Belém Tower (Torre de Belém) was built between 1514 and 1520 in a Manuelino style by the Portuguese architect and sculptor Francisco de Arruda. It was classified as a World Heritage Site in 1983 by UNESCO. Constructed on the northern bank of the Tagus River, this tower was used to defend the city. Years later, it was transformed into a lighthouse and customs house. It's located right by the Jerónimos Monastery, so we recommend visiting them on the same day.

Monument to the Discoveries in Lisbon

The Monument to the Discoveries (Padrão dos Descobrimentos) stands 170 Ft (52 m) tall. It was designed to commemorate the Age of Discoveries in Portugal. The Padrão dos Descobrimentos (Monument to the Discoveries) stands 170 Ft (52 m) tall. This stunning monument was designed to commemorate the Age of Discoveries in Portugal. It was inaugurated in 1960, on the fifth centenary of one of the country's great discoverers, Prince Henry the Navigator, who discovered the Azores, Madeira, and Cape Verde. The tribute is located on the coast of Belém, near Lisbon, and is also very close to other important sights like Belém Tower and Jerónimos Monastery. The Monument to the Discoveries is made up of a group of sculptures that represent the prow of a caravel (a small sailing ship constructed by the Portuguese to explore the Atlantic Ocean). Leading the ship is Prince Henry the Navigator and behind him are many other great Portuguese discoverers.

São Jorge Castle

São Jorge Castle sits on the summit of São Jorge hill, a fantastic lookout point. It is one of the most emblematic symbols of Lisbon and is visible from anywhere in the city. São Jorge Castle (Castelo de São Jorge) is one of Lisbon's most emblematic landmarks. The silhouette of the Castle stands out both by day and when illuminated at night, located on the summit of São Jorge hill, the highest in Lisbon. The hillside also houses two of the city's neighbourhoods called Alfama and Castelo.

A small fortress was built by the Visigoths during the fifth century. It was modified and enlarged by the Moors in the mid-eleventh century and during the reign of Afonso I of Portugal (1109 – 1185), it was altered and in later years transformed into a Royal Palace. Finally, it was completely restored in 1938.

The Castle reached its maximum splendour during the thirteenth century and lasted until the sixteenth century when it was occupied by both the Kings of Portugal and the Bishop. Only a few years ago, Phoenician, Greek and Carthaginian ruins were found in the area, and are currently being uncovered.

Lisbon neighbourhoods

The most traditional neighbourhoods are Baixa, Chiado, Bairro Alto, Alfama and Belém. Each one of these districts has its own unique vitality and essence.

In addition to these traditional areas, there are two very modern areas of Lisbon. The first is called Marquess of Pombal Square (Praça do Marquês de Pombal) and its surroundings. The second is the area around the Park of the Nations (Parque das Nações), which was constructed for the 1998 Lisbon World Exposition.

Baixa

Baixa is the liveliest and most central neighborhood in Lisbon. It was rebuilt by the Marquis of Pombal after the Great Earthquake of 1755.

Chiado & Bairro Alto

Chiado and Bairro Alto are Lisbon's bohemian and alternative neighborhoods. They are separated by the square Praça Luís de Camões.

Alfama

Alfama is an authentic fishing neighborhood located between the Atlantic Ocean and Lisbon's São Jorge Castle. It is where Fado was created.

Park of the Nations

Park of the Nations (Parque das Nações) is an area that was created for the 1998 World Expo in Lisbon. It's a modern, vibrant area, with many open spaces.

The Instituto Superior Técnico (IST, also known as Técnico, and stylized TÉCNICO LISBOA (Higher Technical Institute) is the school of engineering and technology of the University of Lisbon. It was founded as an autonomous school in 1911, and was integrated into the Technical University of Lisbon (now part of the University of Lisbon) in 1930. IST is the largest school of engineering in Portugal by number of enrolled students, faculty size, scientific production and patents.

IST has three campuses, all located in the Lisbon metropolitan area: the Alameda campus in Lisbon, the Taguspark campus in the Oeiras municipality, and the *Tecnológico e Nuclear* campus in the Loures municipality. The school is divided in 11 departments that are responsible for teaching undergraduate and postgraduate programs. Each department is organized in sections, which group together specific subjects within its scientific area. In addition, the laboratories of the several departments support the teaching and research activities carried out at IST.

IST is a member of several university partnerships, including CLUSTER, CESAER, T.I.M.E., TPC, and the ATHENS Programme.

History

The *Instituto Superior Técnico* (IST) was created from the split of the Lisbon Commercial and Industrial Institute (IICL) into two schools. Following the implantation of the Republic in Portugal in 1910, Alfredo Bensaúde, a professor of Mineralogy and Geology at the IICL, was invited by Manuel de Brito Camacho, Minister of Development in the Provisional Government, to create and lead a new technical school, as part of nationwide education reforms. A decree approved on 23 May 1911 and published in the *Diário do Governo* declared that the IICL would be split into two schools: the *Instituto Superior do Comércio* (current Lisbon School of Economics and Management) and the *Instituto Superior Técnico*.

Bust of Alfredo Bensaúde, first director of the IST, in the Central Pavillion

Alfredo Bensaúde was the first director of the IST, a position he held from 1911 to 1920. He implemented its first pedagogical program, which had five engineering courses: mining engineering, civil engineering, mechanical engineering, electrical engineering, and chemical-industrial engineering. Under his direction, there was an investment in theoretical-practical teaching where workshops and laboratories, as well as the library, played an essential role. He also noted for recruiting foreign teachers, which he considered to have an essential role in organizing some of the courses.

The first facilities of the IST were located in the Rua da Boavista in Lisbon. In 1927, Duarte Pacheco became director of the IST and started the project for a new campus for the school. He requested

the design to architect Porfírio Pardal Monteiro, who counted with the collaboration of Luís Benavente, a fellow architect, in the project. The construction of the Alameda campus started in 1928 and was finished in 1935, with the inauguration happening the following year. IST became the first academic institution in Portugal with its own campus.In the meantime, in 1930, IST became part of the newly created Technical University of Lisbon.

Central Pavillion of the Alameda campus, the main building of the IST

In 1948, the IST hosted the "Fifteen Years of Public Works" exhibition, an event organized by the Portuguese State to exhibit the new infrastructures built in the first 15 years of the *Estado Novo*. The statue of a woman holding a square and compass, by Salvador Barata Feyo, placed in the northern side of the campus, is a sculpture from this exhibition that was permanently added to the Alameda campus.

Between 1952 and 1972, 12 study centres were established in Portugal, three of them at IST, in the fields of Chemistry, Geology and Mineralogy, and Electronics. These centres were responsible for promoting faculty training and scientific qualification through doctoral studies in universities and research centres abroad.

In 1970, the minimum period for obtaining a bachelor's degree decreased from six to five years, and the number of students enrolled at IST significantly increased. During the 1970s, scientific research at IST also has a major increase, through the creation of the Interdisciplinary Complex building in 1973, which gathered together various autonomous research units.

During the 1990s, more engineering courses, including Master and PhD degrees, were added to IST's curricular offer. The facilities in the Alameda campus had the greatest expansion in this decade, with the construction of the Civil Engineering and Architecture Pavilion and the North and South towers.

In 2000, IST inaugurated a new campus in the municipality of Oeiras, specifically in the Taguspark, the first Portuguese science and technology park. In the academic year 20062007, the Declaration of Bologna was successfully implemented for all IST programmes, reducing the time to obtain a bachelor's degree to three years. In 2012, the *Tecnológico e Nuclear* campus was added to the IST, following the discontinuation of the Technological and Nuclear Institute.

Today IST is involved with several of Portugal's research, development and technology transfer institutions and offers a vast number of degrees in science and engineering areas, at undergraduate, master and doctoral levels. IST is also part of several networks and international programmes to promote student mobility, both at undergraduate and postgraduate levels.

Campuses and facilities

The IST has three campuses: the Alameda campus in Lisbon, the Taguspark campus in the Oeiras municipality, and the *Tecnológico e Nuclear* campus in the Loures municipality.

Alameda campus

The Alameda campus is the primary location of the IST. It was inaugurated in 1936 as the first dedicated university campus in Portugal.It is located in the *freguesia* of Areeiro, in Lisbon.

The campus originally had 7 buildings. Throughout the yers, new buildings were constructed inside the campus, expanding the facilities of the IST. Some of the buildings added after 1936 include:

- The Interdisciplinary Complex, opened in 1973;
- The Civil Engineering and Architecture Pavilion, opened in 1993;
- The North Tower, opened in 1994;
- The South Tower, opened in 2000;
- The Social Action Pavilion, opened in 2003.

Civil Engineering and Architecture Pavilion, in the Alameda campus

Currently the campus has a total of 26 buildings. Apart from lecture and research buildings, it includes a dedicated canteen building, a building for the students' association, playing fields for sports, an indoor swimming pool, and a kindergarten

Taguspark campus

Taguspark campus in Porto Salvo

The IST inaugurated a second campus in the Taguspark, a science and technology park in Porto Salvo, in the Oeiras municipality, in 2000. The campus consists of a main building, a sports field and a hall of residence.

Taguspark is located about 14 km to the west of the Alameda campus. A free shuttle bus service connecting the Alameda and Taguspark campuses is available for exclusive use of the IST community.

As of the academic year 2023–2024, three bachelor's degree programmes and five master's degree programmes are lectured in the Taguspark campus.

Tecnológico e Nuclear campus

The *Tecnológico e Nuclear* campus was added to the IST in 2012. It is located in Bobadela, in the municipality of Loures, about 9 km northeast of the Alamada campus. Prior to its addition to the IST, the campus belonged to the Technological and Nuclear Institute (Portuguese: *Instituto Tecnológico e Nuclear)*, which was extinguished in December 2011 by governmental decree.

The campus contained the only nuclear reactor in Portugal, which was used for more than 50 years for scientific research. The reactor was stopped on 11 May 2016 and dismantled in 2019.

As of the academic year 2023–2024, two master's degree programmes use the facilities in this campus: Radiation Protection and Safety, and Science and Technology for the Cultural Heritage.

CiTUA
CENTRE for INNOVATION in TERRITORY, URBANISM AND ARCHITECTURE

Based on a humanistic approach, and through collaborative innovation, starting from the culture of places and guided by a problem orientated pragmatic approach, CiTUA vision is driven by the following main principles:

- the significance of the material and immaterial legacy of natural and man-made territories, which provide a basis for developing diachronic (historical) representations of urban and architectural phenomena, understanding past dynamics and trends towards a major efective long-term changes;
- the necessary reconstruction of the relationship between the global and the local scale of urban territories from economic, social, political, technological, cultural and environmental perspectives;
- the significance and dynamic condition of the local dimension of urban territories, with its distinctiveness, represent a potential for creating, maintaining and dignifying livable, self-sustainable, and adaptable solutions that are fully adjusted to the specificity of the site and the socioeconomic and governance context.

CiTUA's outputs will serve to highlight general empirical spatial and social patterns showing how urban territories function, and to demonstrate the diversity of territories based on the analysis of deviations from these patterns but will also serve to inform and validate new approaches and models concerning future territories.

This approach avoids "exceptionalism" (i.e. all territories are different and no general proposition can be formulated about them) and "determinism" (i.e. a unique principle governs how territories function, regardless of time and place) emphasizing pluralism, knowledge and continuous (instrumental and conceptual) learning (i.e. changes that leads to modification of policies and changes in beliefs).

The faculty and students working with CiTUA take an interdisciplinary approach to contemporary problems and pursue innovative solutions by leveraging the assets of Tecnico, a research school located in a dynamic and diverse metropolitan city.

CiTUA's mission is:

- to carry out high quality cross-disciplinary and collaborative research and knowledge development on urban territories that connects urban and architectural culture with the core engineering science disciplines investigated at IST;
- to collect and process rich and varied territorial, urban and architectural data to support knowledge generation and inform the debate and prospection of the future of urban territories and their built spaces, including documenting and inquiring theories and processes involved in (re)making urban territories;
- to understand the interactions between the built fabric of urban territories and their social, economic, cultural and environmental dynamics and the potentials and conditions that ensure urban cohesion and liveability, including policy making and good governance strategies to respond to, or recover from, contemporary challenges and threats;
- to disseminate the work carried out in publications, conferences, seminars and other type of outreach activities;
- to establish links between the research outputs and high quality educational programmes, promoting also collaborative dynamics with the industry and public authorities.

OBJECTIVES

CiTUA's goals include engaged and rigorous research that is policy relevant and replicable. The activities of CiTUA are directed towards leading-edge research developments on urban territories with the following specific goals:

- to analyse, test, monitor, evaluate and optimize the capacity and use of present urban territories from the scale of the city- region up to the individual building to respond to socio-economic environmental changes and ensure a more balanced and sustainable relation between urban and natural material and imaterial legacy, including the rediscovery, reuse, redevelopment and reinterpretation of past discourses and practices;
- to develop efficient methodologies, affordable technologies and solutions to respond to the needs of expanding urban territories driven by rapidly changing and very culturally diversified millieux, including in developing countries that have recently entered in a strong process of urbanization;
- to evaluate models of governance, financial and management procedures, in different political and socio-cultural contexts, aiming to create conditions and promoting spaces of dignity and social cohesion, while pursuing a more efficient and fair administration of public interest and goods.

STRATEGY

To achieve these objectives CiTUA adopts a strategical framework based on:

- a process of knowledge building on urban territories according to a multiscale approach, which combines theoretical knowledge, evidence-based knowledge generated on the territory, methodological knowledge derived from comparative approaches, technological expertise and experiential knowledge and competences generated into the practice; cooperation between research and practice is, first and foremost, a form of producing and disseminating new knowledge that benefits both researchers and actors operating within the territory.
- active intellectual collaboration among researchers with varied backgrounds and perspectives acquired in different areas of science, sectors (e.g. university, industry, governmental and regional administration) and regions.
- strategic partnerships and cooperation with other R&D centres and institutions, to promote a worldwide multidisciplinary research network including national and international Universities, R&D institutions, central and local administration entities and the industrial sector, with special focus on Portuguese and Spanish speaking countries.

- advanced formative and life learning actions to share research findings and introducing young researchers to large-scale collaborative research ventures.
- the diffusion of scientific results through publications, seminars, conferences, exchange visiting programs and scientific meetings at both national and international level.
- new and diversified outreach activities based on the concept of open science and innovation, through connections and interactions between the academic and the nonacademic communities and knowledge bases.

CiTUA encourages a collaborative attitude among senior and junior researchers and doctoral students through the development and implementation of “research-training” sessions designed to promote dialogue and cross-fertilization between experiences and concepts. The emphasis on case studies and fieldwork (i.e. empirical reality) is understood as an opportunity to enrich and challenge the theoretical, methodological, and cross-disciplinary frameworks and approaches.

CiTUA strategy involves a continuous process of exchange between researchers as part of an attempt to understand urban territories and their evolution in an ever-changing environment. This process considers the development of a basic framework of interrelated questions based on thematic issues or topics. Key questions provide a basis for the co-construction of a common aim or project shared by a group of researchers and justified based on the shared ground of the questions raised. The result is the identification of potential resources in which a project can be developed.

The development of a platform of collaboration allowing for the confrontation of connecting perspectives, disciplines, and practical experiences, promotes external perspectives through interventions by experts or researchers and encourages dialogue. This enables researchers to appropriate the relevant knowledge, processes and resources and develop their own projects accordingly. It is precisely the process of capitalization of knowledge and the distinction between raw information and transmissible knowledge that will provide the understanding needed to achieve a degree of scientific autonomy.

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 UBI was Prof.

Cândido Manuel Passos Morgado, who would remain in office between August 21, 1980 and January 19, 1996, when Professor Manuel José dos Santos Silva took office as Rector , who remained in office until June 19, 2009. On this date, Professor João António de Sampaio Rodrigues Queiroz takes office as the third Rector of the institution. On September 5th, 2013, Professor António Fidalgo takes office, who remains in office until June 8th, 2021, the date on which the fifth and current Rector, Professor Mário Lino Barata Raposo, takes office.

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

Officially recognized in August 1991, ISEC Lisboa - Higher Institute of Education and Sciences, is defined as a private non-profit higher education and research establishment whose institutional mission is to provide scientific, technical, cultural, pedagogical, professional and human training. As an institution of public interest, ISEC aims for growth driven by the national needs as well as the objectives that it statutorily pursues, thus contributing to the qualified, integrated and harmonious development of higher education in Portugal.

This mission is mainly accomplished through a training project guided by high standards and inspired by ethical and humanist principles, to prepare citizens of culture and competent professionals. The adequacy of a training project to quality professional performance depends largely on the integration of scientifically produced knowledge. This is why the learning experience marked by intellectual curiosity and the spirit of research represents, in our educational project, a strategy for integrating theoretical and practical knowledge, critical reflection and lifelong professional development. (https://www.iseclisboa.pt/index.php/en/).

The (EGEA) The School of Management, Engineering and Aeronautics is a is the ISEC Lisboa school that offers a wide range of opportunities for students who wish to enter the job market in exciting and challenging careers, whether in the private sector or in the public or social sector, with education and training programs in the fields of management, engineering and aeronautics. Here students have the opportunity to acquire theoretical and practical knowledge preparing to face innovative professional challenges.

The training provided by the School prepares students to participate significantly in the application of the scientific knowledge acquired, in the projection and development of innovative technologies, in the improvement and maintenance of systems, structures, devices and processes, in addition to contributing to the advancement of science and society as a whole, involving the coordination and organization of resources and processes necessary to efficiently lead and manage systems and Organizations.

The laboratories and specialized facilities that are available, allow to provide an active practical education. In addition, partnerships with relevant institutions, companies, organizations, and entities provide internship opportunities during the courses or even employment after their completion. The presence of highly qualified Professors at EGEA, who guarantee the quality of teaching and scientific research, allow to increase the credibility of ISEC Lisboa, attracting more students and this also positively influences new partnerships with companies, institutions, and organizations of society and with other national or international academic institutions.

Academic excellence is essential for us. That is why our teachers have advanced academic training in their respective areas of specialization and, therefore, provide a deep and up-todate knowledge on the topics they teach, allowing us to offer a high-quality education. Our teachers not only teach, but guide students and contribute to the production of knowledge, innovation, and the discovery of new solutions to complex problems related to the areas of EGEA's training offer. They possess improved pedagogical skills, are familiar with modern teaching methods and can adapt their approaches to understand the needs of students, which allows them to transmit knowledge effectively.

In summary, an innovative, comprehensive and challenging training offer, qualified teachers, updated equipment, proximity between Teachers and Students, permanent work without interruptions, are fundamental pillars for the educational success of the School of Management, Engineering and Aeronautics, ensuring that students receive a quality education, are prepared to face the challenges of the professional world and contribute to the transmission of scientific knowledge that meets the needs of the professional world and contribute to the transmission of scientific knowledge that meets the diverse needs of society, solving complex problems, creating solutions to improve people's lives and acquiring skills that allow strategic decisionmaking for the growth and sustainable success of the country.

AETA – Aeronautics, Space and Air Transport. The line of research in Aeronautics, Space and Air Transport (AETA) constituted by the research professors of ISEC Lisboa and their students in these areas, arises, because they believe that it is possible the involvement of all in the fields of research of aviation, air transport, aeronautics and space given the capacity of the installed faculty.

Through practical experiences and rigorous empirical evaluations and with the increasing availability of data, advances in modelling techniques and the growth of computational capabilities, development of artificial intelligence (AI), machine learning (ML) and innovative optimization methods to provide digital solutions it is possible to develop within the ISEC Lisboa Research Centre for the applied research subordinate Aeronautics, Space and Air Transport.

The AETA research group contributes to the understanding and optimisation of air transport processes and support coordination between different stakeholders at different operational levels. In addition, following the current environmental challenges and the EU's climate objectives, part of the group's research effort will be to study how new technological developments could be incorporated into new operational concepts to further accelerate the sustainability of aviation, as well as all developments in aeronautics and space, thus contributing to CEIA's mission to promote scientific research practices among ISEC Lisbon faculty and students in the various areas of training of the institution, in a sustained and organized way, in order to contribute to the activity of scientific production and dissemination of knowledge of ISEC Lisboa. This line of research is supported by scientific production, participation in international and national projects, members of research centres of excellence and professional experience by the professors of the aeronautics department and that can be confirmed through their ORCIDs.

The main mission of this line of research at ISEC Lisboa is related to the following aspects:

- Develop a deep and systematic vision on the field of studies of competitiveness, innovation and entrepreneurship applied to the Aeronautics, Space and Air Transport sector;
- Allow the elaboration and implementation of solid research plans, in accordance with ethical and methodological standards, likely to generate contributions to the development of scientific knowledge in the field of management, engineering and aeronautics.
- Assist in the presentation, dissemination of research results within the academic community.
- Encourage students, teachers and other interested parties to autonomously promote the advancement of scientific knowledge in these areas of study. Increase cooperation with researchers from other institutions, through the participation of our members in national and international scientific networks, participation in joint research projects and the co-authorship of scientific articles.
- Maintain a very stimulating research environment and promote close cooperation among members, encouraging the publication of their preliminary work in the Research Centre and organising seminars, conferences and other internal events and external participations with the aim of facilitating communication and sharing of ideas among

members, and organising at least once a year a workshop of the Centre where all members of the various units meet.
- Develop a critical point of view in relation to the production and use of scientific knowledge.
- Promote the development of thematic areas of research of excellence.
- Follow-up meetings and information sharing will also be developed in the line, fostering research by teachers and students.

RESEARCH AREAS

The AETA research group at CEIA aims to develop innovative methodologies and decision-making frameworks to analyse and optimise the operations of the air transport sector to improve global efficiency, capacity, safety, resilience and sustainability. It intends, through this line of research at CEIA, to apply and further develop advanced applied research and artificial intelligence methods to formulate and solve models for the aviation sector are specific focus areas, in the aeronautics and space strand concentrated on:

- AERODYNAMICS AND AEROACOUSTICS: Drag reduction; active and passive control of the boundary layer; wind tunnel design; aerodynamics of road vehicles; aerodynamic optimization; quantitative track analysis; low noise fans; modeling and simulation of compressible and incompressible flows; aeroacoustics; computational fluid mechanics; hydrodynamic instability; turbulence; boundary layer, experimental aerodynamics; experimental aeroacoustics.
- AEROELASTICITY, DYNAMICS AND FLIGHT CONTROL: Computational aeroelasticity; semi-empirical models for non-stationary aerodynamics; study and prediction of aeroelastic phenomena (flutter, buffeting, galloping, etc.); aeroelastic model design for wind tunnel; modal analysis of aeronautical structures; vibration analysis in complete aircraft; aeroservoelasticity; application of unconventional control techniques in aeroservoelasticity; mathematical models of intelligent structures; application of new materials for active control of structures; smart materials; modeling and identification of flight dynamics; aircraft stability and control; aircraft performance; nonlinear aircraft dynamics; aircraft guidance and piloting; flight simulators.
- AERONAUTICAL STRUCTURES: Theoretical and experimental analysis of aeronautical structures; structure instability; structural junctions; structures under impact; structural repairs; intelligent structures and materials; structural integrity monitoring; models for predicting damage and failure in composite material structures; computational modeling of aeronautical structures via the Finite Element Method; theoretical and experimental analysis of intelligent materials and structures; structures in natural composites, biopolymers and biodegradable polymers.
- ASTRODYNAMICS: such as orbital and attitude motion of terrestrial satellites, design of interplanetary missions, situational awareness of spacecraft, determination of orbit and trajectory optimization, and the problem of drawing the interplanetary trajectory of collision of space bodies with planet Earth.

And in the area of air transport as:

- AIRPORT OPERATIONS which address several of the current and future challenges of airport operations, including: Promoting the efficient use of limited airport capacity, for example by understanding and improving the recovery process, gate assignment, airport surface handling operations and airport terminal operations. Develop efficient solutions for collaborative decision-making, promoting a reliable and equitable decision-making process, while facilitating the secure sharing of data between various stakeholders. Study and develop decision support solutions to support the deployment of innovative and greener technologies and processes, such as electric taxiing. Exploit data provided by airports, air traffic control entities and other relevant stakeholders to propose predictive solutions that can anticipate capacity shortages and operational

disruptions. Current research on this topic can be supported by national airport infrastructures by facilitating access to data and transforming these into living laboratories to test the solutions developed in CEIA's AETA research line.

- AIR OPERATIONS where several of the current and future challenges of air operations are addressed, including: Develop adaptive planning solutions to plan the long-term operations of airlines, including network development and fleet planning, while dealing with uncertainty. Develop learning approaches to scheduling airline operations, both for passengers and cargo, while dealing with uncertainty and limited resources. Tackle dynamic and complex operations control challenges by proposing fast, highly efficient AI solutions for outage management. Study and model the use of greener operational solutions for commercial aviation, including innovative electric aircraft design solutions or improved operating concepts. Work on this topic may be partially sponsored by research projects funded by airlines and aircraft manufacturing partners.
- AIRCRAFT MAINTENANCE, where it addresses several of the current and future challenges of aircraft maintenance, including: Develop digital solutions for intelligent aircraft maintenance operations, including the development of ML techniques to exploit the increasing availability of aircraft sensor data and predict and diagnose the health conditions of aircraft systems. Develop optimization and AI solutions to schedule aircraft maintenance operations that ensure high fleet availability while dealing with outages and exploring the benefits of predictive maintenance. Promote and develop condition-based maintenance solutions by studying the impact of these solutions on the efficiency of aircraft maintenance operations. Facilitate the adoption of conditionbased maintenance solutions in practice, studying the proposition of modeling approaches that can contribute to the explainability of ML techniques and interpretation of the results produced. The group can have a research collaboration with TAP Engineering and Maintenance, addressing relevant practical challenges and contributing directly to innovation and knowledge transfer.
- INNOVATIVE AIR MOBILITY: can study the operational challenges of innovative air mobility solutions, including drones and air taxis, taking into account the growing needs of personal mobility through the development of operational and planning models to study the use of unmanned electric aerial vehicles in support of or complementary to the current operations of airlines. As part of the work, the AETA group can develop models to support decisions concerning the composition of the fleet, the topology of an urban air mobility network for specific case studies, the dynamic scheduling of missions, the integration of this urban air mobility system into the existing urban system and the assessment of mobility impacts, safety and environment of this type of mobility solutions.
- HUMAN FACTORS AND ERGONOMICS: The gradual development of technology and artificial intelligence (AI) has put at our disposal robust and adaptive decision-making (DM) methods that can reduce the occurrence of human error and risk index in engineering applications. Human factors (HF) research challenges should be fully taken into account in the DM process, especially in the field of air traffic control (ATV). In order for air traffic controllers (ATCOs) to efficiently play their important role in aviation safety and reliability, applied research on this topic emerges as an area of high interest that can contribute to better training of ATCOs in the challenges of digitalization.

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TÉCNICO LISBOA

UNIVERSIDADE BEIRA INTERIOR

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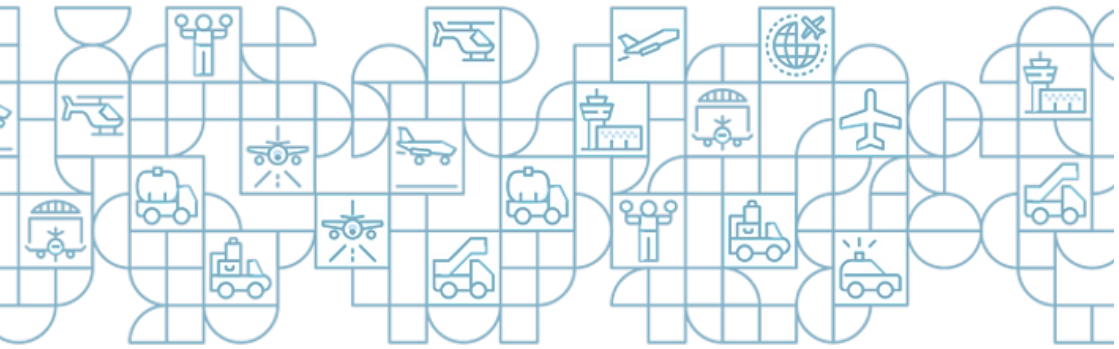

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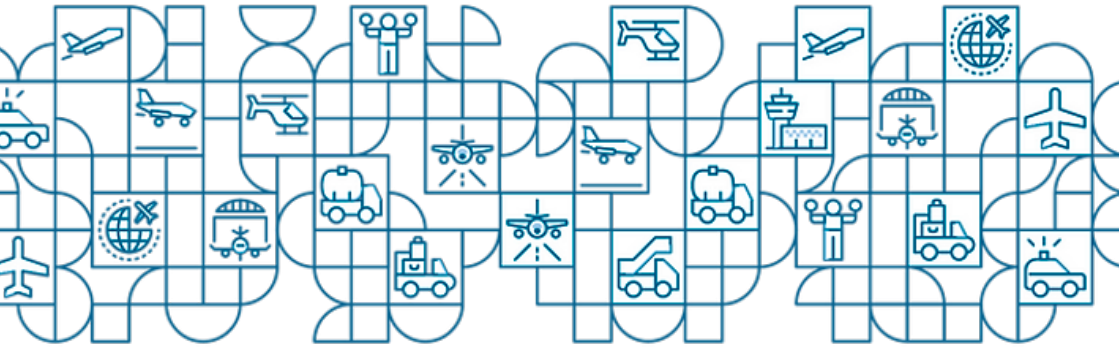

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Aircraft Selection for Regional Airline Operations: A Strategic Analysis for the Colombian Case

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Abstract/Resumo/Resumen

This paper presents a comprehensive strategic analysis specifically tailored to the Colombian context, with a primary focus on aircraft selection for regional airline operations. Given Colombia's distinctive geographical and market characteristics, characterized by diverse terrain and fluctuating demand patterns, the study thoroughly examines the intricacies involved in making aircraft choices. Throughout the analysis, a wide range of aircraft types and operational criteria are meticulously evaluated, considering factors such as route structure, passenger preferences, regulatory frameworks, and Colombia-specific economic considerations. The analyses encompass various options, including the purchase of new aircraft and the exploration of different leasing arrangements. Through the integration of both qualitative assessments and quantitative analyses, this research aims to provide customized insights for regional airlines operating within the Colombian market. By employing engineering, economic, and operational concepts, the paper aims to offer a nuanced understanding of the trade-offs and opportunities associated with different aircraft selection strategies. Furthermore, this paper offers a strategic framework designed to facilitate decision-making processes regarding aircraft selection. The overarching goal is to optimize operational efficiency, enhance profitability, and bolster competitive positioning within the Colombian aviation sector. Through a rigorous examination of key factors and strategic considerations, this analysis seeks to provide actionable recommendations to regional airlines navigating the complex landscape of aircraft selection in Colombia.

Aircraft Selection for Regional Airline Operations: A Strategic Analysis for the Colombian Case

1. Introduction

The Colombian aviation industry is experiencing a notable boom. It is expected that the demand for air travel will significantly increase in the coming years, driven by various factors such as sustained economic growth, the rise of the middle class, and increased regional connectivity [1] This growth not only represents an opportunity for the larger airlines operating in the country but also opens a vast field of possibilities for regional airlines, which can play a fundamental role in connecting cities and regions not served by the major carriers.

Both Airbus and Boeing, the two main manufacturers of commercial aircraft in the world, have made optimistic forecasts about the growth of air traffic in Latin America, specifically including the Colombian market. According to Airbus estimates, passenger traffic in the region is expected to grow at an average annual rate of 4.3% until 2040 [2] On the other hand, Boeing has forecasted a slightly higher growth rate of 4.4% annually for the same period [3]. These projections reflect a widespread optimism in the aviation industry regarding the growth potential of the region.

In the specific case of Colombia, even more robust growth is expected. Airbus estimates that passenger traffic in Colombia will grow at an average annual rate of 5.1% until 2040 [2], while Boeing predicts a growth rate of 5.2% annually for the same period [3]. These figures reflect the dynamism and vitality of the Colombian economy, as well as the increasing demand for air transportation services in the country.

This increase in demand for air travel poses significant challenges and opportunities for Colombian regional airlines. On one hand, it represents a unique opportunity to expand their operations and increase their market share. On the other hand, it also implies the need to adapt to the new market realities and make strategic decisions regarding fleet renewal.

Many of the Colombian regional airlines currently operate with aircraft that are quite old, with an average age of over 20 years [4]. While these aircraft may have been suitable for market needs in the past, the evolution of market conditions and technological advancements in the aviation industry suggest the need for fleet renewal. Acquiring newer and more efficient aircraft can not only help reduce operating costs and improve the passenger experience but also enhance the competitiveness of regional airlines in an increasingly competitive market. According to IATA, new aircraft can consume up to 25% less fuel than older aircraft [5].

An exhaustive literature review was conducted with the aim of finding various methods that help identify certain aircraft selection criteria. This provides a more solid vision on how to choose the optimal aircraft to operate on regional routes. In this context, it was found that the author Wail I. Harassani addresses the evaluation and selection of an aircraft fleet for a local airline in Jeddah and Madinah, Saudi Arabia. In his study, Harassani thoroughly analyzes various costs associated with aircraft operation, such as fuel, maintenance, insurance, and depreciation. The process involves a meticulous evaluation of the efficiency of different types of aircraft, considering factors such as the cost of the trip and the cost per seat-mile. Detailed analyses of the performance of each aircraft are carried out, considering their capabilities at the end of the route and at airports, as well as specific operational rules for domestic and international routes. The results of his study show that the EMB145 aircraft is the most efficient option for the given network. [6], [7].

On the other hand, authors Slavica Dožić and Milica Kalić employ the COPRAS (Complex Proportional Assessment) method, a multi-criteria decision-making technique used to compare and evaluate alternatives based on multiple criteria. This method helps determine the importance of each criterion and rank alternatives according to their suitability for the established objective. In their study, they used the

COPRAS method to evaluate aircraft alternatives based on multiple criteria such as price, payment conditions, total costs per ASM, among others. This method is based on quantitative and qualitative data and relies on pairwise comparisons to determine the importance of one element over another concerning a given attribute [8].

On the other hand, Baŭgra Baŭgcı and Murat Kartal explain the use of the SWARA and COPRAS methods in the aircraft selection process of an airline. The SWARA method (Stepwise Weight Assessment Ratio Analysis) is used to determine the weights of criteria in decision-making scenarios, such as purchase cost, fuel capacity, maximum seat capacity, range, maximum takeoff weight, and payload capacity. After establishing the final weights of the criteria using the SWARA method, the COPRAS method is applied to evaluate aircraft alternatives. This involves creating a decision matrix, normalizing the matrix, creating a weighted normalized matrix, and calculating values to evaluate the alternatives. By combining the SWARA and COPRAS methods, airlines can systematically evaluate and prioritize criteria, assess aircraft alternatives, and make informed decisions aligned with their operational and strategic objectives [9].

The proposed method aims to provide a more objective view in the financial domain, in contrast to other more subjective approaches like SWARA or COPRAS, which utilize selection matrices [[10]. It is essential to clearly understand financial indicators and how they directly affect airline finances. To perform these calculations, it is necessary to consider both the direct and indirect costs of each company, as these costs are the most significant and affect aircraft maintenance, fuel consumption, the number of crew members required for the flight, among other aspects.

This article aims to conduct a strategic analysis of aircraft selection in the Colombian market, focusing on various perspectives including the Cost Available Seat Kilometer (CASK) to provide an objective view of the economic landscape. We will delve into specific growth opportunities within the Colombian market and conduct a detailed analysis of regional travel forecasts, identifying the most demanded routes and market expansion opportunities. Additionally, we will explore strategic and financial considerations associated with the acquisition of new aircraft and the retirement of existing ones. Special attention will be given to different acquisition methods, such as operational leases, where the aircraft must be returned to the lessor in similar or better condition at the end of the contract, and financial leases, where monthly payments are made, allowing the airline to eventually own the aircraft.
By comprehensively analyzing these factors, our goal is to provide Colombian regional airlines with valuable insights and a solid foundation for making informed decisions and seizing growth opportunities in the regional market.

2. Methodology

The methodology is related to the financial aspects of the airlines, it is recognized as a crucial factor due to its long-term sustainability. A key component of this approach is understanding the specific characteristics of each different aircraft, as well as getting a deep knowledge of the geography where the operations will take place. In Colombia, many cities are distributed in mountainous areas, and routes are generally short, as illustrated in Figure 1, based on reports from the UAEAC [11] (Unidad Administrativa Especial de Aeronáutica Civil). These flights typically last 1 hour or 1.5 hours. Because of the high costs of engines and aircraft fuel and maintenance, it is important to select candidates with a specific criterion and economically viable.

Some of the specifications for the aircraft to be selected include their classification as regional aircraft, which implies a capacity to transport up to 100 passengers and conduct short-distance flights. Additionally, operating under a low-cost model is anticipated, which means that all seats will be classified as economy class, and point-to-point flights will be offered without loyalty programs or other additional services.

To carry out the aircraft selection, prioritizing the evaluation of financial aspects is essential to outline the best available option. This involves obtaining information on the aircraft leasing cost and the expenses associated with its operation and maintenance. Additionally, it is crucial to define the specific routes on

which the aircraft will operate and determine whether it will better suit a low-cost or traditional (legacy) configuration. With this data in hand, the Available Seat per Kilometer (ASK), a fundamental indicator in the aviation industry, along with the Cost Available Seat per Kilometer (CASK) and Revenue Available Seat per Kilometer (RASK), can be calculated, providing a clear perspective on the financial viability of the operation.

Figure 1 – Passengers-Cargo
Source: UAEAC [11]

3. Aircraft selection

For aircraft selection, various factors are considered. The most important factor for the proposed methodology is the acquisition cost, which is the monthly lease price of the aircraft. Additionally, the characteristics of each aircraft must be considered, such as passenger capacity, fuel consumption, range, speed, among others. All these characteristics will be obtained directly from the manuals.

The age of each aircraft also plays an important role in acquisition, as an older aircraft has a lower cost but may require more maintenance and have higher fuel consumption. On the other hand, a new aircraft may have a higher acquisition cost, but maintenance costs may be lower or covered by the manufacturer in the early years. Another factor to consider is the type of lease contract under which the aircraft operates, as this can be operational or financial.

Considering the aforementioned, for the weighting and subsequent selection of the aircraft that best fits the needs of the regional market in Colombia, constant variables are considered, which are shown in Table 1, where the number of seats, the occupancy factor, and an approximate distance of what constitutes a regional route are determined.

Table 1 - Constant Variables of the Matrix

Seats	78
Flight distance	195
Load factor	80%
BH	0.83

In addition to the proposed model, it is crucial to consider other variables that influence aircraft selection, which are essential for calculating the CASK and RASK that the airline will have for that aircraft on the selected route. These variables in table 2 that include the aircraft lease cost, which, as mentioned, is linked

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to the "age" of the aircraft, and it is necessary to determine its economic impact in terms of maintenance per flight hour (BH). Similarly, aspects such as fuel consumption per hour are critical, as higher consumption will result in higher associated expenses. Finally, crew costs vary according to each airline's salary policy, and expenses related to airport, overflight, sales and distribution, and general and administrative costs are subject to each country's regulations.

Table 2 - Variable variables of the matrix

Aircraft cost [USD/month]
Maintenace [USD/BH]
Fuel [Gal/h]
Crew [USD]
Airport cost [USD]
Overflight [USD]
Sales & distributor [USD]
General & administer [USD]

Having all this data, it is possible to calculate the CASK, which subsequently helps determine the cost per trip and then calculate the RASK. These three factors are crucial to determine which option best fits the benefits that are sought from that route and therefore from that aircraft.

Furthermore, it is necessary to be aware of all the current regulations in the country, including the flight times of the crew and how many flights they can perform in a day. With this information, it is also possible to establish how many routes the aircraft can cover per day, which will also be an important factor in determining the aircraft.

4. Results

For the selection of aircraft, a search must be conducted, taking into consideration the characteristics expressed above. This is how two aircraft are identified, which meet the requirements stipulated for the specific case. First, we have the ATR 72-600, which is a turboprop aircraft with a maximum capacity for 72 passengers, a MTOW (Maximum Take-off Weight) of 16.313 lb, a speed of 500 km/h, and a fuel consumption of 1.432 lb/h [12].

Figure 2 – ATR 72 - 600
Source: [13]

On the other hand, we have the CRJ700, which is a turbofan aircraft, with a maximum capacity for 78 passengers. It has a higher fuel consumption than the ATR, at 444 U.S. gal/h, but it has a higher speed of 876 km/h. Additionally, it has a much larger MTOW (Maximum Take-off Weight), and range compared to its competitor, at 72,750 lb and 1,434 NM (Nautical Miles) respectively.

Figure 3 – CRJ700
Source: [14]

Knowing the selected aircraft, the values of the variables in the matrix from Table 2 were determined in different scenarios. The selected scenarios include a new ATR, one that is 5 years old, one that is 10 years old, as well as a 5-year-old and a 10-year-old CRJ100. These aircraft have been well received in the regional market, and they manage to comply with many of the stipulated variables for the choice. In addition, the same aircraft of different ages are sought to identify if this has a significant change in the indicators. This allows comparisons to be made between them when calculating the CASK and RASK. The values considered for each item mentioned are shown in Table 3.

It is important to highlight that the choice of the right aircraft can have a significant impact on an airline's profitability. Therefore, this analysis is crucial for making informed decisions about the aircraft fleet. In addition, this approach can help airlines adapt to changes in the market and effectively respond to fluctuations in passenger demand. In summary, this analysis provides a valuable tool for strategic management in the aviation industry.

Table 3 – Operational cost

Aircraft	ATR NEW	ATR 5 YEARS	ATR 10 YEARS	CRJ700 5 YEARS	CRJ700 10 YEARS
Aircraft cost [USD/month]	190,000.00	125,000.00	90,000.00	120,000.00	85,000.00
Maintenace [USD/BH]	300.00	300.00	300.00	450.00	450.00
Fuel [Gal/h]	213.41	213.41	213.41	444.00	444.00
Crew [USD]	136,000.00	136,000.00	136,000.00	136,000.00	136,000.00
Airport cost [USD]	70.00	70.00	70.00	70.00	70.00
Overflight [USD]	34.90	34.90	34.90	34.90	34.90
Sales & distributor [USD]	2.00	2.00	2.00	2.00	2.00
General & administer [USD]	2.00	2.00	2.00	2.00	2.00

With this data, the entire financial analysis is conducted. This process considers factors such as ASK, CASK, and RASK, including the Block Hours (BH) factor, which is the hours the aircraft is occupied, from the closing of the doors to landing at its destination [15] In this case, a route is chosen from Medellin (SKRG) to Ibague (SKIB), which is approximately 195 km away

Table 4 - Financial indicators

Aircraft	ATR NEW	ATR 5 YEARS	ATR 10 YEARS	CRJ700 5 YEARS	CRJ700 10 YEARS
% revenue			1.20		
Total cost [Dollars]	2,277.16	2,096.55	1,999.38	2,703.71	2,616.21
ASK [Dollars]	15,210.00	15,210.00	15,210.00	15,210.00	15,210.00
CASK [Cents]	14.97	13.78	13.15	17.78	17.20
Cost of trip [Dollars]	29.19	26.88	25.63	34.66	33.54
Flight cost [Dollars]	2,027.56	1,846.95	1,749.78	2,454.11	2,366.61
Revenue [Dollars]	2,732.59	2,515.87	2,399.26	3,244.45	3,139.45
Fee [Dollars]	43.79	40.32	38.45	51.99	50.31
RASK [Cents]	17.97	16.54	15.77	21.33	20.64

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After conducting a thorough financial analysis, we examine the CASK values of each aircraft according to their age. This indicator allows us to understand the cost of operating each seat per kilometer. Based on this, we conclude that:

1. First, we discard the option of having an aircraft with a turbofan engine. Despite its speed, the high fuel consumption is not justified for short flights, where the aircraft does not reach its cruising speed.
2. Although the CASK of a 10-year-old ATR is lower than that of a new one, this aircraft could imply higher maintenance costs.

5. Conclusions

This method provides an objective and quantitative perspective on the financial aspects of airline operations. Its main goal is to minimize the cost per operation, while maximizing corporate benefits. This approach allows for an accurate estimate of the ticket cost, which is essential for determining the viability of a specific route. In addition, this financial approach can be instrumental for airlines in strategic decision-making. By understanding the CASK, airlines can identify opportunities to improve efficiency, optimize routes, and effectively adjust ticket prices. This can result in increased profitability and competitiveness in the aviation market. In summary, the proposed method plays a crucial role in the financial management of the aviation industry. This study contributes to the existing literature by providing a detailed analysis of how operating costs and ticket prices can influence the profitability of airlines. The findings of this study may be useful for aviation industry professionals, researchers, and policy makers.

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Análisis del efecto de posibles regulaciones de las emisiones de la aviación distintas de CO2

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Abstract/Resumo/Resumen

Dentro del proceso de medidas para limitar el cambio climático, la línea principal de acción se ha dirigido al proceso de descarbonización. La descarbonización de la aviación se ha convertido en prioritaria, con un objetivo, aprobado por OACI en 2022, de alcanzar cero emisiones netas de carbono en el año 2050. El resto de las emisiones de la aviación (fundamentalmente estelas de condensación y óxidos de nitrógeno) han recibido una menor atención debido a una serie de factores que hacen más complicado su estudio, cuantificación y regulación. Sin embargo, la certidumbre de que sus efectos pueden ser superiores a los del CO2 ha hecho que se estén buscando medios para regular sus efectos. El propósito de la presente investigación se centra en, a la vista de los recientes avances de la investigación en este tema, y de los desarrollos normativos en estudio en la Unión Europea, desarrollar un modelo de simulación de los efectos de la aviación sobre el cambio climático que tenga en cuenta, además, las emisiones distintas del CO2. Para ello se seguirán los siguientes pasos: -Identificación de un modelo de cálculo y de datos relevantes - Seguir los avances de la investigación en el tema - Selección de modelos meteorológicos y climáticos a utilizar - Estudiar los posibles incentivos para reducir y controlar estas emisiones Se espera con ello dotar a las partes interesadas de mayor información y de una herramienta que permita simular el efecto de potenciales medidas a tomar, tanto operativas como regulatorias.

Análisis del efecto de posibles regulaciones de las emisiones de la aviación distintas de CO_2

1. Introducción

La figura 1 representa un esquema del tipo de emisiones producidas por la combustión de queroseno en un motor reactor moderno. Como puede verse, la mezcla del combustible con el aire a altas temperaturas dentro de la cámara de combustión produciría en el caso de una mezcla perfecta CO_2 y vapor de agua, a lo que habría que añadir óxidos de azufre, por el contenido de este último elemento que suele llevar el queroseno de aviación.
Dado que en el mundo real la mezcla no es perfecta, aparecen otros productos, como hidrocarburos inquemados (UHC), monóxido de carbono (CO). Partículas sólidas de carbono y óxidos de nitrógeno (NOx). El carácter estricto de la especificación de los querosenos más usados en aviación comercial (Jet A y Jet A1) hace que el combustible consumido en todo el mundo tenga una composición prácticamente idéntica.

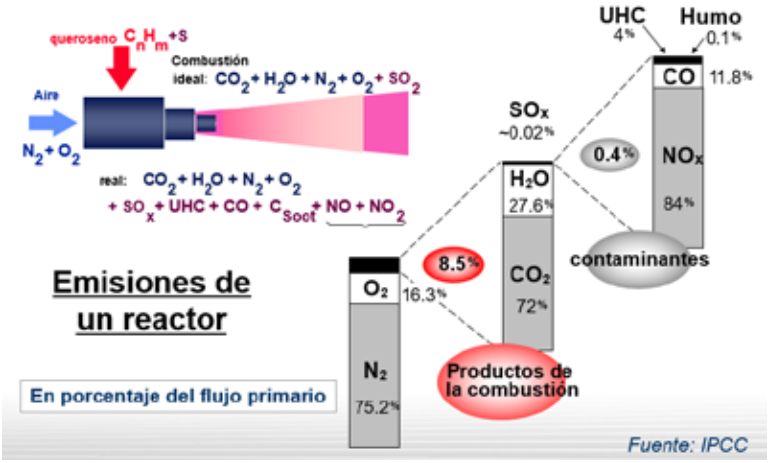

Figura 1 – Esquema del proceso de combustión de queroseno en un motor reactor. Los porcentajes indican peso
Fuente: IPCC Aviation and the global Atmosphere [1]

La inyección de estas emisiones en la atmósfera terrestre, dentro de las zonas de vuelos de los aviones comerciales actuales (hasta 14.000 m de altitud) tienen diversos efectos sobre el cambio climático:

- Emisión de CO_2: gas de efecto invernadero que produce calentamiento atmosférico
- Emisión de NOx: ningún efecto directo, pero emitido en altitud, contribuye a crear ozono y a destruir metano (ambos gases de efecto invernadero). El resultado neto es de calentamiento
- Emisión de vapor de agua: efecto directo de calentamiento leve, pero en determinadas condiciones de altitud, humedad y temperatura puede formar estelas de condensación (contrails), con un efecto importante de calentamiento
- Emisión de partículas sólidas, principalmente carbón: efecto de calentamiento leve
- Emisión de compuestos de azufre: efecto de enfriamiento leve
- Emisión de UHC y CO: efecto despreciable.

La Figura 2 es la más reciente estimación global de los efectos de cada una de las substancias emitidas en las últimas décadas. Los efectos están valorados en términos de Fuerza Radiante Efectiva (ERF, en

milivatios por metro cuadrado), que es la unidad más frecuentemente empleada por la comunidad científica, y representa los efectos globales sobre la atmósfera de las diferentes emisiones. A efectos de valorar los efectos sobre la temperatura de la superficie terrestre, se emplea otra unidad, cuyos resultados numéricos son algo superiores a las cifras del ERF.

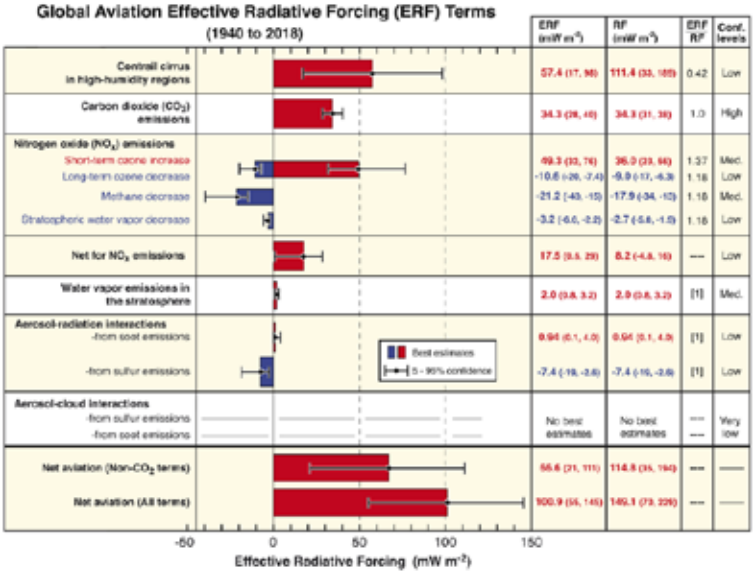

Figura 2 – Estimación de ERF de la aviación mundial en el período 1940-2018. Las barras rojas indican calentamiento y las azules enfriamiento. Las líneas negras horizontales representan intervalos de confianza 5-95% de las estimaciones
Fuente: [2]

Según puede verse en la Figura 2, los principales elementos con vistas al cambio climático serían las estelas de condensación (aproximadamente 55% del efecto total), CO_2 (35%) y NOx (15%), mientras que los compuestos de azufre sería el principal factor de enfriamiento (5%). Sin embargo, los niveles de confianza son muy distintos, con un +/- 5% en el CO_2, frente a un +/-40% en las estelas de condensación.

2. Iniciativas para el control de emisiones distintas de CO_2

Dentro del proceso mundial de medidas para limitar el cambio climático, la línea principal de acción se ha dirigido al proceso de descarbonización, para disminuir el uso de combustibles fósiles y sustituirlos por fuentes de energía renovables. Aunque el CO_2 puede no ser único producto de la aviación mundial con efectos sobre el cambio climático, sus características de larga vida media, estabilidad química y fácil difusión hacen que sus efectos sean los mismos con independencia del tipo de fuente y lugar de emisión. Por tanto, la descarbonización de la aviación se ha convertido en la línea de acción prioritaria, con un objetivo, aprobado por OACI en 2022, de alcanzar cero emisiones netas de carbono en el año 2050.

El resto de las emisiones de la aviación han recibido una menor atención debido a una serie de factores que hacen más complicado su estudio, cuantificación y regulación. Tanto las estelas de condensación como los óxidos de nitrógeno tienen sus efectos climáticos cuando son emitidos en altitudes elevadas, lo que hace que la aviación sea la única actividad que necesita controlar este aspecto. Por otra parte, el conocimiento científico de sus mecanismos de formación e interacción con otros elementos atmosféricos es aún escaso y los márgenes de error de las estimaciones son considerables. Finalmente, sus efectos

dependen mucho del lugar y el momento en que se emitan, siendo las condiciones de temperatura, humedad, composición atmosférica y luz solar, aspectos influyentes para sus efectos en el calentamiento atmosférico.

Sin embargo, la certidumbre de que sus efectos pueden ser superiores a los del CO_2 ha hecho que se estén buscando medios para regular sus efectos. En 2019, la Comisión de la Unión Europea (UE) encargó a la Agencia Europea de Seguridad Aérea (EASA) un estudio sobre los efectos de estas emisiones y las políticas de control más adecuadas, haciendo referencia a la norma en vigor del Comercio de Emisiones (ETS). El estudio, publicado en setiembre de 2020, revisaba el status científico del problema, las opciones tecnológicas y operativas para limitar su impacto, y las posibles políticas que la UE podía adoptar en este contexto [3]. Tras una serie de largas discusiones, la UE aprovechó la Directiva 2023/958, actualizando la normativa ETS, para incluir la creación de un grupo de Seguimiento, Verificación e Información (MRV) para estudiar este tema [4].

El propósito fundamental del grupo será establecer los instrumentos necesarios para crear una herramienta efectiva de evaluación y control, basada en principios científicos. El proceso del estudio tendrá cuatro etapas:

- Identificación de un modelo de cálculo y de los datos relevantes para su empleo
- Seguir los avances de la investigación en el tema
- Selección oficial de modelos meteorológicos y climáticos a utilizar
- Estudiar los posibles incentivos para reducir y controlar estas emisiones.

La Comisión de la UE emitió una convocatoria para la formación de este grupo MRV en abril de 2023, con el propósito de poder empezar los trabajos en 2024.
Hasta el momento no parece que haya otros Estados interesados en promover regulaciones en este campo, aunque tanto la NASA como su equivalente en Japón, están realizando estudios y experimentos, centrados especialmente en la formación de estelas de condensación, con el propósito de averiguar si, con la información meteorológica disponible, sería posible optimizar las trayectorias de los vuelos comerciales para minimizar este fenómeno [5].

3. Modelo para la estimación de las emisiones distintas del CO_2

El Grupo de investigación en Sostenibilidad del Transporte Aéreo de la Universidad Politécnica de Madrid ha desarrollado diversos modelos que estiman las emisiones relativas a las operaciones de aeronaves, que se diferencian en el distinto nivel de agregación tanto de los datos de entrada, como de los resultados

Se describen aquí dos de estos modelos:

- Modelo agregado [6]
- Modelo desagregado

3.1 Modelo agregado

El modelo calcula a partir de las coordenadas de los aeropuertos de origen y de destino de cada vuelo, la distancia ortodrómica entre ambos.
Para ello lleva incorporado un calculador de distancias y una base de datos con las coordenadas de la práctica totalidad de los aeropuertos (identificados bien por su código OACI o por su código IATA).
El modelo incorpora la información de la base de datos Corinair en la que, para cada tipo de avión (igualmente identificados bien por su código OACI o por su código IATA), se aproxima el consumo de combustible del vuelo como una función lineal de la distancia del mismo, diferenciando la fase LTO (Landing and Take off: todas las operaciones por debajo de 3,000 pies) del resto del vuelo. Para aviones más recientes estas funciones se han ajustado con datos de vuelos reales.
A partir del consumo de combustible, se determinan las emisiones que son proporcionales al mismo, fundamentalmente CO_2, utilizando un factor de 3.15.
Éste es un procedimiento simplificado para la evaluación del consumo de combustible ya que no tiene en cuenta la dependencia del consumo de combustible de un vuelo dado con datos reales como peso al

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despegue, trayectoria, altitud, velocidad y condiciones meteorológicas. Además, incorpora hipótesis para estimar el consumo de combustible de ciertos tipos de aviones a partir de tipos similares. El impacto de estas simplificaciones podría ser relevante en la evaluación del consumo de combustible o emisiones de CO_2 de un vuelo en particular, pero son mucho menos importantes para estimaciones agregadas ya efectos comparativos.

3.2 Modelo desagregado

El modelo calcula, a partir de la trayectoria del avión (latitud, longitud y altitud en función del tiempo) y de la masa al despegue, el flujo de combustible en cada intervalo temporal, utilizando las librerías de BADA [7] con los datos de diseño y actuaciones del tipo de avión correspondiente
El consumo de combustible (y las emisiones asociadas) se obtienen a partir de los flujos correspondientes para los intervalos temporales deseados, lo que permite clasificarlas de acuerdo a múltiples criterios si se desea, por segmento de vuelo por ejemplo: LTO, crucero, etc.

A partir del consumo de combustible, se determinan las emisiones que son proporcionales al mismo: CO_2, H_2O, SOx.

Otras emisiones como NOx, HC, CO se calculan interpolando los datos de emisiones certificadas de los motores, a partir del empuje previamente calculado, o a partir de los índices de emisiones certificadas. En la Figura 3 se muestra el diagrama de flujo del modelo.

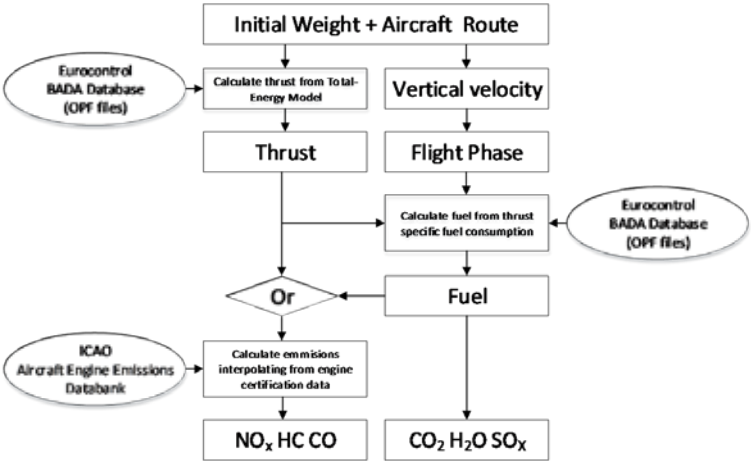

Figura 3 – Diagrama de flujo del modelo agregado para estimr las emisiones de CO_2 y distintas al CO_2
Fuente: Autores

Los modelos se han calibrado utilizando datos reales de consumo de combustible proporcionados por compañías aéreas y fabricantes de aeronaves, de los que e han obtenido funciones del consumo de combustible en función de la ditancia, como las que se muestran en la Figura 4.

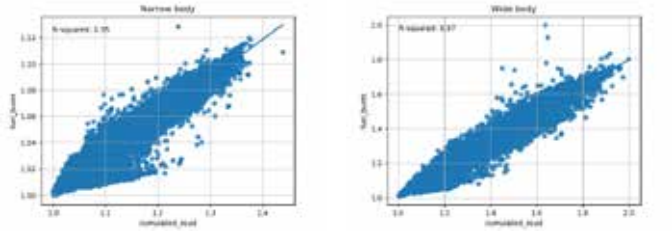

Figura 4 – Consumos de combustible estimados en función de la distancia, para un avión típico de pasillo único y para un avión típico de fuselaje ancho.
Fuente: Autores

4. Impacto económico de las emisiones: medidas de Mercado

Los modelos que se han desarrollado para estimar las emisones de las aeronaves, permiten evaluar la repercusión de las medidas de mercado, tanto en vigor, como el Comercio de Emisiones (ETS) en la Unión Europea, o el sistema CORSIA de OACI, como en estudio, como la posibilidad de graver con un impuesto al combustible o a las emisiones, así como el impacto de la utilización creciente de combustibles sostenibles de aviación.

4.1 Medidas económicas en discusión relacionadas con el impacto ambiental

En cierta manera podría clasificarse en este apartado CORSIA, puesto que el primer período en el que habrá efectos económicos es el trienio 2024-2026, asumiendo que el período piloto 2021-2023, en el que se están finalizando los detalles del mecanismo y los curos de formación en todos los países participantes, acabe con los resultados esperados.

De la misma forma debe destacarse la evolución prevista del ETS europeo, en la que se irán eliminando progresivamente los permisos de emisión gratuitos hasta que desaparezcan totalmente en el año 2027, con un fuerte impacto económico en los operadores del mercado intraeuropeo por los altos precios del mercado de permisos de emisión.

Las medidas económicas que aparecen en la mayor parte de las discusiones legislativas actuales se centran en dos áreas diferentes: la imposición de un impuesto sobre el combustible y la aplicación medidas para apoyar la introducción de SAF, principalmente en forma de mandatos sobre la cantidad mínima a mezclar con el queroseno de origen fósil.

Estas dos áreas de trabajo, junto con la actualización de la Directiva general de ETS y su compatibilidad con CORSIA, fueron designadas como objetivos preferentes por la Comisión Europea, dentro del paquete de normas “Fit for 55”, aprobado el 14 de julio de 2021.

4.2 Impuesto sobre el combustible

La normativa que emana del Convenio de Chicago prohíbe la aplicación de impuestos sobre elementos subidos al avión para ser consumidos a lo largo de los vuelos internacionales, incluyendo, por tanto, el combustible. Al ser una normativa de OACI, esto no se aplica a los vuelos domésticos, donde los Estados tienen libertad para regular estos aspectos del uso de energía en los medios de transporte. Varios Estados imponen este tipo de gravámenes. En algunos de ellos, con estructura federal, como Estados Unidos y Canadá, cada estado puede fijar su propio nivel de impuesto y la cifra que se les atribuye puede variar de uno a otro.

En el campo internacional y ante la petición de varios Estados, OACI aprobó en 1999 una resolución, reflejada en el documento Doc 8632, admitiendo la aplicación de impuestos en el combustible de vuelos

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internacionales si los dos Estados, de origen y destino del vuelo, lo aceptaban e incluían este punto en al Acuerdo Bilateral de Derechos de Tráfico que afectaba a estos vuelos. Hasta el momento, ningún Estado ha hecho uso de esta posibilidad, temerosos de perjudicar la competitividad de sus compañías aéreas frente a las de otros países.

La UE siguió el rumbo de OACI, con la Directiva 2003/96/CE, del 2003, eximiendo de impuestos el combustible de aviación tanto en vuelos comerciales internacionales como en domésticos, pero dejando abierta esta posibilidad a sus Estados miembros, mediante acuerdos bi o multilaterales, e incluso sugiriendo una tasa mínima de 0,33€. Tampoco ningún Estado se ha decidido a tomar la iniciativa por ahora, pero las previsiones de la revisión de esa Directiva, efectuada en 2022 por el Parlamento, en el documento *Fit for 55* abre las posibilidades a un futuro acuerdo multilateral europeo en este punto.

Las evidentes consecuencias de este impuesto sobre el aumento de precios del transporte y la correspondiente disminución de la demanda, puestas de manifiesto en numerosos estudios hacen que las Administraciones se muestren precavidas en su adopción. La aplicación en solamente algunos países puede convertirse en un elemento de pérdida de competitividad, no solo para las compañías aéreas afectadas, sino también para algunos mercados aéreos de tarifas bajas, como muchos turísticos de media distancia.

4.3 Medidas de introducción de SAF

No existe ninguna norma general sobre cómo introducir un combustible que, en estos momentos puede ser tres o cuatro veces más caro que el queroseno de origen fósil. Algunos países, como Estados Unidos y Canadá, están estudiando medidas para incentivar fiscal y financieramente la producción de SAF pero, en general, se acepta que las desventajas económicas de este combustible van a subsistir y su introducción habrá de hacerse mediante mandatos, obligando a que el combustible suministrado a los aviones comerciales tenga una cantidad mínima de SAF.

Dentro del ya citado paquete de medidas *Fit for 55*, se encuentra una propuesta para el Parlamento europeo y el Consejo, por el que se impondría un mandato a todos los suministradores de combustible en los aeropuertos europeos para incluir una proporción mínima de SAF, empezando con un 2% en el año 2025, hasta llegar al 63% en 2050. A partir del 2030, a esto habría que añadir un mínimo de *e-kerosene*, comenzando por 0,7%. Se prohibiría también el *tankering.*

El esquema del mandato de SAF sería:

- 2% a partir de 2025
- 5% a partir de 2030, con un mínimo de 0,7% de *e-kerosene*
- 20% a partir de 2030, con un mínimo de 5% de *e-kerosene*
- 32% a partir de 2030, con un mínimo de 8% de *e-kerosene*
- 38% a partir de 2030, con un mínimo de 11% de *e-kerosene*
- 63% a partir de 2030, con un mínimo de 28% de *e-kerosene*

Como aspectos peculiares de esta propuesta, deben notarse que la obligación recae sobre los suministradores de combustible y no sobre las líneas aéreas, y que todos los tipos de SAF, certificados según los estándares de la UE, se valoran igual, con independencia de su intensidad en la reducción de carbono.

Teniendo en cuenta el alto precio previsible del SAF, el efecto sobre las compañías aéreas sería un incremento del coste del combustible en los vuelos que despeguen de la UE.

5. Conclusiones

Las consecuencias económicas de las regulaciones ambientales existentes en estos momentos son particularmente importantes en los vuelos entre países de la UE más los que se unan al régimen de ETS.

A escala mundial, se aplicará la normativa de CORSIA, que afectará a la mayor parte de los vuelos internacionales.
En un futuro próximo, se intensificará el coste del ETS y comenzará a notarse aumentos de precio de combustible, y de los títulos de transporte en consecuencia, con la introducción del SAF que, posiblemente, se haría en diversas formas en distintos países.
La aplicación de impuestos sobre el queroseno o el CO_2 emitido parece más dudosa ante la falta de consenso internacional y los efectos directos sobre la competitividad de las compañías. No obstante, algunas administraciones como la Comisión Europea han explicitado su voluntad de imponerlos lo antes posible.
Se añade la necesidad de empezar a monitorizar y reporter las emisiones distintas al CO2, lo que abre la puerta a que en un future no muy lejano las medidas de Mercado actualmente en vigor para el CO2, se puedan extender también a estas otras emisiones. Por eso, la disponibilidad de un modelo que permita estimar todas estas emisiones, es una herramienta indispensable no solo desde el punto de vista de la Investigación, sino desde el punto de vista de los operadores, reguladores, y demás partes interesadas del sector de la aviación.

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"Understanding Tourist Behavior and Awareness in Airline Voluntary Carbon Offset Programs: A Portuguese Perspective"

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Abstract/Resumo/Resumen

This study assesses how voluntary carbon offset (VCO) programs influence airline industry practices and tourists' responses to these initiatives. Conducted online between February 28 and April 30, 2023, it surveyed Portuguese residents who traveled by air in the preceding year. The findings indicate a significant link between recalling an offset payment offer and the likelihood of contributing to the program, although only 20.33% of respondents remembered such an offer. Tourists were less likely to remember these offers and instead prioritize cost-related factors—like cheaper airfares and lower VCO fees. Despite their limited familiarity with VCO programs, tourists travel decisions are less swayed by additional information. The research also delves into the characteristics and viewpoints of Portuguese air travelers, shedding light on the broader implications for market-based environmental strategies in aviation. This research illustrates that the mere presence of a VCO program does not automatically lead to awareness of offset options among air travelers, highlighting the complexities and challenges in effectively implementing market-based sustainability instruments. It also highlights a unique perspective among tourists, a key demographic in aviation industry growth. This difference in perspective emphasizes the need to address aviation emissions in conjunction with the tourism sector and their interlinked nature in environmental strategy implementation.

Understanding Tourist Behavior and Awareness in Airline Voluntary Carbon Offset Programs: A Portuguese Perspective

1. Introduction

The short-term reality underscores a pressing dilemma: the aviation sector currently lacks viable means to counteract its rising greenhouse gases emissions. Technological advancements and improvements in fuel and operational efficiencies have thus far been insufficient to stabilize, much less reduce, aviation's emission levels [1]. This situation is compounded by the fact that, although the overall contribution of aviation to global emissions is comparatively small, the carbon intensity per passenger per kilometer significantly exceeds that of alternative transportation modes [2]. Specifically, car and air travel emerge as the primary drivers of the climate impact from passenger travel, overshadowing the contributions from other modes, including public transport [3]. Leisure air travel, in particular, represents a significant portion of long-haul flights, with the emissions from such travel far surpassing those from routine transportation activities at home over a year [3].

While a reduction in emission factors for road vehicles is projected in the coming decades, the anticipated decrease for air travel is notably smaller [3]. This discrepancy highlights the urgent need for solutions tailored to the aviation industry. However, curtailing international aviation growth, despite being an effective measure for emission reduction, is deemed impractical by both the industry and travelers, underscoring the need for alternative strategies [4].

The issue of sustainability is often sidelined by air travelers in their personal travel decisions, even though a majority recognize it as a significant problem within the aviation sector [6]. Research indicates air travelers prefer to offset emissions than reduce the frequency of flights [5]. Furthermore, research highlights a dichotomy among travelers: those with strong environmental values who engage in sustainable travel behaviors, and tourists who disregard their environmental impact [5]. Tourists distinguish their travel experiences from everyday life, experiencing discomfort and cognitive dissonance when faced with the environmental impact of their flights [7]. Even environmentally conscious tourists are reluctant to reduce flight frequency as a climate change mitigation strategy [8]–[10].

In this context, voluntary carbon offset (VCO) programs emerge as a readily available, albeit imperfect, tool for mitigating emissions. Despite its limitations in directly reducing emissions, offsetting represents a pragmatic approach to engaging passengers in sustainability efforts. Therefore, exploring the attitudes and behaviors of passengers in general, and of tourists specifically, towards behaviors that mitigate emissions is important for developing and promoting practices that can contribute to the sustainability of air travel, even as we await the widespread deployment of more effective technological solutions. Moreover, delving into passengers' behaviors in VCO programs may also illuminate pathways for developing other viable alternatives to address aviation emissions in the current scenario.

This study examines the behaviors and attitudes of Portuguese passengers towards VCO programs. The focus on Portugal is driven by several factors: significant variations in environmental attitudes based on geographic location [5] underscore the need for localized analysis; a notable gap in existing research on this topic within Portugal; the country's dedicated efforts towards leading in sustainable mobility; and the crucial role of aviation in supporting its vibrant tourism sector, which is vital for economic sustainability.

2. Methodology

An online survey delineated in Table 1 was conducted from February 28 to April 30, 2023, among Portuguese residents who had traveled by air with airlines that offered VCO programs, either independently or via partnerships, throughout the entire duration of the study. The eligibility criteria for participation were defined to ensure the inclusion of respondents who possessed autonomous decision-making authority regarding the payment of air travel-related charges. Consequently, individuals younger than 18 years of age were excluded from the study. Furthermore, this study specifically targeted individuals who traveled in the preceding year to ensure a focused and relevant sample. Extant research often examines travel behaviors over a period of 1 to 3 years [5].

Table 1 – Survey Outline

Section	Sub-section	Options
Socio-demographic Attributes	Gender	Male, Female
	Age Bracket	Less than 18, 18-30, 31-40, 41-50, 51-60, Over 61
	Trip Frequency	0, 1, 2-3, 4 or more
	Trip Purpose	Business, Tourism, Other
	Airlines Used	Multiple choice of most used European airlines with option to specify others
Offset Behavior	Recall Offer	Yes, No
	Recall Value	
	Offset at least once during the past year	
Attitudes Towards Emissions. Agreement with statements.	It is important to control carbon emissions from commercial aviation.	5-point Likert scale: • Strongly Disagree, • Disagree, • Neutral, • Agree, • Strongly Agree
	It is important to control carbon emissions from general aviation (private jets).	
	I am familiar with carbon emissions offset programs.	
	Carbon emissions offset programs are useful to reduce carbon emissions.	
	I am familiar with how the carbon emissions charge is calculated.	
	The calculation of the carbon emissions charge is fair.	
	Airlines in general can be trusted to use the emission charges resources in offset programs.	

Section	Sub-section	Options
Inclination to Pay. Increase in inclination to pay in these scenarios.	Low cost airlines can be trusted to use the emission charges resources in offset programs.	3-point Likert scale: • Neutral, • Slightly Inclined, • Strongly Inclined
	You were better informed about the emissions program.	
	The charge was paid directly to the organization carrying out the offset program.	
	The airline service was better.	
	The air ticket was 10% cheaper.	
	The charge was 10% cheaper.	
	You were travelling in business or first class.	
	You were travelling for business purposes.	
	You were travelling for tourism or other purposes.	

We received a total of 936 responses, out of which 660 were complete. We then selected 534 who traveled with airlines where VCO programs were available. EasyJet, for instance, was excluded due to its VCO program being launched in January 2023, after the start of the study period. 325 respondents traveled with Ryanair, 244 with TAP, 93 with both, and 58 with neither. Table 2 provides a demographic breakdown of the survey sample by age bracket and gender, highlighting a balanced distribution across different age groups.

All collected responses were systematically organized into a spreadsheet for subsequent analysis. The data were then processed and analyzed using R. Given that several variables in our analysis are categorical or ordinal, we used a combination of methods to examine the strength of the associations between them. To measure the strength of the associations between certain categorical variables, we used Cramer's V (ϕ_c)**,** and, to measure the statistical significance of the associations, we used Pearson's chi-square tests. To assess the strength and meaningfulness of association between the variables, we used regression analysis. Unless otherwise stated, the coefficients in our regression models were included in this report and are meant to be interpreted as measures of association with an explanatory rather than predictive value. Furthermore, to test for differences in medians of Likert scale variables between subgroups, we conducted Wilcoxon rank sum tests with continuity correction. These methods provided us with a comprehensive understanding of the relationships between our variables.

Table 2 – Sample Breakdown

Age bracket	Total	Male	Female
18-30	125	48	77
31-40	116	60	56
41-50	111	71	40
51-60	114	70	44
Over 61	68	36	32
Total	534	285	249

3. Results

3.1. Analysis of Offsetters' Attitudes

During the research period, 141 participants (26.40%) contributed to a VCO program at least once. Among these, 76 individuals recalled the VCO offer (Table 3), and 22 additionally remembered its monetary value. This pattern reveals a profound environmental commitment among participants who offset even without recalling the VCO offer specifically, indicating a pre-existing resolve to offset, independent of airline strategies.

64% of offsetters were men, which contrasts with the general assumption that women are more likely to engage in offsetting [5]. No statistically significant relationships were found between age and offsetting (Figure 1): Cramér's V (ϕc) = 0.082, Chi-Square (χ^2) = 6.76, p = 0.149 and Wilcoxon rank sum (W) = 27194, p = .739. This contrasts with prevalent research that younger individuals are more likely to offset [5].

Figure 1 - Age Breakdown by Offset Option

Table 3 - Confusion Matrix: Offer Recollection versus Offset

		Recall Offer		
Offset		Yes	No	Total
	Yes	76	65	141
	No	45	348	393
	Total	121	413	534

Figures 2 and 3 present the distribution of Likert scale responses where a statistically significant relationship with offsetters has been identified. 89% of respondents widely acknowledged the importance of controlling aviation emissions, with no demographic differences observed in these environmental attitudes. Offsetters, however, demonstrated a greater awareness and understanding of the offset program and its cost implications than non-offsetters, as evidenced by their significantly higher levels of familiarity (W=22521, p<.001) and continued interest in learning more about the program (W=23250, p<.001). Half of the offsetters believed that additional information could potentially influence their decision to offset further, unlike non-offsetters, where the same proportion indicated that more information would not sway their decisions.

No significant variance was observed in the willingness to pay between offsetters and non-offsetters based on ticket prices or offset charges. Nonetheless, offsetters showed a stronger preference for offsetting when traveling for non-business reasons (W=21971, p<.001), suggesting they perceive leisure or personal travel as more optional, with greater latitude for environmental consideration. Offsetters also indicated a greater likelihood to offset if the airline offered superior service (W=22358, p<.001), aligning with prior findings that service quality might reflect an airline's environmental commitment [11]. This perception is thought to stem from the obscurity surrounding airlines' environmental initiatives, with low-cost carriers and less frequently used airlines deemed less eco-friendly.

Figure 2 – Environmental Attitudes of Offsetters

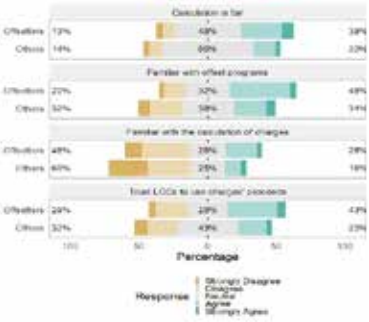
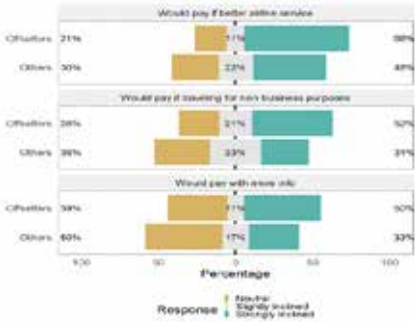


Figure 3 – Inclination to Offset of Offsetters



In order to identify significant predictors of individuals' propensity to engage in carbon offsetting practices and recollection of the VCO offer, we employed binomial regression analysis, meticulously evaluating a range of models to ascertain the most robust and informative predictors. The selection of the final model was guided by a thorough examination of both the Akaike Information Criterion (AIC) and the residual deviance, ensuring an optimal balance between model accuracy and complexity.

3.1.1. Predictors of Offsetting

Recalling the VCO option significantly increased the probability of offsetting. This outcome is consistent with findings in Germany, where the uptake rate among individuals with prior knowledge of VCO programs was notably higher (23%) compared to the overall uptake rate (7.67%) [11]. Similarly, findings in Australia reported an enhanced uptake rate (24%) among participants who had previously encountered the option to offset, compared to a general uptake rate of 13% [12].

Individuals traveling for reasons beyond business or tourism showed a decreased propensity to engage in offsetting. Although the association between offsetting and traveling for non-business/tourism purposes contributes minimally to the model's deviance (8.157), it offers a compelling insight worthy of deeper exploration. This relationship implies a significant link between the decision to offset and the intrinsic value of the trip. Previous research corroborates this observation, indicating that business and long-haul travelers show a lesser tendency to offset [5] , suggesting a nuanced understanding of travelers' offsetting behavior in relation to their travel motives.

The statistical significance of the model ($\chi^2 = 105.38$, df = 2, $p < 0.001$) underscores the robustness of these findings. A noteworthy reduction in model deviance from 616.50 in the null model to 501.48 in the full model, combined with a highly significant p-value (< 2.2e-16), highlights the model's substantial improvement in explaining participants' payment behaviors. The Akaike Information Criterion (AIC) value of 517.12 further supports the model's adequacy in capturing the observed data patterns.

Table 4 – Binomial Regression Results (Offset ~ Recall Offer + Purposes Other than Business or Tourism)

Term	*Estimate*	*Std. Error*	*Statistic*	*P.value*
(Intercept)	-1.5880	0.1375	-11.552	<.001
Recall offer	2.2561	0.2367	9.530	<.001
Purposes Other than Business or Tourism	-1.0941	0.4138	-2.644	.00819

3.1.2. Predictors of Recalling the VCO Offer

413 participants recalled the VCO option. A binomial regression was employed to explore the factors influencing such recollection, specifically examining the frequency of travel, gender, and exclusive travel for tourism. The model demonstrated statistical significance ($\chi^2 = 32.185$, df = 4, $p < 0.001$), suggesting that these predictors collectively enhance the model's fit beyond a baseline model lacking any predictors. The Akaike Information Criterion (AIC) value of 549.33 further supports the model's adequacy in capturing the observed data patterns.

Individuals who traveled more frequently were more likely to recall the VCO offer. This finding is logical, as those who travel often have increased exposure to the offer. Frequent travel experiences enhance the likelihood of encountering and subsequently recalling the VCO program.

Women were observed to be 0.7036 times less likely than men to recall the offer. This finding is further illuminated by the composition of the high-frequency business traveler group, where 101 out of 149 travelers are men, hinting at a greater tendency among men to recall the VCO offer. Even though, this gender disparity warrants further investigation, especially in light of existing literature that documents gender differences in web navigation and product involvement [13].

Individuals traveling exclusively for tourism were 0.4957 times less likely to recall the offer. Among the 328 participants who traveled solely for tourism, 58 recalled the offer and 81 engaged in offsetting. Women represent 51% of the individuals who travel for tourism only and 40% of the rest of the sample. There is a weak but statistically significant relationship between these two variables: Cramér's V (ϕc) = 0.075, Chi-Square (χ^2) = 5.84, p = 0.16.

Table 5 – Binomial Regression Results (Paid Charge ~ Recall Offer + Gender + Tourism Only)

Term	*Estimate*	*Std. Error*	*Statistic*	*P.value*
(Intercept)	-1.1570	0.2709	-4.271	<.001
2 -3 trips	0.6267	0.2681	2.338	.01940
4 or more trips	08515	0.2969	2.868	.00412
Women	-0.7036	0.2223	-3.165	.00155
Tourism Only	-0.4957	0.2213	-2.240	.02512

3.2. Analysis of Tourists' Attitudes

Figures 4 and 5 present the distribution of Likert scale responses where a statistically significant relationship with those traveling for tourism only has been identified. Despite limited familiarity and interest in offset programs among tourists - only 27% were familiar with the offset programs (W=40255, p<.001) and a mere 13% understood the calculation of the charges (W=41243, p<.001). 52% would not alter their inclination to offset even with additional information (W=37.654, p=.015). This aligns with extant research that simply providing more environmental information is unlikely to lead to a higher uptake rate of carbon offset programs and has limited impact on overall environmental behavior [5].

Figure 4 – Environmental Attitudes of Tourists Only

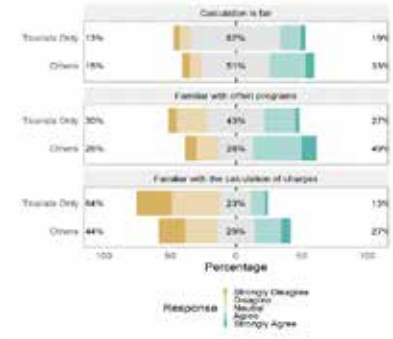
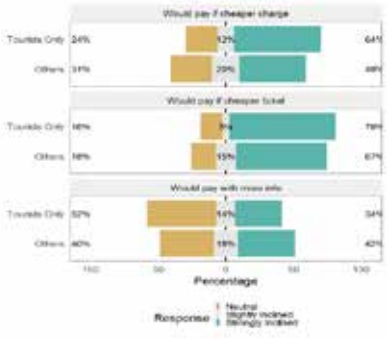


Figure 5 – Inclination to Offset of Tourists Only



64% of tourists reported they would be more inclined to offset if the offset charge was less expensive (W=30349, p=.00978), and 79% if the airfare was cheaper (W=29025, p=.001888). This observation implies that tourists tend to link the expense associated with mitigating their individual environmental impact to the aggregate cost of air travel. Given that tourists have limited familiarity with and interest in offsetting, the presentation of offset charges alongside ancillary air transport services could potentially reinforce their perception. This observation is situated within a broader research context that underscores the complexity of consumer cost sensitivity towards carbon offsetting. While some studies highlight divergent views on this sensitivity [5], others find that the cost of carbon offsetting does not significantly affect consumers' decisions to offset [14] or point out that there are distinct variations in cost sensitivity among different consumer segments with respect to the value of offsets[15]–[17].

While 68% of all respondents VCO programs as a valuable tool, only 25% express trust in the fairness of the calculation of the charge. Offsetters have the highest levels of trust in fairness of the calculation of the charge (W=23050, p<.001) while tourists have the lowest (W=37466, p = .1506) .Offsetters also trust LCCs more than other respondents (W= 23524, p = .0053). We have found that perception of fairness in the calculation of the charge is associated with trust in LCCs in such a way that as the perceived fairness of the calculation increased, the odds of perceiving trust in LCCs increased, holding all other variables constant (Table 7). We have fitted a

proportional odds regression after having graphically determined that the distribution of the variables is reasonably similar. The model was found to be statistically significant ($\chi^2(4) = 120.7786$, $p < 0.001$), indicating that the predictor variables significantly explain the variation in the response variable.

The reason for this finding is not completely clear but previous research suggests that distrust in LCCs may be associated with lack of transparency in ancillary charges [18], [19] and resentment against unclear luggage policies [20]. There may be other underlying factors that justify this relationship, and future research could explore these further. However, these findings suggest that providing clear and transparent information about how charges are calculated could be a potential opportunity for LCCs to build or strengthen trust among travelers.

Table 6 - Regression Results (Trust LCC ~ Calculation is Fair)

Term	Estimate	Std. Error	Statistic	P.value	Coefficient Type
Disagree Calculation is Fair	0.987037	0.492214	2.0053	0.045	Coefficient
Neutral Calculation is Fair	2.190463	0.434691	5.039127	0	Coefficient
Agree Calculation is Fair	3.462953	0.471286	7.347884	0	Coefficient
Strongly Agree Calculation is Fair	5.059973	0.627265	8.066728	0	Coefficient
1|2 Disagree	-0.36998	0.408403	-0.90592	0.365	Intercept
2|3 Neutral	1.433914	0.424515	3.377768	0.001	Intercept
3|4 Agree	3.325516	0.436846	7.612553	0	Intercept
4|5 Strongly Agree	5.876551	0.490423	11.98261	0	Intercept

4. Conclusion

This study provides a comprehensive insight into the attitudes and behaviors of air travelers towards VCO programs.

The research uncovered a complex relationship between travelers' awareness of environmental issues, their travel purposes, and their propensity to engage in carbon offsetting. While recalling the VCO offer significantly boosted the likelihood of offsetting, the motivations behind travel—whether for business, tourism, or other reasons—played a nuanced role in individuals' decisions to offset their emissions. Notably, individuals traveling for reasons beyond business or tourism exhibited a lower inclination towards offsetting. Moreover, those who traveled exclusively for tourism purposes demonstrated a reduced likelihood of remembering the VCO offer.

The observation that 53% of offsetters could not recall the VCO offer at the time of survey indicates a deeper, more intrinsic commitment to environmental sustainability among this group. This phenomenon suggests that their decision to participate in VCO programs is not merely a response to specific promotions or offers from airlines but is rooted in a fundamental environmental ethos that guides their behavior. Such participants are likely motivated by a strong sense of personal responsibility towards mitigating climate change, which prompts them to seek out and engage in carbon offsetting regardless of whether they are explicitly reminded of the option.

The findings also shed light on tourists' limited understanding and interest in VCO programs, indicating that simply providing more information is not enough to significantly increase offsetting rates. Tourists exhibit a heightened sensitivity to cost-related factors, tending to closely link the offset charge to the total expense of air travel. This is likely due to the presence of strong money cues, such as presenting the charges alongside ancillary services during the booking process.

Trust in low-cost carriers and the perceived fairness of the charge calculation were identified as critical factors affecting travelers' attitudes towards offsetting. Offsetters typically demonstrate higher trust in both low-cost carriers and the fairness of the offset charge calculation. In contrast, tourists often exhibit reduced trust in the fairness of these charges.

These findings highlight the presence of two distinct segments among air travelers: those deeply committed to environmental initiatives, and tourists. The former group demonstrates a profound environmental ethos, driving a significant portion of them to participate in VCO programs not as a reaction to promotions, but as an expression of their intrinsic commitment to sustainability. Conversely, tourists, characterized by their heightened cost sensitivity and lower trust in the fairness of offset charge calculations, display less engagement with VCO initiatives.

Diverging from prevailing trends in research, men were more likely than women to participate in carbon offsetting. Men also demonstrated a higher likelihood of recalling the VCO offer, a fact that might be linked to their dominant representation within the business travel sector, known for its high travel frequency.

Future research should delve into the trust disparities between offsetters and tourists, particularly focusing on offsetters' higher trust levels and tourists' skepticism, alongside examining the connection between trust in low-cost carriers and perceptions of fairness in VCO charge calculations. Additionally, it is important to investigate the gender-related differences in recalling the VCO offer, with a noted lower recall rate among women. Additionally, it is relevant to understand the factors influencing the decision-making process for travelers with non-tourism and non-business motives, where the utility of the trip may impact their likelihood to offset. These areas offer rich avenues for understanding the nuances of traveler behavior and attitudes towards carbon offsetting.

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LCCs Influence on Aviation Market Growth and Development

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Abstract/Resumo/Resumen

This article was written with the aim of understanding what has led to the growing success of low-cost airlines (LCCs) and what its impact has been on the development and growth of the aviation industry.In order to develop this study, a literature review was carried out, addressing the competitive advantages of LCCs, the operational practices of two of the main Low-Cost airlines and their impact on airport management. The aim was to understand how the efficiency and innovations of these companies are crucial to the development and continued expansion of the aviation industry, highlighting the importance of adaptable business models and innovative approaches in the global aviation context.The results of the research are expected to show that low-cost airlines (LCCs) have a significant influence on the growth and development of the aviation market. Efficient resource management, innovative operational strategies, democratization of access to air transport and their ability to adapt quickly to market changes are expected to be crucial factors in their continued success and impact on the industry.This article provides evidence of the influence of low-cost airlines (LCCs) on the aviation sector, highlighting a paradigm shift in air travel with more affordable prices and diversified routes. Through a literature review, it emphasizes the impact of LCCs on the continued growth of the industry, the democratization of air transport and the redefinition of the flying experience.

LCCs Influence on Aviation Market Growth and Development

1. Introduction

The emergence and growth of low-cost airlines reflects the changes that have taken place in the aviation industry. The traditional air travel model was dominated by companies that offered quality services, but at relatively high prices. However, the arrival of low-cost airlines such as Ryanair, EasyJet, Southwest and others has revolutionized the industry by proposing a completely different approach. These companies have drastically reduced operating costs by eliminating secondary services and opting for a standardized fleet of aircraft, often made up of just a single model. This strategy has allowed them to offer much lower prices than traditional airlines, making air travel accessible to other audiences.

In addition, flexibility in managing routes and schedules has allowed low-cost airlines to respond quickly to changes in demand, adapting to different markets and different times of the year. This level of flexibility has made them particularly resilient to economic crises and unpredictable events, such as the COVID-19 pandemic, which have severely affected many traditional airlines.

We will try to highlight the factors that have not only made LCCs one of the examples of efficiency within the aviation industry, but also one of the key players in the paradigm shift and the continued growth and development of the aviation industry.

2. Methodology

To develop this article, a practical and organized approach was adopted to carry out a qualitative literature review on low-cost airlines (LCC). The main objective was to understand why LCCs are an example of efficiency in the aviation industry and how they have contributed to the paradigm shift and continued growth of the airline industry.

It was necessary to carefully choose sources, such as scientific articles and specialist websites, based on their relevance and credibility. Criteria were established to include or exclude documents, thus ensuring a cohesive set of references.

The structure of the article followed a clear logic. With an introduction explaining the importance of LCC, followed by a literature review that critically analyzes the articles chosen. Each quote was contextualized to show how it contributed to understanding the efficiency of LCCs and their role in the development of the aviation industry.

The conclusions were based on the quantitative and qualitative evidence from the literature review, highlighting the role of LCCs in the industry's paradigm shift and growth. The discussion combined numerical data with theoretical arguments, providing insight into the impact of LCC on aviation.

In summary, the methodology used focused on a practical analysis of the specialized literature, providing a solid basis for understanding how LCC has shaped the aviation industry.

3. Low-cost airlines and their competitive advantages.

Low-cost airlines are airlines that don't offer the traditional services normally included in the ticket price, and therefore offer lower prices but less comfort. They have a lower operating cost structure than other traditional airlines and compensate for low ticket prices by charging somewhat exorbitant amounts for food, priority boarding, seat allocation and luggage. In addition, many low-cost airlines have only one type of aircraft in their fleet, reducing the need to train their crew for different aircraft [1].

In recent years, the growth of low-cost airlines has been exponential due to the increase in economic activities, the facility to travel, the growth of the tourism industry, quick urban commercialization, the change in lifestyles and consumer preferences for low-cost, non-airline services. Similarly, due to the increase in last-minute bookings and the uncertainty surrounding international travel, low-cost carriers (LCC) offer customers greater flexibility in canceling and changing their trips [2].

A determining factor for the high efficiency of LCCs is the use of the point-to-point system, which makes it possible to directly connect a number of cities without interrupting the service, even if the route is not direct,

compared to the Hub-to-Hub system where each destination is connected via a single intermediate location called a hub. The point-to-point business model in the air transport sector is a system in which airlines take passengers directly from one specific city to another without intermediate stops or hubs.

Point-to-point models provide shorter travel times, are more practical and usually result in more competitive prices due to lower operating costs. The factors that lead low-cost airlines to adopt this model are efficiency, cost savings, simplified operations, direct demand, fare structure, speed of response, among others. In addition, this model allows airlines to serve a wider range of destinations.

Another determining factor is that instead of centering their operations around major hubs (large international airports) like traditional airlines, LCCs fly to less congested secondary and regional airports with lower landing fees, penetrating other markets. Another aspect is the facility to adjust routes or operations based on seasonal demand or emerging trends, without the need to change their fleets. These factors explain the rapid adoption of this model by airlines and represent a trend in rise [3].

The low maintenance cost of aircraft operated by low-cost carriers is a determining factor in the growth of their market share. The modern aircraft used by LCCs are designed for quick turnarounds. This means that they spend less time on the ground between flights, which leads to greater aircraft utilization and a consequent increase in revenue. Reduced downtime also means lower aircraft maintenance costs and greater operational utilization. LCCs usually operate a standard model of aircraft, which allows them to negotiate favorable conditions with aircraft manufacturers and maintenance service providers [2].

The affordability of low-cost airlines attracts a large number of passengers and makes air travel accessible to several classes of air travelers. Increased efficiency, better use of LCC fleets and lower costs allow them to offer significant discounts on airfares. Most customers want to reach their destination quickly and cheaply and will give up food and in-flight entertainment to save money. This desire to save money also extends to business travelers, as companies increasingly focus on reducing travel expenses. The widespread adoption of ticketless travel and internet delivery services has benefited LCCs. This reduces the need for complex and expensive ticketing systems which traditional airlines use to manage their complex pricing structures [2].

3.1. Southwest Airlines' growth and influence

Southwest was the first airline to stand out from conventional airlines with its point-to-point service in short-distance cities and by seeing its direct competition as buses and cars. By offering high-frequency flights at affordable prices, it avoided, in theory, direct competition with conventional airlines.

The hub-and-spoke system makes it possible to consolidate traffic and thus achieve high occupancy rates, but Southwest preferred to forgo this system and offer a point-to-point service [4]. At the beginning of the 2000s, Southwest generated around 120-125 million RPM (Revenue Passenger Miles) per aircraft per year, which was lower than the industry average. Considering this information and given the fact that short-haul flights involve more take-offs and landings, resulting in more time on the ground for aircraft, by adopting this strategy, the only way Southwest could outperform the competition was to minimize the time aircraft spent on the ground. In terms of minimizing ground time, Southwest has become known for its 15-minute turnaround time. Today its turnaround time is 30 minutes due to new security procedures, but this is still less than the average turnaround time for a domestic flight, which is 45 minutes to 1 hour.

Table 1 referring to June 15, 2001, show that Southwest outperforms all other airlines in three of the four points evaluated. American Eagle's aircraft spent 32.7 minutes at the gate, compared to Southwest's which spent 35.4 minutes.

This is due to the fact that Southwest has larger aircraft than American Eagle. According [5] looked at average runway departure times at 35 US airports for Southwest and all other airlines and found that cab departure times increase with airport traffic; however, Southwest achieves lower times regardless of airport size.

Table 1- Average turnaround time in minutes at Albany, NY airport on June 15, 2001
Source: Gillen, David, and Ashish Lall. "Competitive Advantage of Low-Cost Carriers: Some Implications for Airports." Journal of Air Transport Management, vol. 10, no. 1, Jan. 2004, pp. 41–50,

Airline	Taxi-in	Gate	Taxi-out	Total
American	4.0	79.5	26.0	109.5
American Eagle	4.0	**32.7**	10.3	47.0
Delta	5.3	87.7	13.7	106.7
Northwest	4.7	38.3	14.0	57.0
Southwest	**2.7**	35.4	**7.9**	**46.0**
United	3.5	80.5	10.5	94.5
US Air	3.4	47.7	15.9	67.0

Note: American Eagle uses smaller aircraft than Southwest.

This shows that the faster turnarounds were not because Southwest serves smaller or less congested suburban airports, as it also serves larger and more congested airports and times are still lower than other airlines.

The company was a pioneer in the United States when it introduced the possibility of traveling without the need for a printed ticket. In a context where airlines still relied heavily on travel agencies for flight bookings, in 1999 Southwest was already selling around 70% of the seats on its planes directly or via its website. This approach allowed the company to significantly reduce costs related to commissions paid to travel agencies. Southwest has only one class of service with unassigned seats. It does not provide hot meals, only peanuts, raisins, and drinks. This approach results in cost reductions and simplifies operational processes, in line with the company's focus on short-haul flights where, according to the company, meals are not important. Southwest operates with a standardized fleet of Boeing 737 aircraft (a smaller aircraft suitable for short-haul flights), which reduces maintenance and training costs and allows its employees to have specialized knowledge of the aircraft.

The use of less congested airports in large cities and airports without significant congestion in small cities reduces the time planes are in the air, as there is less waiting time to land; taxi-time is shorter; there are fewer hold-ups at the boarding gate and the costs of the boarding gate and landing fees are lower. This not only reduces costs, but also makes travel easier and reinforces the company's policy of not interlining passengers or baggage.

Everything described above contributes to reducing the company's costs per mile and cementing its position in the aviation sector, thus demonstrating that operational efficiency is not a strategy, but a result of it [5].

3.2. Ryanair's Business Model

Considering that Ryanair began its activity in 1985 with just 25 employees and a single plane and is currently the largest European low-cost operator, with 741 destinations and a team of more than 5,000 employees, it is important to identify the methods and strategies implemented by the company that have allowed it to succeed and to analyze the factors that have brought it notoriety among consumers.

When it first entered the market, the company adopted a cost-focused leadership strategy. Thus, with the help of its competitive prices and an aggressive cost-cutting policy, the company established itself as a low-cost company, initially focused only on the Irish and British markets. Over time, by expanding its operations to continental Europe, the company abandoned its cost-focused leadership strategy to become a "low-price" leader.

The expansion strategy implemented by the company has allowed it to acquire a dominant position in the European market. The increase on the number of destinations operated by Ryanair was possible thanks to the creation of new subsidiaries, located in different countries. In 2007, Ryanair had 20 subsidiaries throughout the European Union (a fact that led the International Air Transport Association (IATA) to name Ryanair the world's largest airline in 2007) but since then, the number of subsidiaries has increased every year.

Ryanair, like all low-cost carriers, is adopting a cost-cutting strategy in order to remain competitive in the market, with the aim of offering the lowest fares. In fact, the airline has followed Southwest's lead when it comes to operational efficiency, actively striving to reduce costs in order to become a European low-cost leader. Its cost-cutting strategy focuses on six key aspects: the aircraft used, the elimination of some traditionally free services, the outsourcing of some high-cost operations, airport taxes and flight policies, staff costs, as well as the company's productivity and advertising costs. However, when it comes to the planes used by Ryanair, it should be noted that, since 1999, the company has embarked on a fleet replacement and expansion program worth almost 17 billion euros. All of Ryanair's old Boeing 737-200 aircraft have been replaced by 272 new Boeing 737-

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800 Next Generation aircraft. Ryanair's fleet currently consists of 1 Boeing 737-700, 284 Boeing 737-800 and 51 Boeing 737-200 MAX aircraft. This demonstrates that Ryanair is concerned not only with profit, but also with the quality of the services offered and the environmental impact of its operations. In fact, the company is currently the industry leader in terms of environmental efficiency and is constantly working to improve its performance.

From the outset, Ryanair adopted an aggressive direct sales approach. In 2007, the airline recorded more than 90% of its direct sales via the Internet. This method successfully implemented by Ryanair offered advantages for both the company and its customers. Selling tickets over the Internet is undoubtedly the biggest advantage and the most significant operating cost saving factor that the aviation sector has seen in recent years. Furthermore, selling directly to the market has enabled the company to have detailed information about its customers. Consumers also benefit, as they can compare the prices of several companies and choose the lowest one.

Considering all the aspects mentioned above, we can say that Ryanair's business model is the closest to the model started by Southwest Airline. The company is one of the true "low-cost and no frill" LCCs, with a strict point-to-point system, an exclusively economy configuration, no seat allocation at check-in, no designated cargo services, and no miles traveled program. In addition, Ryanair's model, which focuses on costs rather than markets, has proved to be one of the most efficient approaches in the low-cost carrier sector [6].

4. The Influence of LCCs on Airport Management

According [7], using a dataset made up of 23,402 flight codes, 3,270 routes and 100 European airports, with a total of 3,486,376 observations and taking into account the various variables that can delay a flight (such as weather variables or the fact that larger planes require longer boarding and disembarking operations) it was concluded that, on average, the presence of LCCs at an airport contributes to reducing delays for all flights landing at a given airport, thus constituting a positive externality for all airlines serving the airport.

A higher percentage of LCCs at the airport of origin improves the punctuality performance of all flights (and therefore airlines) departing from that airport. This result comes from the faster turnarounds of LCC aircraft, which free up parking spaces and boarding gates in good time, thus giving other airlines more time to carry out their own operations [7].

Is also confirmed that a greater number of flights landing at the same time at a given airport is a negative externality and that flights landing at airports with high daily traffic tend to perform worse in terms of punctuality. This suggests that large airports, unlike small ones, may find it more difficult to mitigate the "snowball effect" of accumulated delays because they lack spare capacity in terms of alternative landing slots, which can serve to mitigate or cushion delays, thus confirming yet another competitive advantage for LCCs, which in many situations prioritize the use of secondary regional airports over large international airports [7].

This article also points out that if a given route is predominantly operated by an LCC, the average delay is lower, which means that, on average, LCCs are more punctual than traditional airlines and also that if a traditional airline has to compete with an LCC on a given route, this is because traditional airlines are better able to compete with LCCs in terms of quality of service (punctuality being one of the quality criteria) than in terms of price.

According [7] it's also conclude that LCCs represent both a threat and a challenge for traditional airlines and show that a mix of FSCs and LCCs at the same airport can be considered when making strategic airport management decisions, since this intra-airport competition is beneficial for reducing airline flight delays and therefore increasing service quality and passenger satisfaction.

5. Key Elements that Led to the Increase in LCC Market Share.

One of the decisive elements in the growth of LCCs was the liberalization and deregulation of air transport. This took market share away from traditional airlines, many of which reacted by creating their own low-cost airline.

Over time, this factor also encouraged airlines to diversify the methods and strategies they used to maintain or improve their profitability. Thus, the original low-cost business model was gradually adapted and altered, generating several new versions [8].

One of the factors behind the growth of the LCC market is the increasing popularity of short-haul flights and the growing demand for domestic flights. The sustainable solution offered by low-cost carriers is also considered to be one of the market growth factors, as concerns about sustainability have increased worldwide. With

sustainability being one of the biggest concerns today, airlines are focusing on improving the sustainability of aircraft by reducing carbon emissions, using sustainable aviation fuel, and using carbon capture technology.

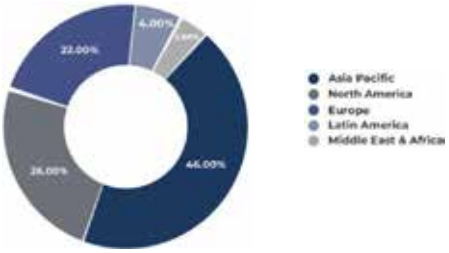
In addition, the growing implementation of analytics to manage fixed assets, the expansion of the integration of asset management solutions and the increase in mobility solutions are all aspects that are predicted to have a positive impact on the business of the global low-cost airline market.

It is also important to note that during the history of aviation, one of the main obstacles for ordinary citizens to travel was the high-ticket prices and fees associated with the services. By setting affordable base prices and giving passengers the flexibility to choose tickets according to their budget, thereby facilitating access to their desired destinations, LCCs have changed the paradigm of civil aviation. With the implementation of low prices, demand for the services provided by low-cost airlines has increased significantly, which is also one of the major factors not only for growth, but also for increased competitiveness in the market, which justifies the fact that there are now more and more of them. The LCC business model has also led to airlines that had no real incentive to look for new routes taking on routes that had never or rarely been operated. This has intensified competition on these routes and made it possible to fly to new destinations that once had a reduced range of services provided by airlines, promoting the development of these destinations and, consequently, their airports. In order to promote this expansion of routes, airlines have entered into collaborations and partnerships with other companies and even made acquisitions. Nowadays, airlines provide services in more places, allowing passengers to travel to more diverse destinations. In order to expand in the market, several of the main traditional airlines are trying to develop collaborations to operate services identical to those provided by low-cost airlines [2].

At European level, the growth of LCCs was initially concentrated in Western Europe, but with the enlargement of the European Union in 2004, LCCs progressively expanded into Central and Eastern Europe, stimulating strong growth in these emerging markets. Although some LCCs have started operating in large European hubs, they tend to operate in less congested secondary airports and can decide to enter and exit new markets in a relatively short time [9].

Over time, Ryanair has successfully implemented four types of strategies: a cost leadership strategy focused initially on Ireland and Great Britain, an expansion strategy that has allowed it to acquire a dominant position in Europe, a cost reduction strategy aimed at giving the company the title of "low fares leader" and an aggressive online direct sales strategy [6].

Graph 1 shows the market shares of low-cost airlines by region and shows that Asia-Pacific dominated the market with the largest market share in 2022. The growth of the market is attributed to the increase in population in the region. Population growth has increased mainly in the middle and upper middle-class populations, which is expected to drive market growth in the region. Changing lifestyle preferences and travel habits are also likely to drive the growth of the aviation market. Growing government initiatives for affordable air travel services, especially in countries such as China and India, will contribute to driving market growth in Asia-Pacific. North America is expected to increase its market share over the next 10 years. The region's growth is attributed to the increase in consumers' disposable income in these regions. The United States holds 30% of the global domestic airline market. The growth of the low-cost carrier is due to lower ticket prices. The increase in domestic flights for business and personal purposes, along with the competitive nature of the general aviation sector in the region is one of several factors promoting its market growth [2].



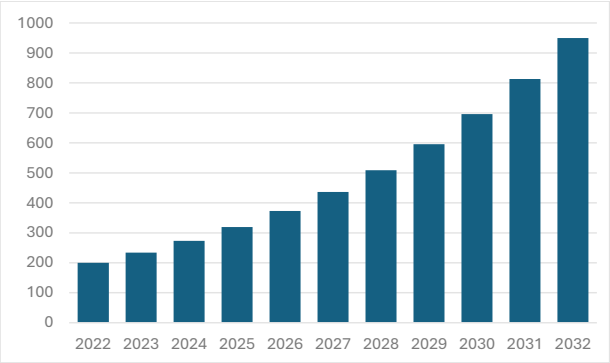
Graph 1- LCCs market share 2022(%)
Source: Low-Cost Carrier Market Size to Worth USD 949.97 Bn by 2032." Www.precedenceresearch.com, July 2023, www.precedenceresearch.com/low- cost-carrier-market. Accessed 12 Oct. 23.

As can be seen in **table 2**, during the first nine months of 2022, Ryanair operated more flights in Europe (2,584 average daily flights) than any other airline; this corresponds to 10.1% of all flights in Europe [9].

Table 2- List of companies' average daily flights operated in Europe between January and September 2022 (LCCs are marked in blue)
Source: Eurocontrol. "EUROCONTROL Data Snapshot #34." Www.eurocontrol.int, 25 Oct. 2022, www.eurocontrol.int/publication/eurocontro l-data-snapshot-34-rise-low-cost-carriers- europe. Accessed 24 Oct. 2023.

Airline/ Airline Group (January-September 2022)	Avg. daily flight (2022)	% of operated flights in Europe (2022)	% change vs. 2019
Ryanair Group	2,584	10.1%	+9%
easyJet Group	1,367	5.3%	-21%
Turkish Airlines	1,253	4.9%	-8%
Lufthansa Airlines	1,046	4.1%	-31%
Air France Group	945	3.7%	-22%
KLM Group	716	2.8%	-18%
Wizz Air Group	660	2.6%	+12%
British Airways Group	626	2.4%	-32%
Vueling	547	2.1%	-12%
SAS Group	520	2.0%	-37%
Eurowings Group	430	1.7%	-37%
Pegasus	423	1.7%	-11%
TUI Group	383	1.5%	-15%
Norwegian Group	341	1.3%	-46%
SWISS Group	332	1.3%	-29%

According to the factors described above, in [2] it is stated that the market share of LCCs in 2032 will be 4.74 times greater than the market share in 2022, as can be seen in **Graph 2**.



Graph 2- LCCs Market size from 2022 to 2032 (USD billion)
Source: Low-Cost Carrier Market Size to Worth USD 949.97 Bn by 2032." Www.precedenceresearch.com, July 2023, www.precedenceresearch.com/low- cost-carrier-market. Accessed 12 Oct. 23.

6. Conclusion

Based on the literature review, it is clear that low-cost airlines have played a crucial role in the sustained growth and development of the aviation sector. Their innovative approach, focused on operational efficiency and cost optimization, has redefined market dynamics, thereby democratizing access to air transport. Globally, LCCs have contributed to the expansion of connectivity, making air travel more accessible to a wider audience.

The ability to adjust quickly to changing demand, as evidenced during the pandemic, demonstrates the resilience of LCCs. The LCC business model has not only encouraged competition, resulting in more competitive prices, but has also catalyzed fleet modernization and the adoption of more efficient technologies. This push for efficiency

has, meanwhile, stimulated innovation in various areas, from operations management to the implementation of eco-efficient solutions. In addition, the presence of LCCs has often promoted the development of secondary airports, increasing accessibility to different regions, and representing a positive externality with regard to the efficiency of airport operations.

The positive influence of LCCs on the growth of the aviation sector is indisputable, marking an era in which aviation is becoming not just a means of transportation for elites, but a viable option for an increasing number of people. However, it is crucial that this growth is accompanied by continued efforts to guarantee environmental sustainability and operational safety, thus ensuring that the development of the aviation sector at a global level remains balanced and responsible.

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Transporte aéreo pós-crise: Análise da falência de companhias aéreas depois da pandemia Covid-19

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Abstract/Resumo/Resumen

Este estudo tem o objetivo de analisar a falência de companhias aéreas num período de tempo posterior à Covid-19 e determinar a influência que a pandemia exerceu sobre o funcionamento das mesmas. Este ensaio utiliza uma abordagem qualitativa para apresentar os seus resultados. Consiste na pesquisa de artigos científicos, teses e outros estudos relacionados com a pandemia e a falência de várias companhias aéreas entre 2018 e 2023. Por último, é efetuado a análise dos fatores que levaram à declaração da falência, com o objetivo de determinar o impacte da pandemia em casos entre 2020 e 2023, comparando-os com casos pré-pandemia. Através deste estudo, pretende-se descobrir que a pandemia continua a condicionar o funcionamento das companhias aéreas e contribuindo para as suas falências anos após o levantamento do estado de emergência. Apesar da recuperação moderada do setor, que se aproxima cada vez mais dos seus valores antes da pandemia, muitas empresas vão ter dificuldades em retomar o seu nível de funcionamento normal. Muitos estudos abordam o impacte da pandemia no transporte aéreo e os seus efeitos a curto prazo, descrevendo o estado da indústria em 2020. Este estudo pretende adicionar a este tema através da análise das suas consequências 3 anos depois e destacar a importância de uma crise no funcionamento a longo prazo de uma companhia aérea.

Transporte aéreo pós-crise: Análise da falência de companhias aéreas entre 2018 e 2022

1. Introdução

1.1. Contextualização

A indústria do transporte aéreo, apesar dos benefícios que apresenta para o comércio e turismo global, possui várias características que a tornam numa atividade difícl de gerir. Estas características incluem custos fixos elevados, procura cíclica, concorrência intensa e a vulnerabilidade a choques externos [1]. Devido às condições desfavoráveis do mercado resultantes destas características, a probabilidade de uma companhia aérea declarar falência é elevada. Por conseguinte, a razão pela sua falência pode basear-se numa ou mais destas características, com cada caso dispondo de fatores diferentes que correspondem a razões diferentes. Quando se trata de uma crise, como a pandemia de Covid-19 em 2020, é possível verificar uma tendência de generalização nos factos que levam uma transportadora a terminar a sua atividade comercial. Este estudo tenciona descrever as razões da falência de companhias aéreas desde 2018 até 2022, de forma a verificar o papel e a influência que a pandemia exerceu na ocorrência de cada um destes casos. O seu foco centra-se nos factos envolvidos na falência das companhias aéreas, desde o contexto da situação da empresa até ao fim da sua operação.

1.2. Objetivo Geral

Para este estudo, o objetivo geral consiste no estudo das situações financeiras de determinadas companhias aéreas que faliram entre 2018 e 2022. Pretende-se analisar as características e decisões tomadas pelas companhias aéreas neste período de tempo, tendo em conta a infuência de fatores externos, cujas consequências resultaram no encerramento das suas atividades comerciais.

1.3. Objetivos Específicos

Complementando o objetivo geral abordado no capítulo acima, foram definidos objetivos específicos que reforçam a temática abordada. Esses objetivos são:

- Compreender a razão das falências das companhias aéreas e determinar a influência da pandemia nas suas ocorrências
- Determinar os vários tipos de falência que ocorreram no período de tempo definido
- Determinar a existência de uma generalização nas razões pela falência de companhias aéreas a partir de 2020

1.4. Questão de Investigação

A questão de investigação representa a pergunta principal a que se pretende responder ao efetuar uma investigação. É através desta interrogação que a estrutura do estudo é definida e os meios para alcançar uma conclusão são elaborados. A questão de investigação deste estudo é: “Como é que a pandemia de Covid-19 influenciou as causas e razões da falência de companhias aéreas entre 2018 e 2022?”

2. Revisão da Literatura

A ligação entre o transporte aéreo e a economia global é um dos temas mais documentados na história da aeronáutica. Um dos maiores contribuintes para esta temática é Button [2], que analisa a importância de tendências económicas na evolução do transporte aéreo, a forma como estas influenciam as mudanças no setor, dando exemplos da desregulamentação nos Estados Unidos e na Europa e a introdução da economia aplicada nas várias infraestruturas envolvidas nesta indústria.

Outros estudos que abordam esta interação incluem Ferreira [3], que propõe um modelo para determinar a influência de determinados fatores internos e externos do transporte aéreo na atividade comercial das companhias aéreas e Mantin e Rubin [4], que abordam a importância da volatilidade do preço na gestão de receita de empresas em qualquer indústria, incluindo o transporte aéreo, destacando o seu efeito na tomada de decisão de compra dos consumidores e, consequentemente, a variação de determinados indicadores como o preço médio de tarifa e o número total de vendas . Li et al. [5] analisam o conceito de "Responsabilidade Social Corporativa" ou CSR no contexto do transporte aéreo chinês, no qual as companhias aéreas públicas e privadas do país são incentivadas a assumir o cargo de representantes do próprio estado, contribuindo para o seu desenvolvimento económico, cultural e político.

Infelizmente, o transporte aéreo é caracterizado pela sua fraca lucratividade e vulnerabilidade a choques externos como crises e conflitos regionais, o que pode condicionar a operação das companhias aéreas. Tolkin [1] analisa os fatores responsáveis para a declaração de falência de companhias aéreas nos Estados Unidos da América, recorrendo à descrição das suas estruturas de custos e indicadores de desempenho normalmente utilizados, concluindo com um caso de estudo envolvendo a Trans World Airlines e a American Airlines. Ng et al. [6] estudam os efeitos de uma falência num determinado mercado, utilizando o caso da Japan Airlines no período entre 2010 e 2012, descobrindo que a transportadora consolidou a sua escala de rotas mais eficientes e os seus concorrentes aumentaram o seu número de voos e adquiriram maior quota de mercado doméstico. De todas as crises que afetaram negativamente o transporte aéreo, a pandemia de Covid-19 é considerada a mais significativa na sua história, com várias investigações baseadas nos seus efeitos para a indústria em cada uma das regiões. Estes estudos incluem o de Botlíková, Botlík e Stuchlíková [7], que se centra no mercado europeu e a elaboração de leis que condicionaram a sua recuperação financeira; Abdullah, Achsani e Suhendi [8], que utilizaram 4 companhias aéreas asiáticas para descrever a situação financeira do transporte aéreo na região Ásia Pacífico; e Maciel [9], que descreve os efeitos da pandemia no transporte aéreo brasileiro. Após a leitura destes e outros estudos , o presente trabalho pretende adicionar a este tema, através da análise da falência de companhias aéreas particulares, num período de tempo que engloba a pandemia, com o propósito de averiguar as causas que levaram a estas declarações e a influência que a Covid-19 exerceu sobre estas ocorrências.

3. Metodologia

3.1. Introdução

Este capítulo pretende descrever e apresentar a abordagem que vai ser tomada para a obtenção de resultados, cuja finalidade é determinar as soluções para os objetivos definidos no início da investigação. Segundo Goundar [10], a metodologia de investigação é um termo coletivo pelo processo estruturado de executar uma investigação, no qual se definem os métodos adequados para a descoberta de soluções para determinadas questões, que depois serão utilizadas para descrever, explicar e prever certos fenómenos dentro da temática específica. Para este estudo, adotou-se uma metodologia mista, utilizando meios qualitativos e quantitativos, com o propósito de combinar a análise interpretativa de documentos escritos e dados estatísticos. Através desta metologia, será efetuada uma revisão de literatura narrativa sob a base de caso de estudo, cuja função é a descrição sucinta dos factos e dados relacionados com a falência de companhias aéreas, recorrendo a várias fontes e referências, para apresentar uma perspetiva clara e bem definida da temática durante um determinado período de tempo. Assim, a metodologia deste estudo divide-se em duas partes: a recolha de dados e referências pertinentes ao tema de discussão, e a sua análise e interpretação.

3.2. Recolha de dados

O primeiro passo da metodologia, referente à recolha de dados, envolve a pesquisa de companhias aéreas que faliram entre 2018 e 2022. Para este objetivo, recorre-se às listas anuais de transportadoras falidas da Allplane, uma empresa de consultoria criada por Miguel Ros [11], das quais são selecionadas quatro a cinco companhias aéreas que dispõem de várias fontes de informação sobre as suas falências e as causas responsáveis pelas suas ocorrências.

A amostra incluí transportadoras de todas as regiões do mundo, sendo o processo de seleção baseado no número e acessibilidade de fontes que descrevem a sua falência. Estas fontes incluem casos de estudo, artigos científicos e artigos jornalísticos que abordam o fim das transportadoras, sendo que as mais pesquisadas incluem os websites da Simple Flying, ch-aviation, International Flight Network, entre outros. Simultaneamente, serão pesquisados relatórios e gráficos estatísticos da IATA para contextualizar o estado da indústria do transporte aéreo entre 2018 e 2022, o que permite uma melhor compreensão do ambiente em que as companhias aéreas falidas se encontravam quando terminaram as operações.

3.3. Análise e apresentação

A fase seguinte do estudo consiste na apresentação dos dados obtidos através das fontes pesquisadas no subcapítulo anterior, descrevendo as causas e razões por detrás do fim das operações das companhias aéreas escolhidas. Esta fase encontra-se dividida em três partes, correspondendo aos períodos de tempo prévios à pandemia (2018-2019), no decorrer da pandemia (2020) e posteriormente (2021-2022), cada uma adotando uma estrutura composta por uma descrição do estado da indústria durante o período de tempo em destaque, seguida por uma tabela das companhias aéreas que faliram durante esse período e concluindo com uma descrição dos eventos que levaram às suas falências e fim de atividades comerciais.

3.4. Discussão dos resultados obtidos

A parte final do estudo envolve a interpretação dos dados obtidos, considerando os objetivos gerais e específicos estabelecidos no início da investigação. Serão averiguadas as causas das falência das companhias aéreas em cada período de tempo, o destaque de fatores comuns entre casos e a influência da pandemia em casos a partir de 2020. Finalmente, será respondida a questão de investigação a partir dos resultados finais verificados. A Figura 1 mostra como cada fator contribui para a falência de uma companhia aérea.

Figura 1- Fatores que contribuem para a falência de uma companhia aérea
Fonte: Autores

4. Análise de Resultados

4.1. Período pré-pandemia (2018-2019)

Antes de 2020, a indústria do transporte aéreo encontrava-se numa posição estável e propícia para o seu crescimento em todo o mundo. Vários fatores contribuíram para este desenvolvimento, com destaque particular para a redução contínua dos custos gerais de transporte e o aumento do número de ligações entre cidades [12]. A taxa de empregabilidade durante o período da pré-pandemia continuou a apresentar tendências positivas em 2018 e 2019 [13], enquanto que indicadores de desempenho como o Revenue Passenger Kilometer (RPK), o indicador que determina a receita que uma companhia aérea gere por passageiro e por quilómetro voado, continuaram a registar aumentos mensais a nível doméstico e internacional [14].

Tabela 1- Companhias aéreas falidas no período pré-pandemia
Fonte: Autoria própria, baseado nas listas fornecidas por Allplane [16]

Companhia aérea	Ano de fundação	País de origem	Ano de falência
Saratov Airlines	1931	Rússia	2018
VLM Airlines	1992	Bélgica	2018
Onejet	2015	Estados Unidos da América	2018
Orient Thai Airlines	1995	Tailândia	2018
Flybmi	1987	Reino Unido	2019
Jet Airways	1992	Índia	2019
Aigle Azur	1946	França	2019
Thomas Cook	1841	Reino Unido	2019
Far Eastern Air Transport	1957	Taiwan	2019

Porém, esta tendência crescente registou um abrandamento significativo comparado com anos anteriores, tendo a receita por quilómetro voado (RPK) diminuído 8,6% em 2017 para 6,3% em 2018 [13], com uma redução adicional de 4,1% em 2019 comparado com 7,1% de 2018 [15], o que demonstra a estabilização geral da indústria durante este período. O desenvolvimento de cada região durante a pré-pandemia apresentou resultados variados.

A Tabela 1 evidencia que (1): o caso da Saratov Airlines deve-se à anulação de uma certificação necessária para efetuar o transporte aéreo. Esta transportadora viu o seu certificado de operador aéreo revogado devido a um acidente e a várias falhas de segurança. (2): a incapacidade de assegurar uma prestação de serviços consistente durante as épocas baixas pode resultar no fim das operações, o que foi o caso da VLM Airlines, que declarou falência em dezembro de 2018 devido à falta de investimentos no inverno e à acumulação de dívidas a uma organização bancária belga . (3): a declaração de falência pode ser imposta sobre uma companhia aérea pelos seus investidores se esta demonstrar a incapacidade de cumprir com as suas obrigações financeiras, destacando o caso da Onejet, uma companhia aérea de viagens executivas dos Estados Unidos, que foi liquidada pelos seus credores devido ao atraso de pagamentos, mais tarde resultando em vários processos e uma investigação criminal pela FBI. (4): A Orient Thai Airlines foi prejudicada por um acidente envolvendo a sua subsidiária low cost One-Two-Go em 2004, a perda de grande parte da sua frota numa inundação do aeroporto de Bangkok em 2011 e sanções impostas pelas autoridades chinesas em 2016 devido ao incumprimento dos seus regulamentos, culminando num processo de reestruturação e mais tarde uma declaração de falência em 2018. (5): a Flybmi foi vítima dos efeitos colaterais causados pelo Brexit em 2019, incluindo o corte de ligações com destinos para a UE e o aumento de custos com combustível e carbono, salientados pela sua fraca imagem de marca após a aquisição e fusão da BMI pela British Airways em 2012. (6): Jet Airways demonstra a importância de adaptar a estratégia empresarial de acordo com as mudanças no mercado. Ahmed et al. [17] afirma que a decisão de manter a estrutura de operações inalterada, teve consequências severas para a transportadora, causando a perda de uma quota de mercado doméstica extensa para as *low cost* e a acumulação de dívidas, quando adotou uma estratégia semelhante aos seus concorrentes, apesar da incompatibilidade com o seu modelo de negócio [18]. (7): Aigle Azur foi vítima de um desacordo entre os gestores, no qual um dos seus acionistas tentou assumir controlo da transportadora enquanto esta apresentava resultados negativos desde 2012. Estes prejuízos, causados por uma expansão desorganizada no mercado africano, devido ao sucesso das suas rotas para a Argélia, convenceram a empresa que a falência era a melhor opção. (8): O nome Thomas Cook simboliza transporte, com as suas origens baseadas no transporte ferroviário e naval desde 1845. A sua história terminou em 2019, com Abdou [19] a determinar a sua falência devido à acumulação substancial de dívidas desde 2007 (requerendo um investimento de 200 milhões de libras em 2019 para assegurar a sua sobrevivência), o processo lento de adaptação aos novos meios de distribuição digital e complicações políticas derivadas do Brexit. (9): a última companhia aérea abordada neste capítulo é a Far Eastern Airlines, uma transportadora de Taiwan cuja falência se deveu a prejuízos resultantes do aumento do custo do combustível, o foco na concorrência com os transportes ferroviários e o surgimento de problemas com a renovação da sua frota.

4.2. Surgimento da Covid-19 (2020)

Atualmente, 2020 é considerado o pior ano na história do transporte aéreo, sendo esse o ano em que a Covid-19 surgiu e se propagou por todo o mundo. A ameaça desta pandemia na saúde global incentivou os governos regionais a encerrar as suas fronteiras e impôr restrições sobre os meios de transporte para

Tabela 2- Companhias aéreas que faliram em 2020
Fonte: Autoria própria, baseada nas listas fornecidas por Allplane [25]

Companhia aérea	Ano de fundação	País de origem
Flybe	1979	Reino Unido
Compass Airlines	2006	Estados Unidos da América
South African Express	1994	África do Sul
Miami Air International	1990	Estados Unidos da América
TAME EP	1962	Equador
LATAM Argentina	2016	Argentina
NokScoot	2014	Tailândia
Cathay Dragon	1985	Hong Kong
Interjet	2005	México

Estas restrições causaram a maior queda de RPK internacional da indústria, com os meses de março e abril a registarem perdas de aproximadamente 53% e 95% respetivamente [21], [22]. Apoio financeiro foi fornecido pelos governos regionais para sustentar o transporte aéreo durante a crise, alcançando um valor de 173 mil milhões de dólares no fim de novembro [23], porém, estes benefícios foram distribuídos desigualmente, com companhias aéreas nos Estados Unidos, Europa e Asia a receberem mais apoio financeiro do que Estas restrições no Médio Oriente, América Latina e África [23], [24].

A Tabela 2 evidencia que (1): Considerada a maior companhia aérea regional da Europa, a falência da Flybe resultou de um conjunto de más decisões financeiras em circunstâncias desfavoráveis, destacando a encomenda dispendiosa de Embraers, a guerra de preços com a Loganair e a influência do Brexit, culminando com a perda de reservas causadas pela Covid-19. (2): O fator crítico que condenou a Compass Airlines foi a sua dependência em contratos com outras companhias aéreas de maior porte; o fim abrupto do seu contrato com a Delta Air Lines e a requisição de um corte de capacidade de transporte de 14% por parte da American Airlines, ambos resultantes da pandemia, deixaram a companhia aérea numa posição de insustentabilidade, resultando no fim das suas operações. (3): O caso da South African Express segue a tendência de transportadoras regionais terminarem as suas operações em 2020, sendo que esta ocorrência deveu-se a fatores relacionados com a falta de pagamento de dívidas a aeroportos e vários credores, colocando a companhia aérea numa posição desfavorável antes do aparecimento da Covid-19 e concluindo com uma declaração formal de falência em 2022. (4): Após 30 anos de existência, a Miami Air International terminou as suas operações em 2020 devido a complicações financeiras causadas por um acidente no ano anterior, a falta de apoio financeiro por parte do governo americano e a falta de procura dos seus clientes principais, causada pelas restrições impostas sobre o transporte aéreo para combater a pandemia. (5): O Ecuador tomou a iniciativa de encerrar várias empresas públicas devido aos efeitos da pandemia no país. Uma destas empresas é a TAME, uma transportadora criada pela força aérea ecuatoriana em 1962 que se encontrava com mais de 400 milhões de dólares em prejuízos ao longo de 5 anos, possivelmente devido a um plano de expansão apressado que resultou no aumento dos seus custos e dívidas. (6): A Argentina encontrava-se numa posição semelhante ao Ecuador, impondo restrições severas no seu transporte aéreo que resultaram em quedas de 99% de passageiros transportados mensalmente. Isto criou uma situação desfavorável para a LATAM Argentina, terminando a sua atividade comercial em junho após considerar a sua operação no mercado argentino como insustentável. (7): NokScoot, uma companhia aérea criada em 2014 através da junção das transportadoras Nok Air e Scoot da Tailândia e Singapura respetivamente, encontrava-se numa posição desfavorável antes da pandemia; apresentava prejuízos desde a sua criação devido à incapacidade de expandir o seu negócio em mercados competitivos. Várias tentativas foram feitas para obter apoio financeiro governamental para sobreviver à Covid-19, mas não foram suficientes para evitar a sua liquidação. (8): Subsidiárias de grandes companhias aéreas correm sempre o risco de encerrarem as suas operações, de acordo com o estado financeiro da empresa mãe. Infelizmente, foi o que se sucedeu com a Cathay Dragon, uma subsidiária da Cathay Pacific sediada em Hong Kong, que fechou as suas portas como parte de um processo de reorganização empresarial, de forma a combater a perda de receita causada pelos protestos de Hong Kong, os novos transportes ferroviários e a pandemia. (9): Interjet suspendeu as suas operações em 2020 devido a um conjunto de fatores envolvendo problemas com a sua frota de Sukhois, a falta de pagamento de impostos e salários aos seus funcionários e a influência da pandemia no transporte aéreo global. A transportadora foi declarada formalmente falida em 2022, com o processo finalizado em 2023.

4.3. Período pós-pandemia (2021-2022)

Transitando de 2020 para 2021, a indústria do transporte aéreo iniciou uma fase de recuperação económica, com o propósito de regressar ao desenvolvimento que apresentava antes da Covid-19. Apesar do surgimento de novas variantes do vírus como a Delta e a Omicron [26], [27], o setor apresentou aumentos ligeiros no RPK doméstico e internacional, encontrando-se 28,2% e 75,5% abaixo dos níveis pré-pandemia respetivamente [27]. 2022 registou um aumento mais significativo graças ao maior levantamento de restrições de viagem e ao aumento da procura do transporte aéreo pós-pandemia [28].

Tabela 3- Companhias aéreas que faliram no período pós-pandemia
Fonte: Autoria própria, baseada nas listas fornecidas por Allplane [29], [30]

Companhia aérea	Ano de fundação	País de origem	Ano de falência
Air Namibia	1947	Namíbia	2021
Stobart Air	1970	Irelanda	2021
Air Antwerp	2019	Bélgica	2021
Alitalia	1946	Itália	2021
Itapemirim Airlines	2021	Brazil	2021
Eswatini Airlink	1999	Eswatini	2022
Comair	1948	África do Sul	2022
Tchadia Airlines	2018	Chad	2022

A Tabela 3 evidencia que (1): Em fevereiro de 2021, o governo da Namíbia tomou a decisão de encerrar a sua companhia aérea de bandeira (Air Namíbia) após 77 anos de existência, apesar de injetar quase 500 milhões de dólares na transportadora desde a década anterior. Razões pelo fecho de atividades incluem falta de lucratividade acentuada pela pandemia e um processo judicial envolvendo o aluguer e manutenção de uma aeronave pertencente à companhia aérea falida Challengeair. (2): Começando a sua atividade sob o nome Aer Arann em 1970 , Stobart Air terminou as suas operações em 2021, destacando a tentativa mal sucedida de adquirir a transportadora regional Flybe em 2020, a perda de operações devido à pandemia e o fim do seu contrato para operar voos em nome da Aer Lingus. (3) A história da Air Antwerp acabou pouco depois de ter começado; obteve o seu certificado de operador aéreo um ano após a falência da VLM Airlines, infelizmente, viu-se obrigada a encerrar a sua empresa dois anos depois devido às restrições impostas sobre o transporte aéreo pelo governo belga para travar a propagação da Covid-19, privando a companhia aérea dos seus principais clientes: voos executivos. (4): O fim da Alitalia segue um percurso semelhante à Jet Airways: uma companhia aérea reconhecida globalmente, que foi incapaz de se adaptar ao processo de liberalização do transporte aéreo europeu nos anos 90 [31], resultando na acumulação de prejuízos durante duas décadas, acentuada pela resistência dos seus sindicatos [32], que culminaram com a sua administração extraordinária em 2017 e subsequente aquisição pela nova companhia aérea de bandeira italiana, ITA Airways, em 2021. (5): Nesse mesmo ano, o grupo Itapemirim lançou a sua própria companhia aérea para se consolidar num mercado brasileiro doméstico em recuperação. Infelizmente, fechou as portas após 6 meses de operação, destacando a falta de pagamentos aos seus funcionários e a intervenção da Autoridade Nacional da Aviação Civil brasileira, que suspendeu e mais tarde revogou o seu certificado de operador aéreo. (6): Antes de reestabelecer a sua própria companhia aérea de bandeira em 2022, o reino de Eswatini recorreu a uma parceria com a Airlink, uma transportadora sul africana, para ligar o país com o resto do mundo. Com a criação da Eswatini Air, esta parceria foi concluída cordialmente, com o país a destacar o ambiente pós-Covid como uma boa oportunidade para iniciar a sua própria companhia aérea. (7): Entre 2021 e 2022, a Comair deparou-se com casos consecutivos de suspensão de atividades, cujas consequências resultaram na sua falência. Estes casos incluem a adoção de novas restrições no transporte aéreo por parte do governo sul africano para combater a variante Omicron da Covid-19 e uma suspensão temporária do seu certificado de operador aéreo devido a problemas relacionados com os motores e trem de aterragem das suas aeronaves. (8): A disponibilidade de apoios financeiros governamentais nem sempre assegura a sobrevivência de uma companhia aérea, o que pode ser visto no caso da Tchadia Airlines. A transportadora de bandeira do Chad iniciou o processo de liquidação em 2022 após 3 anos de prejuízo acentuados pela pandemia, com os seus acionistas a declararem a falta de um plano de recuperação fiável como uma das razões principais pela falência, apesar do apoio significativo do governo na operação da empresa.

5. Discussão dos Resultados Obtidos

Após a conclusão da pesquisa e análise dos resultados demonstrados no capítulo anterior, é possível traçar um padrão relativamente às causas que levaram às declarações de falência.

Antes da pandemia, o mundo encontrava-se numa posição estável e segura para o desenvolvimento do transporte aéreo. Eventos como o Brexit em 2019 condicionaram a operação da indústria, particularmente no mercado europeu, como foi abordado no caso da Flybmi e a Thomas Cook, mas no geral, o setor apresentou meios favoráveis para a atividade comercial das companhias aéreas. Assim, as falências destacadas durante este período de tempo ocorreram de três formas: a) momentos específicos que obrigaram ao encerramento da companhia aérea, dando o exemplo da Saratov Airlines; b) Acumulação de dívidas e prejuízos que tornaram a sua operação insustentável, destacando a VLM Airlines); c) Um conjunto de fatores cuja junção resultaram na falência (Orient Thai Airlines, Flybmi, Jet Airways, Aigle Azur e Far Eastern Air Transport).

A chegada da Covid-19 em 2020 introduziu uma causa comum entre os casos descritos no período da pandemia, quer fosse a razão principal ou o fator definitivo que levou à falência. Por um lado, Cathay Pacific cita a pandemia como a causa principal pelo encerramento da Cathay Dragon no seu processo de reestruturação. TAME EP e LATAM Argentina foram obrigadas a terminar as suas operações devido a decisões políticas nos seus países de origem para combater a pandemia.Compass Airlines viu-se sem opções quando as suas principais parceiras terminaram acordos com a companhia aérea ou propuseram cortes de capacidade insustentáveis. Por outro lado, companhias aéreas como a Flybe, South African Express, Miami Air International e NokScoot já se deparavam com problemas financeiros antes de 2020. Com a queda na procura do transporte aéreo e o encerramento de várias rotas internacionais, como consequência das medidas de confinamento adotadas pelos governos regionais, estas companhias aéreas não dispunham de meios suficientes para manter o seu negócio durante a crise.

Apesar do levantamento do estado de emergência e o alívio gradual das restrições com o começo de 2021, verifica-se que os efeitos da Covid-19 perduram vários meses depois do sucedido. Casos como Stobart Air e Air Antwerp envolveram a ausência de clientes suficientes para retomar operações ordinárias, juntamente com fatores relacionados com perdas de contratos e restrições governamentais prolongadas. Air Namibia e Tchadia Airlines faliram devido ao registo de resultados insatisfatórios durante longos períodos de tempo incluindo a pandemia. A Comair viu a sua atividade comercial parada em várias instâncias devido à pandemia e problemas relacionados com a sua frota. As companhias aéreas cujas falências não envolveram diretamente a pandemia são: a) Alitalia: encontrava-se sobre administração extraordinária desde 2017 devido à sua má situação financeira desde os anos 90, protegendo a companhia aérea até a sua venda em 2021; b) Eswatini Airlink: o reino de Eswatini terminou a sua parceria com a Airlink para criar a sua companhia aérea de bandeira, não existindo qualquer influência da Covid-19 na sua decisão; c) Itapemirim Airlines: Na sua tentativa de se estabelecer no mercado brasileiro durante a pós-pandemia, esta companhia aérea operou durante seis meses, até o seu certificado de operadora aéreo ter sido revogado pela autoridade aeronáutica civil brasileira devido a possíveis problemas de segurança e resultados financeiros fracos, sem menção da Covid-19.

Desta forma, verifica-se que uma companhia aérea podia declarar falência por diversas razões no período de tempo que antecedeu a pandemia, dispondo de causas e fatores semelhantes, mas com conclusões diferentes. Em 2020, a Covid-19 representou uma causa comum pelo encerramento de uma qualquer companhia aérea, com cada caso a destacar a pandemia como um fator significativo no fim da atividade da empresa. Esta causa comum continua a exercer um peso notável na falência de várias transportadoras durante a pós-pandemia, embora algumas companhias aéreas tenham terminado a sua atividade comercial devido a fatores externos à pandemia (Eswatini Airlink, Alitalia, Itapemirim Airlines).

6. Conclusão

Para concluir, é possível verificar que entre 2018 e 2019, existe uma variação notável nas causas e razões pela declaração de falência das companhias aéreas, desde a má gestão financeira até à influência de

A pandemia de Covid-19 assumiu simultaneamente o papel de catalisador e fator de exacerbação para as transportadoras que já se encontravam numa situação financeira delicada, como foi o caso da Flybe e South African Express.

Por outro lado, a Cathay Pacific aponta para a pandemia como a causa principal por encerrar a sua subsidiária Cathay Dragon. Também se verifica que a pandemia levou a diferentes respostas pelascompanhias aéreas, tendo em conta as suas estratégias de negócio e o contexto nacional onde se encontravam. LATAM Argentina e TAME EP foram impactadas por decisões de política nacional, enquanto que a Compass Airlines enfrentou o fim das suas parcerias. Após o levantamento das restrições, a pandemia continua a influenciar a viabilidade de muitas transportadoras, como foi abordado nos casos da Stobart Air e Air Antwerp. A falência da Alitalia e Eswatini Airlink destacam-se como casos únicos durante a pós-pandemia, não apresentando ligações entre o fim das suas operações e a Covid-19.

Atendendo aos objetivos específicos definidos neste estudo, é possível identificar como a pandemia intensificou problemas existentes na indústria do transporte aéreo. Também se verifica que os tipos de falências foram exacerbadas pela pandemia devido a fatores políticos ou decisões estratégicas falhadas. Por último, confirma-se que existe uma generalização das razões pela falência de companhias aéreas a partir de 2020, com a pandemia a introduzir uma causa comum e significativa nos casos reparados, ressaltando o impacto dos eventos globais.

6.1. Limitações

No decorrer deste estudo, notaram-se algumas limitações que condicionaram a elaboração da investigação, possivelmente influenciando os seus resultados finais. Os dados principais utilizados para este estudo baseiam-se em artigos de fontes jornalísticas centradas na indústria do transporte aéreo. Apesar da fiabilidade da informação destes artigos, a sua natureza subjetiva e interpretativa pode levantar questões quanto aos fatores específicos e objetivos do evento em questão, possivelmente criando discrepâncias entre o artigo publicado e os factos verdadeiros do caso. A pesquisa de dados referentes à falência de companhias aéreas focou-se principalmente em fontes qualitativas de leitura e interpretação, não sendo possível achar fontes estatísticas suficentes para complementar a apresentação dos resultados obtidos. Isto reduz a escala do estudo e limita a descrição das causas principais de uma falência.

6.2. Linhas de Investigação

A capacidade de identificar as causas comuns de casos de falência durante um determinado período de tempo representa uma ferramenta útil para qualquer empresa, dentro ou fora do transporte aéreo. Juntamente com a melhoria na previsão da ocorrência de uma falência, a análise de eventos ou comportamentos que levaram várias companhias aéreas a terminarem as suas operações, quer seja no contexto de uma crise ou não, constituí um tema com várias abordagens e objetivos que podem ser aproveitados.

A influência que uma crise como a Covid-19 exerce sobre as causas que resultam na falência de uma companhia aérea, tendo em conta os vários fatores envolvidos na atividade comercial do transporte aéreo, é um tema com potencial de ser desenvolvido em estudos futuros. A identificação de fatores e comportamentos comuns que ocorrem como resultado de uma crise global pode fornecer uma fonte de conhecimento útil para a indústria do transporte aéreo, servindo de base para novas investigações.

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AI for Aviation: Revolutionizing Aviation Knowledge Management and Decision Making through Data Categorization and Forecasting

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Abstract/Resumo/Resumen

This research aims to evaluate the relevance of new aviation technologies and forecast their implementation within the ecosystem, facilitating predictions of future aviation skill requirements. Data will be collected from scientific databases spanning the inception to implementation stages. Leveraging machine learning techniques, the patterns was identified, yielding valuable insights and analytics. The findings offer predictive capabilities for technology adoption timelines in the aviation industry, informing career planning by delineating necessary competencies for emerging technologies. Anticipated outcomes include improved sector readiness and streamline training initiatives, fostering seamless integration of future aviation professionals, and bridging the technology gap between emerging technologies, aviation organizations, and workers.

AI for Aviation: Revolutionizing Aviation Knowledge Management and Decision Making through Data Categorization and Forecasting

1. Introduction

The aviation industry, for long, labeled as a front runner in technological innovation, is currently undergoing rapid changes against the advancement in information technology and data analytics. The today aviation landscape is characterized by complex operational environments that allow efficiency with safety. Against this background, this work discusses the pivotal role of Artificial Intelligence (AI) in the management and improvement of these environments, particularly its subsets: machine learning and deep learning [1, 2, 3].

AI is the capability of machines to mimic human intelligent behaviors. Machine learning, on the other hand, is a subset of AI and refers to algorithms that parse data, learn from the data, and then apply what has been learned to make informed decisions. Endless efforts to find these patterns eventually gave birth to an automated process called deep learning, itself a subset of machine learning. This is more beneficial, especially in the use of deep learning when it comes to massive data in the aviation industry [4, 5].

In the present work, two artificial intelligence (AI) models are applied: Bidirectional Encoder Representations from Transformers (BERT), which is one of the deepest learning state-of-the-art models, and Random Forest (RF), which is the most robust and simplest compared to other models. BERT particularly stands out in that it has the capability to interpret context within the lines of unstructured text, thus making it very valuable for the research classification and analysis of the vast range of aviation literature and reports [6]. Random Forest presents good classification and risk assessment performance since it involves several decision trees to avoid overfitting, which may be catastrophic to aviation safety and decision-making [7].

BERT and RF in the aviation ecosystem span a multitude of areas. BERT helps in improving the semantic search, information retrieval, and content categorization, as its capability in interpreting complex textual data is enhanced. This implies that the capability is very imperative in the sense that a lot of aviation literature will be consolidated to fall under coherent categories, thus knowledge management will be made easier. On their part, RF contributes through the analysis of operational and performance data via predictive maintenance that could lead to substantial reduction in downtime and the improvements that would follow in efficiency and reliability in airline operations [8].

Such AI tools, when integrated, can hugely increase the efficiency of the aviation ecosystem. For example, predictive maintenance powered by RF ensures the continuity of operational efficiency and, at the same time, aversion of failures even before they occur, hence ensuring safety. Meanwhile, the more advanced text analysis conducted by BERT can actually improve training programs by rapidly and frequently updating the manuals and procedures, as well as updating research and incident reports that guide them, and thus improving the adaptability of the industry to new information. Furthermore, this model applied categorized data using the ARIMA (AutoRegressive Integrated Moving Average) model, which is a commonly used statistical approach to apply in time series forecasting so that the future trend can be predicted. This model is particularly good in handling data that shows non-stationarities, such as seasonal variations or economic cycles, since they are prevalent in aviation due to travel seasons, among others [9].

Using the ARIMA model in prediction of future aviation literature and trends in the industry, then firms would be able to predict changes in technology and regulations, then follow suit with revising strategies. This explains why prediction capability ensures the stakeholders are well informed of the future challenges and opportunities, thus matching resource allocation with strategic planning. BERT combined RF and ARIMA models can bring a comprehensive toolset to enhance the decision-making processes and operational efficiency within the aviation industry, hence ultimately leading to safer and efficient skies [10].

This study aims to evaluate the effectiveness of Machine Learning and Deep Learning models in acquiring knowledge across various facets of Aviation and Aircraft-related subjects. Additionally, it seeks to determine their ability to proficiently classify and organize aviation-related information. Furthermore, the study endeavors to leverage the labeled data generated from these classification processes to forecast future trends within each categorized domain.

The methodology employed in this study encompasses several key steps aimed at comprehensively analyzing and categorizing aviation-related literature: Firstly, academic papers containing the keywords "Aviation" or "Aircraft" are systematically gathered from Web of Science to form the foundational dataset. The next phase is to identify the main classes to facilitate the classification of the collected data, ensuring a structured approach to organizing the information. Subsequently, a rigorous training process ensues, wherein a restricted dataset is utilized to train the machine learning and deep learning models, taking into consideration constraints related to data imbalance. The BERT and RF models are then deployed to extract valuable insights and patterns from the dataset, leveraging the capabilities of both machine learning and deep learning approaches. Following this, data analytics techniques are applied to interpret the results obtained from the models, while the ARIMA model is employed to make future predictions for each class, thus providing a comprehensive understanding of potential trends and developments within the aviation domain.

2. State of the Art

The aviation industry is among the new frontline industries in terms of the adoption of new technological innovations, especially in the use of AI to improve its many facets. Since 2020, great developments have been recorded regarding improvement and efficiency, security, and decision-making processes by AI.

The aviation sector has lately seen huge progress in the area of AI development, more specifically in flight automation. The developedment of AI contributes meaningfully to the realization of a boosted level of flight independence with a pathway to completely independent flights. However, it also looks forward to the vulnerability that may take place in the digital communication system, which is essentially ensuring the flight. This dual-natured impact from AI on aviation raises issues that may be related to the dependability and security of the communication systems, as recently concluded [11]. Further, the work on technologies in the AI domain for enhancing the precision and counter-attack capability of munitions in aviation setups, more particularly in war-type environments [12].

The scope of AI applications in the aviation sector is broadly defined, ranging from developments in flight autonomy to critical roles in military operations and defense strategies. To ensure the aviation system continues to evolve in a safe, efficient, and secure manner, it is crucial to balance these challenges with the benefits of AI. In the aerospace domain, AI's impact extends beyond basic aircraft operations to include simulations of space missions using intelligent mechanical arms and authonomous spacecrafts. These applications demonstrate the profound level of AI integration in complex aerospace operations, involving autonomy, path planning, AI identification, and sensor technology simulations. By leveraging AI across such diverse areas, the aviation and aerospace industries not only enhance efficiency, safety, and innovation but also set the stage for future advancements in both civilian and defense sectors [13].

The transformational effects of AI and robotics are not confined to just commercial aviation but on an expanse of aerospace and defense. Some of the benefits that have been promised through these futuristic manufacturing technologies include cost efficiencies, speed in the design process, and improved productivity on the manufacturing level. This particularly makes their role in today's modern warfare of immense significance, as they contribute not only to the safety but also to the security of troops through the development of unmanned autonomous aircraft. This will make the execution of missions by defense forces have higher accuracy and effectiveness, at the same time risking their personnel. This underscores these points as crucial roles of the technologies, not only in propelling better practice within industries but in addressing the critical defense needs. The potential for reshaping aerospace and defense operations by their very advances in research and development in AI and robotics remains a focusing point toward innovation and strategic advancement [14].

The AI (r)evolution is changing many areas, and it is also improving the field of training and simulation. One example is its application in the training of pilots for the air force. It has enormous potential for improvement. It would totally change everything if these technologies were introduced into such training programs. For example, a system based on algorithms could be used to analyze carefully and then give

important responses regarding the quality of a move made by an aircraft pilot. Without AI, this data might have been influenced by feelings and other factors contrary to reality. This is why AI helps in giving different perspectives while ensuring accuracy during training hence making it more credible. Flying familiarization in pilot training programs is a major area that can benefit significantly from the use of artificial intelligence. Thanks to artificial intelligence simulations, trainees can easily undergo extensive involving an interactive familiarization process without constantly engaging the instructor. AI is clearly very well capable of enhancing the quality and efficiency of Air Force pilot training programs. This makes AI paramount to transforming pilot training programs by making them more accurate, objective, and timely because it simplifies processes than for any other reason. In the current evolving situation, AI has the capacity to change the nature of training and simulation particularly for the high-stakes profession like Air force pilots because it requires a lot of skill. As such, we are encouraged to see it as necessary that we take advantage of any such opportunities offered by this new concept while making sure conventional means are reinvented to ensure greater success through the application of modern technologies [15].

The role of AI in modern life has become irreplaceable, and the same is true in aviation. AI is increasingly contributing to addressing various concerns related to service perception, culture building and market competitiveness in the airline industry. Deepening the concept of service concept, AI has dramatically changed the way service is delivered in the airline industry. Since service orientation has greatly facilitated this process by knowing the needs of customers and ensuring that those needs are met as best as possible for example, AI applications such as chatbots, self-service kiosks, assistance the addition of automated delivery systems all provided seamless customer interaction.

At the same time, AI is also playing an important role in shaping the culture. The airline, as a global powerhouse, with a diverse culture that meets a wide variety of customers from different parts of the world makes AI central to the business. AI therefore helps create a holistic cultural framework that matches the global reach of the airline. Finally, AI gives the airline a market competitive edge. With the advent of digitization and the increasing intensity of the competitive environment, it has become imperative for businesses to embrace technological interventions in order to survive and thrive. AI, in conjunction with big data complex analytics can provide insightful market analysis and technical assistance. Acting as a catalyst, AI contributes to a broader understanding of market dynamics, thereby creating a competitive advantage. Thus, AI is very helpful in addressing the service concept, cultural structure and market competition found in the airline industry. Additionally, as the airline industry continues to mature and integrate technology, the importance of AI is set to increase in these cases as well [16].

Regarding the Air Traffic Management, the potential role and impact of AI has become a subject of substantial interest within the industry, academia, and policy realms, attracting considerable attention and debate. The positive ramifications of such integration are extensive, potentially resulting in dramatic improvements pertaining the efficacy and safety of operations within the air traffic industry. The introduction of AI and its associated technologies in the management of air traffic is, undoubtedly, shaping up to be a significant game-changer within this critical industry. The end-results of this transition may bring about a revolutionary impact that could significantly enhance the operational efficiency and overall safety of air navigation services. Moreover, embracing AI can contribute positively to the industry's pursuit of dealing with pressing and complex issues such as energy transition and environmental protection. By optimizing flight paths and predicting weather patterns, for example, AI can significantly reduce the carbon footprint and energy consumption of aviation, aligning the industry with global sustainability goals. Additionally, AI's potential role in fostering improved coordination between air traffic control and flight deck should not be underestimated. A more effective and clear-cut communication and coordination process, facilitated by AI, could enhance the overall flow of operations and minimize communication errors that may jeopardize safety [17].

It is important to highlight the substantial contributions made by an Integrated Flight Advisory System (IFAS) that significantly integrates AI into its operations. This system considerably aids and enhances pilots' situation awareness and decision-making capabilities. The essence of the IFAS goes beyond mere operational efficiency; it exhibits the significant role AI plays in improving decision-support systems within the aviation industry. It emphasizes the imperative need for decision-making tools that are not only accurate but also efficient, reliable, and dynamic, catering to a wide spectrum of unforeseen circumstances and unforeseen challenges [18].

The aviation sector is increasingly turning to machine learning techniques in its operations. Noteworthy is a study that seeks to establish the combined use of statistical and machine learning methods to analyze the impacts that aviation activities pose on the environment. It is in this area that the authors point out to the transformational capacity of data-driven analysis in enhancing efficiency and accuracy of processes [19]. The use of machine learning methodologies in aviation operations is meant to bring a new era in enhancing efficiency while carrying out operations with a touch of innovation. This, in turn, will help the aviation stakeholder to make a good decision-making process based on deeper insights into complex systems and phenomena through the power of data-driven analysis [7].

In addition, another natural language processing task model is BERT that has found application in aviation contexts. Particularly, research has been conducted in this case for its use in trajectory estimation, emphasizing the role played by trajectory data in interpreting flight intentions and safe flight conduct [20]. Further, the high performance of BERT in the processing of such large aviation text datasets, especially in the analysis of reports of accidents and incidents, is demonstrated. The completion of various text mining techniques allows the extraction of useful findings to make big data full of AI [21]. Besides BERT, the other machine learning model this study showcases as an invaluable asset to the aviation industry is the Random Forest model. Many other studies use the Random Forest model to drive data-driven decisions targeting the optimization of aircraft trajectories. Through adjusted routes, this model increases efficiency in time and fuel use, and therefore acts as an effective tool towards sustainability purposes [22].

On turning to the ARIMA model, being a classic type of time series forecasting technique, its application in aviation is worthwhile. In fact, its application has been quite instrumental in predicting several phenomena linked to aviation, to be precise, from forecasting demand for aviation services to predicting flight volumes [23]. Further use of the designed system has also been in predicting aviation mishaps and fatalities, therefore proving its usefulness in enabling the addressing of some of the most critical security concerns in the industry [24, 10]. The versatility of models like BERT, Random Forest, and ARIMA among others speaks of much greater possibility for these techniques to provide solutions for multiple problems in various areas around aviation missions.

3. Data Management and AI-Training

The initial phase of engaging with AI and Machine Learning constitutes a pivotal stage, crucial for tailoring approaches to align with specific objectives. While BERT and RF Models come pre-trained, fine-tuning these models to the dataset becomes imperative to assess their efficacy in deciphering and comprehending intricate Aviation and Aircraft-related content. The implementation of coding was executed in Python within the Spyder environment utilizing the Anaconda navigator. Subsequently, the data collection phase involved sourcing information from the Web of Science, extracting a substantial volume of academic articles containing either "Aviation" or "Aircraft" as keywords, spanning the period from 2000 to 2024. The extracted data encompassed the Title, Keywords, Journal, and Publication Year of each article. The total count of gathered academic articles amounted to 45818, categorized by publication year as delineated in Table 1.

Table 1 – Collected Papers from Web of Science
Source: Authors

Year	Number of Papers
2000	1437
2001	1497
2002	1429
2003	1439
2004	1670
2005	1636
2006	1714
2007	1858
2008	1953

Year	Number of Papers
2009	1918
2010	1980
2011	1876
2012	1973
2013	1900
2014	1981
2015	1943
2016	1962
2017	1962

Year	Number of Papers
2018	1953
2019	1961
2020	1895
2021	1964
2022	1967
2023	1977
2024	1973

The subsequent step involves training the AI models to comprehend specific Aviation and Aeronautical contexts. For this purpose, a subset comprising 1876 articles were labeled from the entire dataset, serving as the training data. This dataset was segmented into distinct labels, each representing a particular facet of the aeronautical ecosystem. It's worth noting that a higher number of labels typically corresponds to

lower precision in AI models. Hence, it became imperative to optimize the total number of labels to ensure the developed models achieve high precision. The precision of any machine or deep learning model is deemed useful within the range of 70% to 80%, while the industry standard for a realistically robust model lies between 80% to 90%.

Initially, the developed models encompassed 20 different classes, exhibiting a moderate performance with a precision of approximately 72%. However, the overarching goal was to enhance the precision and consequently, the reliability of the models. By refining the number of labels to 14, the precision of the models surged to an impressive 87%. The selected academic article labels are Aerodynamics, Defense, Design, Emerging Technologies, Maintenance, Management, Manufacturing, Operations, Propulsion, RPAS, Reliability, Safety, Structures, and Sustainability. With the establishment of this refined dataset, training commenced with the 1876 articles. To mitigate data imbalances, an equal number of training data were allocated to each class, except for the Management class, which necessitated additional training due to its broad scope of topics. Figure 1 provides a visual representation of the training dataset for both the BERT and Random Forest Models.

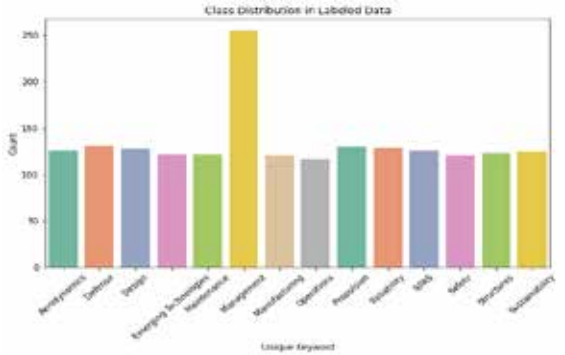

Figure 1 – Labelled Data for BERT and RF Models Training.
Source: Authors

Regarding the performance indicators for both models across each class, the corresponding values are detailed in Table 2. The F1-Score serves as the harmonic mean of precision and recall in a classification model. Both metrics contribute equally to the score, ensuring that the F1-Score accurately reflects the model's reliability. A F1-Score exceeding 0.9 is deemed as Very Good classification, while scores ranging from 0.8 to 0.9 are considered Good, those from 0.5 to 0.8 are categorized as OK, and scores below 0.5 are labeled as Not Good. As for the Area Under the Curve (AUC), this metric represents the model's performance across various classification thresholds. Widely utilized in machine learning, AUC assesses the model's ability to differentiate between classes. An AUC of 0.5 indicates a probability equivalent to a random model, values below 0.5 suggest a model performing worse than random, and an AUC of 1 signifies a perfectly calibrated classification model. Precision is a pivotal measure when evaluating the effectiveness of machine learning models. It represents the accuracy of positive predictions made by the model. Precision is calculated by dividing the number of true positive predictions by the total output of positive predictions, encompassing both true positives and false positives. This metric provides comprehensive insights into the reliability of the model's predictions. Lastly, Accuracy serves as a quantifiable measure to determine how often a machine learning model accurately predicts the outcome. This is achieved by performing by dividing the quantity of exact predictions by the total count of predictions made. Essentially, Accuracy is the response to the key question: how frequently does the model make correct predictions?

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Table 2 – Performance Indicators from BERT and Random Forest Models
Source: Authors

	BERT Model				Random Forest Model			
Class	**F1-Score**	**AUC**	**Precision**	**Accuracy**	**F1-Score**	**AUC**	**Precision**	**Accuracy**
Aerodynamics	0.89	0.97	87.6%	87.3%	0.89	1.00	86.9%	86.6%
Defense	0.95	1.00			0.96	1.00		
Design	0.83	0.97			0.79	0.97		
Emerging Technologies	0.89	1.00			0.92	1.00		
Maintenance	0.89	0.97			0.86	0.99		
Management	0.65	0.92			0.67	0.97		
Manufacturing	0.90	0.99			0.90	0.99		
Operations	0.81	0.98			0.79	0.98		
Propulsion	0.90	0.99			0.91	1.00		
RPAS	0.93	0.98			0.98	1.00		
Reliability	0.89	0.97			0.89	0.99		
Safety	0.89	0.99			0.87	0.99		
Structures	0.89	0.98			0.85	0.99		
Sustainability	0.91	0.99			0.85	0.99		

The best way to visualize model performance is through the Confusion Matrix, a vital instrument in assessing model efficacy, visually denoted through a tabulated structure. This matrix offers an enhanced understanding of the model's performance, including its errors and potential efficiency gaps. Consequently, it guides data practitioners towards a more rigorous analysis of their models, identifying opportunities for refinement and optimization. This is particularly valuable given the critical role of model accuracy in data-driven decision-making. Figure 2(a) and Figure 2(b) illustrate the Confusion Matrix for the BERT and RF Models, respectively.

The Confusion Matrix interpretation for the labeled data can be represented with the true label on the vertical axis and the predicted label by the model on the horizontal axis. For example, in the Aerodynamics Class from Figure 1(a), the BERT Model accurately predicted 32 articles in the correct class but misclassified 6 articles, labeling 2 as Design, 1 as Propulsion, 1 as RPAS, 1 as Structures, and 1 as Sustainability. Another example can be observed in Figure 1(b), where the RF correctly classified 42 articles in the Sustainability label but misclassified 9 articles, assigning 6 of them to the Management label, 1 to Manufacturing, 1 to Propulsion, and 1 to Structures. Both the BERT and RF Models encountered challenges in correctly classifying the Management class, despite additional training data, as illustrated in Figure 1. Specifically, the BERT model correctly classified 31 articles as Management but misidentified 20 articles. Similarly, the RF model correctly identified 38 articles but failed to classify 13 articles accurately. Notwithstanding the satisfactory performance observed in classifying the Management label, it is crucial to highlight the overall exceptional performance of both models in the classification task. This underscores their capacity to effectively classify a diverse range of Aviation and Aeronautical information with an exceedingly high level of precision, demonstrating their robustness and reliability in handling complex datasets within the aviation domain. Regarding predictions, the ARIMA model is formulated by Equation (1), where n represents the number of observations (observation window), and Xt denotes the mean [10].

$$Xt = xt - 1 + xt - 2 + \cdots + xt - {}^{n}/_{n} \qquad (1)$$

Given the exemplary performance achieved by both the BERT and RF models in accurately identifying aviation data, they can be deployed on a broader scale. This entails leveraging their capabilities to label all 45818 academic articles, thereby enabling a comprehensive analysis of data trends and directional insights over time.

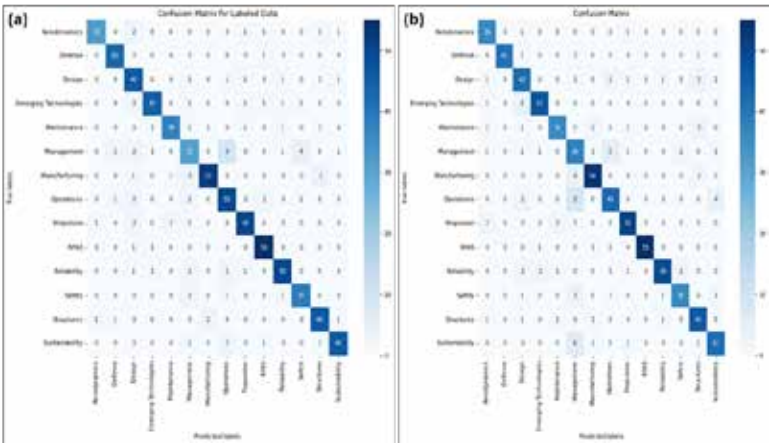

Figure 2 – Confusion Matrix for the Labeled Data unsing the BERT Model (a) and Random Forest Model (b).
Source: Authors

4. Results

To run the complete dataset was used a Intel Pentium i5 with 4 cores at 2.11GHz with 32GB of RAM. BERT, a Deep Learning Model, took 79 minutes to complete the task. Regarding RF, a Machine Learning Model, took about 13 minutes to complete the task.

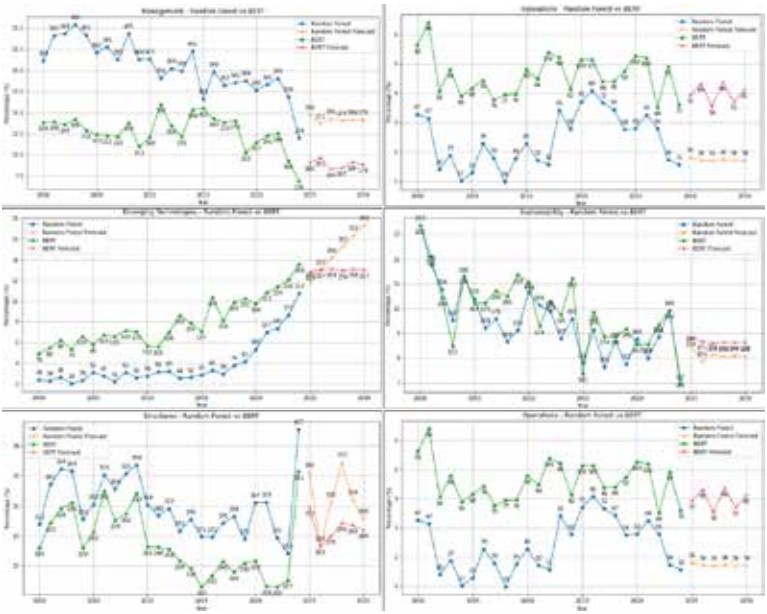

Figure 3 – BERT and Ramdom Forest Historical Data and ARIMA Predictions for Classes “Management”, “Operations”, “Emmerging Technologies”, “Sustainability”, “Structures” and “Operations”.
Source: Authors

The application of both BERT and RF models yields a comprehensive and extensive set of results for each labeled data. Figure 3 illustrates a small portion of the generated data. Analysis of the data provided by the BERT and RF Models indicates a decline in the number of articles related to Management, Sustainability, Defense, Design, and Safety. Conversely, there is an increase in the number of articles pertaining to Aerodynamics and Emerging Technologies, as well as Propulsion. The number of articles remains consistent in classes such as Maintenance, Manufacturing, Operations, Reliability, RPAS, and Structures.

If the number of published articles is indicative of knowledge transfer to the industry, we may observe a decrease in the workforce focusing on Management, Sustainability, Defense, Design, and Safety. In addition to the impact of automation and analytical tools, fluctuations in funding priorities, regulatory changes, evolving research interests, and broader socio-economic or geopolitical factors should be considered when interpreting trends in publication output within these domains. Regarding the Defense label, which also exhibits a reduction, this trend may be attributed to the current geopolitical landscape, leading researchers to withhold their work from publication and maintain it within a close circle of stakeholders. Applying the same correlation analysis, it is anticipated an increase in demand within the domains of Aerodynamics, Emerging Technologies, and Propulsion. While the surge in Emerging Technologies can be attributed to advancements in areas such as AI, Blockchain, and Machine Learning, the uptick in Aerodynamics and Propulsion may be linked to the optimization of aircraft, development of new engines, exploration of alternative fuels, and advancements in space exploration.

5. Conclusion

A Deep Learning and Machine Learning Models were developed to effectively classify complex aviation and aeronautical data, successfully categorizing 45818 academic articles into 14 distinct classes. Both BERT and RF performance are similar, but RF is more time and resource efficient. The data generated by BERT and RF served as historical input for the ARIMA model to forecast the number of academic articles in these classes up to 2030, providing valuable insights into the industry's current and future skill requirements. The robustness of these models extends to their applicability to real-world industry data, offering companies enhanced data analytics and credible information practically in real-time. Such tailored models can significantly benefit various stakeholders in the aviation ecosystem, including airports, airlines, maintenance centers, and design organizations, by providing proactive insights and providing predictive maintenance to minimize downtime, route optimization to enhance operational efficiency, predictive analytics for demand forecasting, and enhanced safety measures through anomaly detection and risk assessment. The implementation of this technology has the potential to unlock substantial economic resources while also freeing up human resources for more functional assignments.

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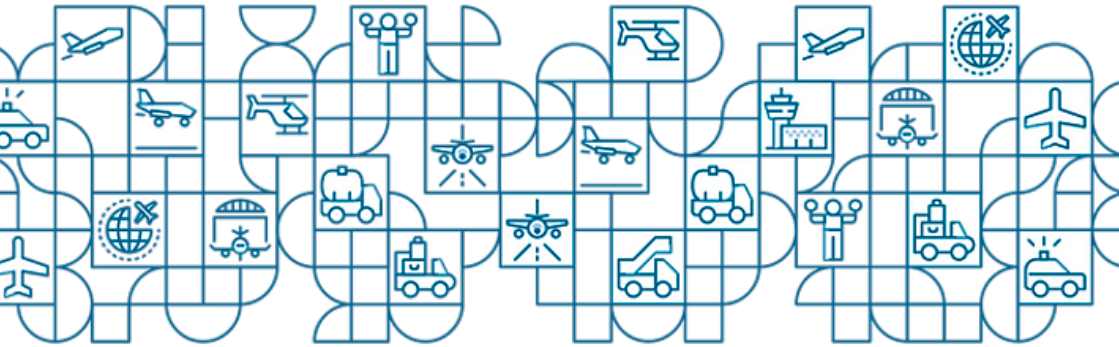
Air Industry



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Análisis de la accesibilidad aérea en el Archipiélago de las Azores: propuesta para su corrección

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Abstract/Resumo/Resumen

El objetivo del trabajo es la realización de un análisis de la accesibilidad aérea interinsular en las Islas Azores (Portugal). Como espacio afectado por la fragmentación territorial, el transporte aéreo es de vital importancia para el desarrollo socioeconómico del Archipiélago, facilitando la movilidad de los residentes y creciente turismo. Ello se ve agravado en Azores por el escaso peso demográfico y económico, además con notorio desequilibrio entre islas. Metodológicamente, analizamos varios parámetros de accesibilidad, centrándonos en la operativa horaria, ya que es la que detectamos que presenta peores ratios. Para ello tomamos los horarios aéreos interinsulares de las temporadas de invierno, con mayor probabilidad de uso por residentes y, por ende, por motivos de desplazamiento relacionados con negocios, sanitarios, administración, etc. Como resultados del artículo, detectamos que si bien se ha trabajado positivamente con la introducción de las obligaciones de servicio público (OSP) aéreas, imponiendo un determinado número de frecuencias, asientos, tope de tarifas, etc., el escaso interés en la mejora de los horarios de operatividad en función de la demanda, está llevando a disponibilidades de tiempo en destino -en una operativa de ida y vuelta en la misma jornada-, escasamente favorable para los viajeros en más del 70% de las rutas operativas. La originalidad del trabajo reside en analizar especialmente el "factor tiempo" en los destinos para los pasajeros en un trayecto de ida y vuelta en el mismo día, como instrumento de mejora de la accesibilidad y, por ende, de cohesión territorial y que ha sido escasamente investigado.

Análisis de la accesibilidad aérea en el Archipiélago de las Azores: propuesta para su corrección

1. Introducción

Las Islas Azores presentan un elemento común a todas las islas, como es la fragmentación territorial y lejanía, con efectos negativos para el desarrollo de su actividad socioeconómica [1]. Además, en las Azores concurre un peso demográfico y económico muy dispar, traduciéndose igualmente en una demanda interinsular de movilidad diferente.

Partiendo de esta vulnerabilidad de las islas, la Unión Europea ya hizo hincapié en 2010 en la denominada "Estrategia Europea para el Desarrollo Económico y Social de las regiones de montaña, las islas y las zonas escasamente pobladas", en tanto que sus especificidades geográficas las excluían de las políticas de "cohesión territorial". En la misma línea se encaminó política de las "Redes Transeuropeas del Transporte" en la misma década [2]. Tampoco hay que olvidar el Fondo Europeo de Desarrollo Regional (FEDER), el Fondo Social Europeo (FSE) o el Fondo de Cohesión (FC), como instrumentos financieros de equilibrio regional y con particular énfasis en las islas. Esto convierte a la "cohesión territorial", en el que la accesibilidad y los transportes juegan un papel fundamental, en una de las directrices principales de la Unión Europea, reconocido por el Tratado de Lisboa como la tercera dimensión del objetivo de cohesión.

Otra particularidad de las islas es que suelen padecer una notoria escasez de materias primas, haciendo aún más dependientes estos territorios del continente [3] y arrastrándolos a un PIB considerablemente menor. Bien es verdad que las particularidades de los archipiélagos son notorias (demografía, PIB, distancias, etc.), pero el elemento común, esto es, la fragmentación territorial, los condiciona por igual, siendo el transporte intermodal, con sus costes económicos y de tiempo, la única vía alternativa para superar el aislamiento. En este sentido, como destaca el Plan Integral de Transportes de Azores, los puertos y aeropuertos de las islas son la columna vertebral del sistema de transportes, sin los que no se podría comprender el desarrollo socioeconómico, incidiendo en la "realidad geográfica, el tamaño de mercado, la estacionalidad y los costes inherentes a la operación", todo ello relacionado con la existencia de las obligaciones de servicio público como instrumento para garantizar las conexiones interinsulares [4].

En el caso de Canarias, se elevaba el coste de la ultraperiferia al 8% de la facturación de las empresas [5], mientras que en Baleares, Bardolet también sopesa la condición diferencial con el continente, indicando que en las islas el "transporte es vital para un desarrollo aceptable de riqueza y de bienestar social" [6]. De todo lo anterior se deduce una falta de oportunidad de los medios insulares frente al continente y donde la aportación de soluciones con instrumentos como las obligaciones de servicio público o el fomento de un mayor reequilibrio regional, deben ser los mecanismos a implementar en aras de paliar las citadas vulnerabilidades de las islas, tal y como reconoce el Libro Verde de la Cohesión Territorial en la Unión Europea [7] y, además, una de las principales demandas del turismo en Azores para reforzar la conectividad turística interinsular [8].

Por su parte, en los últimos años existe un creciente interés por estudiar una accesibilidad basada en el sistema puerta – puerta, en tanto que nos acerca a los verdaderos costes y tiempos de viaje [9]. Esta política nos aproxima a la evaluación de la cohesión territorial que ya intentaba potenciar el Gobierno de las Azores con la filosofía del "billete único" [10]. De hecho, es un proceder que emana de la propia Red Transeuropea de Transportes y de los Libros Blancos de Transporte de 2001 y 2011. Por tanto, es una metodología que especialmente recogemos para este estudio desde el punto de vista del coste y de los tiempos de desplazamiento, conjuntamente con la disponibilidad de tiempo de los viajeros en destino, en línea con lo que previamente han realizado algunos trabajos en ámbitos insulares [11].

En este sentido, muchos trabajos se han centrado en analizar la accesibilidad del transporte público a determinados lugares funcionales, como por ejemplo los comercios o las administraciones, condicionado sobre todo por los horarios de apertura y su compatibilidad con los horarios del transporte público en los espacios rurales o de escasa población [12]. En suma, los horarios de los sistemas de transporte condicionan las decisiones de planificar un desplazamiento, comenzando por si las franjas de operatividad permiten la movilidad y si ello es así, cuándo comenzar el viaje en función de los servicios disponibles en tanto que nos permita un determinado tiempo en los destinos. Es por ello por lo que los análisis de los horarios como garantes de la calidad de las redes de transporte, ha ido adquiriendo protagonismo [13].

2. Metodología

Realizamos en primera instancia un análisis de la accesibilidad aérea interinsular en las Azores en sus diferentes parámetros (físicos, económicos, de tiempo, etc.). Tras realizar un diagnóstico de los principales parámetros de la accesibilidad aérea, detectamos que el principal déficit lo encontramos en la accesibilidad temporal, por lo que va a ser ésta en la que haremos mayor énfasis y, por tanto, motivo central de la explicación metodológica.

Posicionándonos pues en el mencionado problema, particularmente en los tiempos disponibles de los pasajeros en los destinos, vamos a considerar doce programaciones aéreas invernales, hasta la última justo antes de la pandemia de la COVID-19, es decir, la del invierno 2019 – 2020, pues desde marzo de este último año toda la operativa sufrió variaciones significativas a la baja, tergiversando los resultados. Es verdad que desde el otoño de 2021 se ha recuperado gran parte de la operativa, pero la situación dista bastante de la existente con anterioridad a la pandemia. Además, a efectos comparativos, y en aras de apreciar cómo ha evolucionado, evitando el análisis puntual o coyuntural de una sola temporada tomamos, como decíamos, las doce programaciones invernales anteriores de las que disponemos de datos (2009 – 2020), para así tener una mayor perspectiva y analizar qué cambios ha habido. Ello ha supuesto la recopilación sistemática año tras año de una información difícil y tediosa de tratar debido a la gran cantidad de información disponible. Si ya de por si es complicado analizar, comparar y cotejar estos datos en una sola programación, el llevar este análisis más allá de una década como hemos realizado para el caso de los horarios, dificulta sobremanera el trabajo, aunque por el contrario enriquece enormemente los resultados, ya que nos proporciona una perspectiva inigualable de hacia dónde nos lleva la cohesión territorial en las Azores, desde el punto de vista de la "disponibilidad de tiempo" de sus ciudadanos cuando viajan en avión entre islas.

Tomamos siempre las programaciones de las conexiones "directas" de invierno porque metodológicamente no se ven afectadas por el incremento de la oferta y la demanda del estío y, además, en esta última existe una mayor presencia de los viajes por motivos de ocio no tan ligados a la demanda de unos horarios que exigen el regreso en la misma jornada. Por tanto, es lógico pensar -y a expensas de datos fehacientes que nos indiquen los motivos de viaje aunque intentamos obtenerlos, sin éxito, a través de SATA y de la Dirección Regional de Transporte Aéreo y Marítimo del Gobierno de las Azores-, que la movilidad laboral o de negocios entre islas cuenta con una mayor cuota porcentual en invierno y, por tanto, es precisamente este período el que nos interesa. También tendríamos que argumentar que los horarios que nos importaban excluían los fines de semana por este motivo, buscando solo los días laborales donde la presencia de viajeros por trabajo, negocios o sanitarios era mayor . A veces el primer horario de partida y el último de llegada no coincidían exactamente en esos cinco días de la semana (de lunes a viernes), optando por los de mayor prevalencia dentro de este período. Por tanto, siempre optamos por la accesibilidad horaria más beneficiosa para el viajero, es decir, la más temprana y más vespertina, pues muchos *commuters* ante una cierta libertad de opción diaria, a buen seguro se inclinarían por estas alternativas más beneficiosas.

Partiendo de la base de que para analizar la "disponibilidad de tiempo" en los destinos -y en una misma jornada que permita el *round trip* en el día para así no incrementar los costes globales del viaje imputables a una pernoctación-, es necesaria la existencia de dos o más frecuencias directas en cada sentido dentro de una misma ruta, solo tenemos ocho líneas interinsulares que cumplen este requisito, de las doce operativas en enero de 2020.

Como a su vez el cálculo en porcentajes de los tiempos disponibles en horario administrativo y comercial lo hemos fijado metodológicamente entre las 08.00 y las 15.00 horas para el primero (siete horas), y entre las 09.00 – 13.00 y 16.00 – 20.00 horas para el segundo (ocho horas), estos tiempos disponibles quedan a expensas de las variaciones de los horarios de la compañía aérea SATA, horarios éstos que cambian dos veces al año (temporadas de invierno y de Verano). Sabemos que las restantes rutas, al disponer de solo siete frecuencias semanales o menos en cada sentido, hacen imposible el regreso al origen el mismo día o lo restringen aún más en tiempo y coste si se han de realizar escalas para regresar en la misma jornada.

La accesibilidad horaria o "disponibilidad de tiempo" en el destino, condicionada sobre todo por los horarios aéreos, es importante porque va a condicionar la probabilidad de pernoctación en la isla visitada, con los consiguientes costes de alojamiento, dietas alimenticias, etc.

3. Área de estudio

El Archipiélago de las Azores se caracteriza por presentar una gran diversidad social y económica, hecho que tiene notorias connotaciones sobre la conectividad marítima y aérea. Como destacamos en la Tabla 1, la isla de San Miguel reúne casi el 60% de la población y del PIB, bastante distante de Terceira que apenas supera el 20%. Ello significa que el restante 20% de la población y de la economía lo ostentan las otras siete islas. La consecuencia de esta gran diversidad socioeconómica del Archipiélago, se manifiesta en la alta concentración de los distintos parámetros en la isla de San Miguel, condicionando una conectividad muy débil con las restantes islas. No obstante, para garantizar un transporte interinsular sostenible, es indispensable una mínima conectividad con el resto de las islas.

Tabla 1 - Principales macromagnitudes de las Islas Azores en 2019.
Fuente: Serviço Regional de Estatística dos Açores (SREA). Elaboración propia.

Islas	Población	PIB / habitante*	Producto Interior Bruto (%)*
San Miguel	137.307	18.059	58,12
Terceira	55.124	16.935	21,95
Faial	14.521	18.414	6,28
Pico	13.651	15.160	4,85
São Jorge	8.277	15.753	3,08
Santa María	5.616	21.592	2,85
Graciosa	4.208	14.514	1,44
Flores	3.628	14.364	1,22
Corvo	464	19.523	0,21
Total	242.796	17.550	100,00

* Datos referidos a 2018.

Habría que destacar otro hecho y es que el Archipiélago no alcanza los 250 mil efectivos, mientras que el PIB por habitante solo representa el 58 y 89% respectivamente de la media de la Unión Europea y Portugal [14]. Estas cifras suponen un escaso hinterland para la demanda potencial de transporte aéreo interinsular, pues a la escasa población, se une una baja renta con menor posibilidad de movilidad por ocio, trabajo, negocios, etc., siendo ello muy común en todas las islas [15].

En suma, la diversidad socioeconómica del Archipiélago, unido a una escasa población y actividad económica, se constituyen en las principales características. No obstante, habría que destacar el creciente peso del turismo, que en 2019 alcanzó los 970 mil visitantes, con un crecimiento muy destacado desde la llegada a las Islas, en marzo de 2015, de operadores de bajo coste como Ryanair y Easyjet, consiguiendo aumentar la demanda de turistas en el período 2014-2019 un 145%.

Como destacamos en la Figura 1, el movimiento de pasajeros interinsulares y a pesar de partir de cifras muy bajas -de solo 450 mil viajeros por año mediada la década de los ochenta-, tarda casi tres décadas en duplicarse. Pero no será especialmente hasta 2014, cuando con la nueva flota aérea de mayor capacidad y unas obligaciones de servicio público aprobadas en 2009 -y ya habiendo superado la profunda crisis económica-, la movilidad aérea consigue aumentar con bastante rapidez en relación con el período precedente. De este modo, entre 2014 y 2019, ese movimiento de viajeros aéreos creció un 60 %.

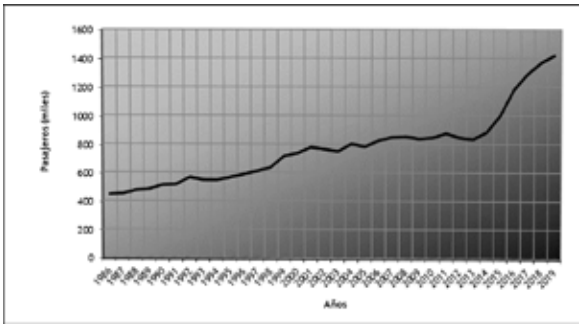

Fig. 1 – Tráfico de pasajeros aéreos interinsulares en Azores (1986 – 2019).
Fuente: Serviço Regional de Estatística dos Açores. Elaboración propia.

Por lo demás, los viajeros interinsulares en Azores son predominantemente aéreos, aunque bien es verdad que casi se reparten a la par con los que se desplazan por mar, pues el 56% lo hacen en avión. Bien es verdad que su distribución es muy desigual, hasta el punto de que casi un tercio de los pasajeros aéreos y marítimos interinsulares se concentran en una sola línea y además por mar, como es la travesía entre las islas de Faial y Pico, sin protagonismo en este caso por parte del avión. Sin embargo, en la segunda ruta con mayor volumen de tráfico (San Miguel – Terceira), el avión mueve el 95 % del tráfico, habiendo superado en el año 2019 los 180 mil viajeros. Salvando el protagonismo del barco en las tres islas centrales, el resto queda a expensas del transporte aéreo, pues aquí las distancias son bastante mayores, salvando además las frecuentes marejadas que afectan al transporte marítimo (véase la Figura 2).

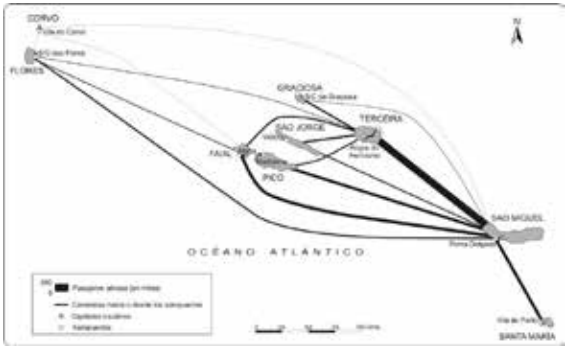

Fig. 2 – Tráfico de pasaje aéreo interinsular con carácter regular en Azores según rutas (2019).
Fuente: Departamento de estadística de SATA. Elaboración propia.

Otra particularidad de la red aérea interinsular de Azores, es que en 2019 casi el 50% del tráfico tuvo lugar en solo los cuatro meses del verano (entre junio y septiembre inclusive). Este hecho denota el fuerte movimiento turístico en el verano, corroborando que nuestro análisis, centrado en la problemática de la conectividad horaria, tiene mayor sentido en invierno, cuando tienen lugar los viajes más exigentes con los horarios, es decir, los centrados en motivos de desplazamiento laborales, sanitarios, etc.

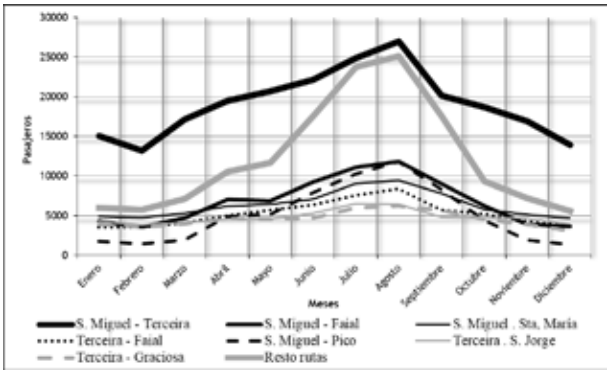

Fig. 3 – Movimiento mensual de pasajeros aéreos interinsulares en Azores según rutas (2019). Fuente: Departamento de estadística de SATA. Elaboración propia.

4. Discusión y resultados

Como decíamos, la demanda de movilidad de pasajeros en las Azores es muy alta en el estío, más aún en el transporte marítimo. Por ello mismo, las frecuencias en la temporada de invierno de 2020 (enero de ese año), mostraban un predominio significativo del modo aéreo, suponiendo dos tercios de las frecuencias totales, y solo el transporte marítimo adquiere cierto significado en el corredor entre Horta (Faial) y el puerto de Madalena (Pico). Realmente la programación de frecuencias aéreas se puede considerar endeble en invierno, ya que se reducen en aproximadamente un 40 % con respecto al verano. Habría que hacer la excepción del corredor San Miguel - Terceira, pues el resto de rutas no alcanza las cuatro diarias en invierno, lo que significaba que en uno o varios días de la semana no se llegaban a las dos frecuencias en cada sentido, necesarias para retornar al origen en la misma jornada. Sin embargo, en ocho rutas aéreas se podía regresar en la misma jornada durante algún día de la semana.

En cuanto a los tiempos de viaje puerta – puerta, es decir, entre capitales insulares, estos rondan, por lo general, entre los 100 y 120 minutos de ida, con un primer horario de llegada en la mañana aceptable entre las dos islas principales y también entre San Miguel y Santa María. El resto de las rutas superaba, incluso ampliamente, las 09.00 horas como referencia de llegada a la capital de destino, situación que, evidentemente, no era la idónea para esa mejora de la conectividad.

Por su parte, el transporte marítimo solo era verdaderamente accesible en un ida y vuelta en el día en el corredor Pico – Faial, pues el elevado tiempo en las otras rutas lo hacían difícilmente competitivo con el avión.

Por lo que respecta a la accesibilidad económica, el coste del desplazamiento de ida para un residente en las Azores rondaba en 2020 los 30 euros de ida y casi el doble si le añadimos los desplazamientos terrestres del puerta a puerta en origen y destino, tanto en el modo aéreo como marítimo, a excepción de la ruta Faial – Pico que era notablemente más asequible en barco. Partiendo de la base de la renta media de un residente, no parece que un trayecto de ida y vuelta signifique un excesivo esfuerzo económico por parte de éstos, por lo que volvemos a señalar que en los horarios -y consiguiente disponibilidad de tiempo en los destinos-, se convierte en uno de los principales problemas de la accesibilidad en el Archipiélago de las Azores.

Por su parte, el análisis de la disponibilidad de asientos en determinadas horas clave, fundamental para considerar un posible *round trip* en la misma jornada, nos vuelve a indicar un déficit importante, especialmente en el horario vespertino. En efecto, salvo en las rutas San Miguel – Terceira y San Miguel – Santa María -y esta última con tan solo una treintena de asientos-, el resto operaba más allá de las 08.30 horas, con previsión de llegada a las capitales de destino superando incluso las 10.00 horas, factor que, como indicábamos, juega totalmente en contra de una mayor cohesión territorial del Archipiélago. En ello también ha tenido que ver el horario de operatividad de las infraestructuras aeroportuarias,

notablemente restringido en algunas islas, pues al cerrar éstas con cierta antelación, condicionan la operatividad aérea también más temprana.

Por último, nos centramos en la accesibilidad horaria, es decir, lo que algunos autores han desarrollado dentro del concepto de la "disponibilidad horaria o de tiempo" en los destinos, todo ello en un sistema puerta – puerta y en un *round trip* en la misma jornada. La condición principal para ello es que existan al menos dos conexiones diarias en cada sentido, es decir, que permitan ese desplazamiento de ida y vuelta en el mismo día. Además, tiene que existir una cierta dispersion horaria que facilite una óptima estancia relativamente prolongada en los destinos dentro de una misma jornada laboral y todo ello acorde con la disponibilidad horaria de las administraciones y comercios en los destinos, partiendo de la base de que estos horarios son los que nos van a servir para evaluar las estancias justificadas de esos pasajeros en los mencionados destinos. En este sentido, dentro de la red interinsular aérea de Azores en enero de 2020, se contabilizaban unas ocho rutas que cumplían con este requisito de las al menos dos frecuencias de ida y vuelta en cada sentido y que reflejamos en la Tabla 2.

Tabla 2 - Accesibilidad horaria a las *"capitales"* de otras islas de Azores en viaje aéreo de un *commuter* en una jornada laboral (enero de 2020).*
Fuente: Horarios de SATA. Elaboración propia.

	Bloques de tiempos de *ida*		Bloques de tiempos en la *vuelta*			Tiempo disponible en lugares funcionales abiertos (%)	
Rutas	Llega avión	Llega capital	Salida capital	Llegada al embarque	Salida avión	Administración	Comercial
San Miguel – Terceira	08.35	09.00	17.30	17.55	18.35	86	69
Terceira – San Miguel	07.40	07.55	19.20	17.35	18.15	100	92
San Miguel – Santa María	07.00	07.10	18.45	18.55	19.35	100	84
Santa María – San Miguel	07.55	08.10	17.45	18.00	18.40	98	72
San Miguel – Faial	11.50	12.10	16.35	16.55	17.35	40	18
Faial – San Miguel	12.30	12.45	11.05	11.20	12.00	0	0
San Miguel - Pico	09.00	09.15	17.35	17.50	18.30	82	67
Pico – San Miguel	10.00	10.15	15.05	15.20	16.00	67	33
Terceira - Pico	10.50	11.05	16.50	17.05	17.45	56	34
Pico - Terceira	11.50	12.15	16.05	16.30	17.10	39	9
Terceira – Graciosa	10.20	10.30	14.40	14.50	15.30	60	19
Graciosa – Terceira	11.15	11.40	13.30	13.55	14.35	40	17
Terceira – Faial	09.25	09.35	15.05	15.25	16.05	77	43
Faial – Terceira	10.30	10.55	14.00	14.25	15.05	44	26
Terceira – San Jorge	10.05	10.15	15.10	15.20	16.00	68	34
San Jorge – Terceira	10.35	11.00	13.55	14.20	15.00	42	25

* Solo se consideran las rutas con dos o más frecuencias diarias en cada sentido.

Para una mayor comprensión de lo que significa esta disponibilidad de tiempo en los destinos, salvando la posible excepcionalidad de una sola programación horaria, hemos tomado unos doce años como perspectiva más que suficiente para así demostrar la regularidad de las vulnerabilidades de la red aérea interinsular de Azores en materia de horarios. Para ello tomamos, de modo gráfico, dos rutas aéreas muy representativas dentro de la red, como son la de San Miguel – Terceira, la de más volumen de tráfico de todas; y la de San Miguel a Faial, también relativamente importante, aunque en menor medida, detectándose ya en esta última una carencia importante en materia de horarios que beneficien a los pasajeros que deseen regresar dentro de la misma jornada laboral (véase la Figura 4).

Bien es verdad que, en líneas generales, detectamos que existe un cierto progreso de la disponibilidad horaria en los destinos desde 2015, percibiéndose en algunas rutas una mejora añadida a partir de 2018 – 2019, coincidiendo con la entrada en vigor de la modificación de las OSP aéreas en 2015.

Si bien es cierto que la conectividad entre San Miguel y las islas de Terceira y Santa María se puede calificar como bastante próximas a la situación ideal en materia de horarios, las rutas restantes son escasamente accesibles, con disponibilidades de tiempo por situaciones administrativas o comerciales que ni siquiera alcanzaban el 30 % en los destinos.

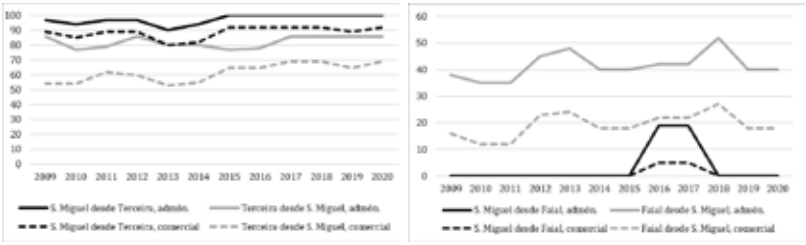

Fig. 4 - Disponibilidad de tiempo de dos rutas aéreas representativas en día laboral y en horario administrativo y comercial en las capitales insulares en las temporadas de invierno entre 2009 y 2020 (en %).
Fuente: Horarios de SATA. Elaboración propia.

Por tanto, los indicadores nos manifiestan la necesidad de mejora del mercado aéreo interinsular de Azores, en especial en materia de horarios. De las ocho rutas consideradas, pues cumplían con el requisito de poder retornar al origen en la misma jornada, solo dos -y otras dos de modo parcial-, contaban con una disponibilidad de tiempo en los destinos superior al 70%, ya fuese por motivos comerciales o administrativos. Este dato pone de manifiesto el alto riesgo de pernoctación obligada con la implicación económica que ello conlleva.

En este sentido y si traducimos el coste que una pernoctación en los destinos supone a los viajeros, podemos deducir que la tarifa del operador aéreo, en este caso *SATA* -y en la que inciden tanto las OSP aéreas [16]-, aun no siendo residual, si que representa un peso significativamente menor en relación con los costes imputables a la mencionada pernoctación. En este caso y como demostramos en la tabla 3 con un caso real para los residentes en Faial y que se desplazaban a San Miguel, la posibilidad de pernoctación en la isla de destino termina por implicar un sobrecoste del 110% sobre la tarifa aérea y de taxi inicial. Todo ello, como decimos, imputable a los gastos extras derivados del alojamiento, manutención extra y horas laborales perdidas en la isla de origen del viaje (Faial en este caso), del día siguiente hasta que el viajero llega a Horta (Capital de Faial) en la primera frecuencia aérea disponible, como decimos de la jornada siguiente.

Tabla 3 - Gastos estimados imputables a un desplazamiento aéreo de ida y vuelta de un residente entre Horta (Faial) y Ponta Delgada (San Miguel) en una situación con y sin pernoctación en enero de 2020 (en euros).
Fuente: Horarios de SATA y SREA. Elaboración propia.

	Taxi Horta	Tarifa aérea	Taxi Ponta Delgada	Hotel	Manutención extra*	Horas laborales*	Total
Retorno en el día	10,00	57,52	8,00	----	----	----	75,52
Pernoctación de un día	10,00	57,52	8,00	50,00	12,00	21.31	158.83

* La *manutención extra* se refiere a una cena básica, pues el desayuno se incluye en la tarifa del alojamiento; y las *horas laborales* a la pérdida de tiempo en el segundo día hasta que el viajero llega a Horta en la primera frecuencia aérea desde San Miguel (09.55 horas), estimándose en este caso 01.55 horas de trabajo. Para ello se ha tomado el salario de un ingeniero civil en enero de 2020 que, según el INE de Portugal, ascendía a 11.12 €/hora laboral.

Por todo ello, es necesario que las OSP de Azores recojan unas determinadas franjas horarias de operatividad, como por ejemplo se consideran en el caso homónimo de las Islas Canarias. De esta manera, la disponibilidad horaria de los pasajeros podría incrementarse de forma importante en los destinos, evitando los elevados costes señalados en la tabla 3. Se demuestra así, coincidiendo con otros trabajos, que la estrategia de actuar sobre los horarios de operatividad de las empresas de transporte es bastante

más efectiva que, por ejemplo, la subvención al pasajero [17], sin menoscabar la importancia de esta última política en aras de fomentar la cohesión territorial de las islas.

Del mismo modo, diversas políticas como el empleo conveniente de una flota diversa, flexible en disponibilidad de plazas y, por ende, adaptada a la demanda, fomentaría esa operativa sujeta a determinadas franjas horarias claves para el incremento de los tiempos disponibles en los destinos, en especial en las primeras horas de la mañana y las últimas de la tarde, a la vez que posibilitaría que las otras líneas con solo una frecuencia diaria, dispusieran al menos de dos para así facilitar el *round trip* en el mismo día, evitando los elevados costes derivados de la pernoctación en los destinos como hemos demostrado.

5. Conclusiones

Hay que argumentar que la accesibilidad aérea interinsular en las Azores ha evolucionado positivamente, en gran medida porque el hinterland demográfico, pero sobre todo el económico, derivado del crecimiento del turismo, ha propiciado un aumento de la demanda de movilidad interinsular. Ello se ha traducido en un incremento de las frecuencias, afectando positivamente también a un abanico mayor de disponibilidad de horarios para viajar. Igualmente, esta circunstancia socioeconómica coincide con la entrada en vigor de las nuevas Obligaciones de Servicio Público aéreas.

No obstante, la aplicación de estas OSPs no han ido acompañadas de una intervención horaria que favorezca la cohesión del Archipiélago, simplemente porque las OSP no exigían el cumplimiento de una operativa aérea en función de las franjas horarias, sino que simplemente disponían que los servicios aéreos interinsulares podrían desarrollarse entre las 06 y las 24 horas y con unas frecuencias mínimas que, evidentemente, variaban según las rutas. Y es que, sin datos fehacientes sobre el porcentaje de viajeros que retornan en la misma jornada a su isla de residencia, la experiencia en otros sistemas insulares, como es el caso de Canarias, demuestra que los regresos en la misma jornada son muy altos siempre que el sistema horario lo permita.

Así pues, tras analizar varios parámetros de accesibilidad aérea, como eran la conectividad, los tiempos de viaje, las frecuencias, las tarifas, la oferta de asientos, detectamos que el principal problema radica en la disponibilidad de tiempo en los destinos, obligando a muchos viajeros a pernoctar fuera de su hogar. Esto último, como hemos calculado en el trabajo, representa para un trabajador residente en las islas más del 100% del coste del boleto aéreo y del taxi de ida y vuelta.

El propio Plan Integrado de los Transportes de Azores (PIT) de 2014, ya aludía a la necesidad de buscar una "excelencia operacional" entre islas a través de los billetes unificados de transporte en el que la intermodalidad basada en un puerta – puerta era la clave del sistema, combinando los transportes terrestres, marítimos y aéreos, pero no solamente desde el punto de vista de la tarifa global como resultado de la utilización de dos o más medios de transporte, sino también de la mejora de la correlación horaria intermodal. Desde este punto de vista se ponía el ejemplo de las tres islas centrales (Faial, Pico y San Jorge), donde el peso del transporte marítimo era muy importante y su vinculación con los horarios del transporte aéreo era fundamental para las conexiones entre si y, especialmente desde este grupo a San Miguel [18]. No obstante, sin el principio básico de unos horarios interinsulares que faciliten el retorno a la isla de residencia en la misma jornada, disminuyendo por ende el "coste global" del desplazamiento, la política del puerta – puerta, incentivada además por la propia Unión Europea a través de sus Libros Blancos de Transporte [19], pierde todo su protagonismo y, desde luego, no fomenta la cohesión territorial de las Azores tal y como hemos demostrado.

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Airline Business Models and the Development of a Flight Pass for the 2030 World Cup: A Case Study

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Abstract/Resumo/Resumen

In this study, the empirical knowledge of five distinct business models employed by various airlines is utilised in a case study that specifically focuses on the upcoming 2030 World Cup. A tailored Flight Pass has been developed to meet the needs of a specific group of customers seeking air travel options between various destinations, particularly during matches. The Flight Pass plan has been formulated based on the Business Model Canvas framework developed by Osterwalder and Pigneur [1], and the product's innovation is captured with a Product Canvas tool. The initial factors to establish and maintain without change are the Value Proposition and Key Activities. Using the exposed method, the aspects of this Flight Pass will be discussed based on the empirical results and scientific foundations presented by the five airlines mentioned. The study findings indicate that the proposed structure enables the feasibility of an unbundled business model. The incorporation of this model facilitates the establishment of a network system with multiple hubs, which effectively encompasses all potential destinations for the 2030 World Cup. It is of utmost importance to integrate with various transportation modes within the MaaS platform.As it stands, this Flight Pass type is not sustainable as a standalone business model that necessitates owning all resources. This is connected to another business model that possesses these resources. This method enhances load factors and ensures predictable revenue, while also fostering a loyal customer base.

Airline Business Models and the Development of a Flight Pass for the 2030 World Cup: A Case Study

1. Introduction

The airline industry is currently experiencing growth in flight passes, which are subscription services that allow users to book unlimited flights for a fixed fee. To evaluate past and current flight pass offers, the Osterwalder [1] Business Model Canvas is a useful tool. Flight passes can be implemented in regions with both high and low air connectivity, and they are particularly useful for large events such as the World Cup. Flight passes can improve customer relationships and constitutes a new channel, as outlined in the business model canvas, and enhance the overall travel experience. A potential implementation of flight passes is being studied for the 2030 World Cup in Portugal, Spain, and Morocco.

2. State-of-the-art

Recent research suggests that companies offering subscription products have grown 3,7 times faster than those offering traditional goods over the past 11 years [2]. This trend is evident across various sectors, including digital services, software-as-a-service, media, and consumer products.

According to Tzuo [3], new subscription models have shifted their focus from products to customers, emphasizing personalized service and the central role of the customer in organizational strategies. This shift, known as servitization, leverages digital platforms and data collection to tailor products to individual preferences.

Warrillow [4] outlines nine subscription business models. Notable examples include the 'All-You-Can-Eat Library Model,' where consumers gain unlimited access to a diverse content library, the 'Front-of-the-Line Model,' which offers priority access to paying customers, commonly observed in the airline industry, and the “consumables” model that manages the regular replacement of consumer goods.

Airline revenue management capitalises on customer price sensitivity through product differentiation. For the purposes of this paper, an emerging trend in revenue management is the concept of flight passes, which offer pre-purchased flight packages with exclusive benefits and an unlimited number of flights [5].

Flight passes, as defined by Gillis [5], are pre-purchased flights with a flat fee per trip and are a customisable product that depends on factors such as class, number of flights, and duration of use. Another perspective on flight passes, referred to as 'Netflix-style aviation,' offers subscription-based air travel that allows for unlimited travel under specific conditions [5], [6].

According to the Maas Alliance [7], Mobility-as-a-service integrates various transportation services into a single, on-demand mobility service with the aim of creating a user-centric ecosystem through a unified interface. Web-based and mobile systems are crucial in enabling the versatility and accessibility of such platforms [8].

3. Method

To recognize aviation business models, it is essential to follow a consistent method of analysis for all studied cases. In this paper, we will use the Product Canvas, based on the Business Model Canvas explained by Osterwalder & Pigneur [1], to identify the evolution of business models and the emergence of a new market segment. The Product Canvas will be applied to a restricted group of companies. Various companies were selected from the full-service to low-cost spectrum based on their current flight pass availability.

To analyze the business models of selected airlines, it is necessary to acquire information that defines them. This ensures homogeneity in the analysis, allows for comparisons, and ensures that the data collected follows the same method. Metrics or information that can be fed into the Canvas blocks should be acquired.

The Canvas was completed using data sourced from airline websites, statistics aggregator websites, account reports, or other appropriate websites. If concrete data was not available, the inductive method, as recommended by Sengur & Sengur [9], was used. In their work they analyzed the statements made by airlines on their websites to characterise the Business Model.

Afterward, the Flight Pass of each company should be analyzed. This paper identifies five airlines across the full-service to low-cost spectrum to provide insights into industry trends and outlooks to facilitate informed decision-making and strategy development. In this paper we identify five airlines within the Full-service to low-cost spectrum (Table 1).

Table 1 - Selected airlines
Source: Authors

Airline	Category	Flight Pass
Alaska Airlines	FSC	Yes
Frontier Airlines	LCC	Yes
Air Canada	FSC	Yes
TAP	FSC	Yes
Ryanair	LCC	No

It is suggested that the study should use the Product Canvas shown in Table 2. This approach combines POA philosophies by Mason & Morrison [10] and Product by Osterwalder [11].

Table 2 - Product Canvas suggested for the analysis of the Flight Pass
Source: Authors

<table>
<tr><th>Business Organisation</th><th colspan="3">Product Architecture</th></tr>
<tr><td rowspan="3">Key Activities</td><td rowspan="3">Value Proposition</td><td colspan="2">Customer Interface</td></tr>
<tr><td>Channels</td><td rowspan="2">Customer Segments</td></tr>
<tr><td>Customer Relationship</td></tr>
<tr><td colspan="4">Pricing Strategy</td></tr>
</table>

Using the Flight Pass Canvas and Business Model Canvas, information was collected from each airline to gain insight into the industry outlook and current trends. This knowledge was then applied to the case study.

A Product Canvas was developed for the 2030 World Cup Flight Pass, starting with two key assumptions: the value proposition and the key activities. These will serve as the foundation for designing the Flight Pass product and its associated business.

The Key Activities will be defined based on the network of cities that will host the 2030 World Cup. The network should be analyzed from a hub-and-spoke or point-to-point perspective. It is necessary to define economic logic at an early stage. The set of activities should be designed to generate profit.

4. Five (5) Airlines, Five (5) Canvas

The Flight Pass Canvas is presented for each of the five airlines. In the case of Ryanair, which does not offer a Flight Pass, the Business Model Canvas is presented instead.

Alaska Airlines Flight Pass Canvas is shown below, Table 3.

Table 3 - Flight Pass Canvas for Alaska Airlines
Source: Authors

<table>
<tr><th>Business Organisation</th><th colspan="3">Product Architecture</th></tr>
<tr><td rowspan="2">Key Activities
Direct routes from the Hub and spoke network.
15 destinations across California and neighbouring states</td><td rowspan="2">Value Proposition
Subscription business model compatible with front-of-the-line, consumable, and simplifier model
Fixed and lower prices for regular travellers</td><td colspan="2">Customer Interface</td></tr>
<tr><td>Channels
Online website

Customer Relationship
Automated service
Accumulates with FFP benefits</td><td>Customer Segments
Business and leisure clients
Short holiday travellers
Regular business clients</td></tr>
<tr><td colspan="3">Pricing Strategy
Fixed monthly fee.
12-month mandatory subscription.
Credits regular trips.
It is necessary to pay taxes and fees.</td></tr>
</table>

Frontier Airlines Flight Pass Canvas is shown below, Table 4.

Table 4 - Flight Pass Canvas for Frontier Airlines
Source: Authors

<table>
<tr><th>Business Organisation</th><th colspan="3">Product Architecture</th></tr>
<tr><td rowspan="3">Key Activities
Use of the full network of Frontier Airlines
Transport passengers on regular flights</td><td rowspan="3">Value Proposition
"All-you-can-eat subscription model"
Unlimited travel
Seasonal, monthly, and annual passes
Last minute flying</td><td colspan="2">Customer Interface</td></tr>
<tr><td>Channels
Online website</td><td rowspan="2">Customer Segments
Last-minute travellers
Seasonal travellers
Leisure clients</td></tr>
<tr><td>Customer Relationship
Automated service
Automatic Renewal
It is possible to use tier status</td></tr>
<tr><td colspan="4">Pricing Strategy
Unlimited travel for a single fee with automatic renewal.
Varies from 159 dollars per month to 499 dollars in a year</td></tr>
</table>

Air Canada's Flight Pass Canvas is shown in Table 5.

Table 5 - Flight Pass Canvas for Frontier Airlines
Source: Authors

<table>
<tr><th>Business Organisation</th><th colspan="3">Product Architecture</th></tr>
<tr><td rowspan="3">Key Activities
Use of Air Canada and subsidiaries' network
Multiple destinations according to the flight pass modality chosen</td><td rowspan="3">Value Proposition
Highly customisable
Buy travel credits at a fixed rate
Consumables model with travel credits
"All-you-can-eat" subscription model in some modalities.
Multiple travellers with the same pass in some modalities</td><td colspan="2">Customer Interface</td></tr>
<tr><td>Channels
Online website and app
Travel agents for buying the flight pass</td><td rowspan="2">Customer Segments
Leisure and Business Clients
Regional, domestic, commuter, and international clients</td></tr>
<tr><td>Customer Relationship
Automated service
Cumulative with FFP
Tier Status Miles can be used</td></tr>
<tr><td colspan="4">Pricing Strategy
Varies according to the modality chosen.
Fixed-rate travel credits
According to the number of credits, travellers, and region prices can vary</td></tr>
</table>

TAP's Flight Pass Canvas is shown in Table 6.

Table 6 - Flight Pass Canvas for TAP Air Portugal
Source: Authors

<table>
<tr><th>Business Organisation</th><th colspan="3">Product Architecture</th></tr>
<tr><td rowspan="3">Key Activities
Use of European TAP network
Multiple destinations according to the flight pass modality chosen</td><td rowspan="3">Value Proposition
Highly customisable
Buy trips at a fixed rate
Consumables model with travel credits
"All-you-can-eat" subscription model for unlimited travel modality
Multiple travellers with the same pass in some modalities</td><td colspan="2">Customer Interface</td></tr>
<tr><td>Channels
Online website and app</td><td rowspan="2">Customer Segments
Leisure and Business Clients
Regional, domestic, commuter, and international clients</td></tr>
<tr><td>Customer Relationship
Automated service
Cumulative with FFP</td></tr>
<tr><td colspan="4">Pricing Strategy
Varies according to the modality selected.
Fixed rates
Prices may vary based on the number of credits, travellers, and region.</td></tr>
</table>

Finally, in Figure 1**Erro! A origem da referência não foi encontrada.** is shown Ryanair's Business Model Canvas.

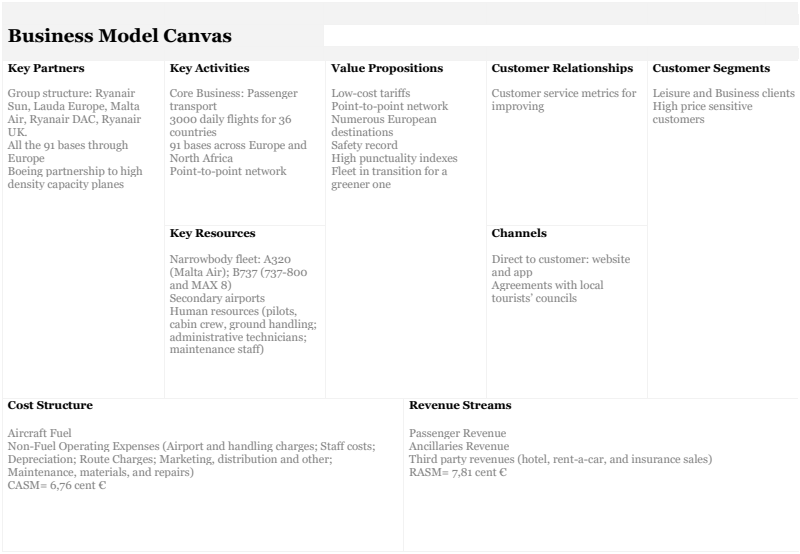

Figure 1 - Ryanair Business Model Canvas
Source: Authors

5. Results

5.1. Value Proposition

Two primary Flight Pass subscription models are considered: the 'all-you-can-eat library' model and the 'consumables' model. The former offers unlimited access to a set of routes, facilitating unrestricted travel within the airline network, which can increase the load factor on existing transport networks. However, its viability relies on a well-established transportation network with minimal demand. In contrast, the 'consumables' model provides a regular supply of travel credits or flight hours, offering predictability for both consumers and companies.

Alaska Airlines, Air Canada, and TAP offer similar models that emphasize personalization of trips and destination networks. These models mitigate the impact of price fluctuations and enable fixed fares, attracting customers who prioritize time and cost savings. TAP's model, with its extensive personalisation options, is particularly advantageous for events such as the 2030 World Cup.

Furthermore, a more enticing value proposition may be required, possibly complemented by the 'front-of-the-line' model, which offers ancillary services such as lounge access and priority boarding. This can appeal to passengers seeking enhanced comfort and luxury. Collaborating with other transportation modes and partners, such as hotels and car rentals, can simplify the travel experience. Offering a comprehensive package, including accommodation and entertainment services, through a higher Flight Pass price or monthly subscription, can enhance customer satisfaction and expand the tourism element beyond the event itself. Integration with mobility-as-a-service platforms and partnerships with local tourist boards can facilitate seamless travel experiences and broaden the scope of customer options.

5.2. Key Activities

The transportation network for the 2030 World Cup Flight Pass must be developed by selecting between a hub-and-spoke or point-to-point model, depending on the established value proposition. Point-to-point networks prioritize convenience, niche market service, and reduced turnaround times, and are associated with low-cost

business models. However, this model may be impractical for all destinations due to excessive scale and resource demands. Selected hubs, such as Lisbon, Madrid, and Casablanca, redirect passengers efficiently, enabling increased route frequencies without expanding the fleet. This is in line with the value proposition of accommodating dynamic event-related demand.

It is not necessary for the chosen hubs to connect to all destinations directly. Competitive air transportation is sufficient, with alternative transport options such as road or rail available for non-competitive routes. High-frequency hub connections ensure efficient passenger transfers. Route selection prioritizes daily frequency to ensure commercial viability based on existing market supply.

The current network design does not include a connection to Zaragoza, which could be addressed through non-regular service or partnerships, such as utilizing the Spanish high-speed rail network. To prepare for potential World Cup hosting, Murcia's limited daily air connections may need to be strengthened. Morocco's internal transportation system may require air transport for unserved routes, especially to cater to foreign tourists.

Redundant transportation options, such as high-speed rail within a 500 km radius, complement air travel, ensuring passenger mobility even in full flight scenarios. Collaboration within the Mobility-as-a-Service framework further enhances inter-modality and travel accessibility, aligning with evolving transportation needs.

Next (Figure 2) it is presented a suggested network.

Figure 2 - Destination network for the 2030 World Cup Flight Pass
Source: Authors

5.3. Customer Segments

The Flight Pass primarily targets leisure travellers attending World Cup events and residents of Portugal, Spain, and Morocco who seek convenient travel options for match attendance. The service is aimed at budget-conscious passengers who prioritize fixed pricing and ease of booking. The Flight Pass may also appeal to those who are less concerned with seat flexibility. In addition, it may appeal to business travellers, especially through event-related companies that offer curated passes with fixed prices and flexible travel options. Although the Flight Pass is primarily aimed at frequent leisure travellers, it can also meet the needs of corporate travel without changing its core value proposition. This flexibility also applies to employees of service providers for the 2030 World Cup, enabling them to take advantage of fixed fares negotiated by their companies.

5.4. Channels

The companies surveyed primarily use online channels to sell Flight Passes directly to consumers. They also work with third-party travel agencies through the Global Distribution System (GDS) for pass distribution. However, their focus is on establishing partnerships solely for Flight Pass distribution, while seat reservation systems remain internalized. The distribution system operates in two ways: directly to customers via the company's website or mobile app, offering customized passes and customer support; and through third parties such as travel agencies, selling predefined passes without personalization. Seat inventory management is exclusively

handled by the GDS, ensuring seat availability through partner carriers within the Mobility-as-a-Service framework.

5.5. Customer Relationship

The Flight Pass creates automated customer relationships, encouraging frequent service usage. Personalisation allows customers to create itineraries without immediately selecting a destination or date. Efficient online support resolves issues promptly. Unlike traditional programmes, there is no mileage system, simplifying the product and ensuring customer loyalty. This approach optimises cost structure by eliminating the need for a Frequent Flyer Program. Flight Pass ensures customer retention without additional incentives.

5.6. Price Strategy

The pricing strategy is based on the product's value proposition, with a focus on customization and simplicity. A customizable travel pre-sales model considers various factors, such as booking time, number of flights, class, and destination group. It is recommended to integrate MaaS services, such as public transport, with customizable options. The revenue management system establishes prices for Flight Passes, which offer fixed rates for trips without set dates or destinations, aligning with modern airline ticketing systems. While some companies offer fixed monthly fees or one-time purchases, Air Canada's installment model is notable for its flexibility, as it partners with credit companies to offer advantageous conditions. The Flight Pass price includes all taxes and fees, simplifying the payment process for customers and ensuring transparency.

5.7. Canvas

The product canvas for the 2030 World Cup Flight Pass, developed using the method described above, is shown in Table 7 below.

Table 7 - 2030 World Cup Flight Pass Canvas

Source: Authors

<table>
<tr><th>Business Organisation</th><th colspan="3">Product Architecture</th></tr>
<tr><td rowspan="3">Key Activities
Defined destinations based on the demand
Hub-and-spoke network, with hubs at Casablanca, Madrid, Barcelona, and Lisboa
Multiple destinations according to the flight pass modality chosen</td><td rowspan="3">Value Proposition
Highly customisable
Buy trips at a fixed rate
Consumables model
For corporate purposes, there are multiple travellers with the same pass in some modalities.</td><td colspan="2">Customer Interface</td></tr>
<tr><td>Channels
Online website and app
Travel agencies only with a popular flight pass</td><td rowspan="2">Customer Segments
Leisure Clients
Corporate clients
2030 World Cup workforce</td></tr>
<tr><td>Customer Relationship
Automated service</td></tr>
<tr><td colspan="4">Pricing Strategy
Varies according to the modality chosen.
The price of the Flight Pass varies according to revenue management techniques, considering demand and other factors.
According to the number of credits, class, and region prices can vary</td></tr>
</table>

6. Conclusion

The product canvas presented here is a result of empirical analysis. To apply the World Cup 2030 results, a case study analysis was conducted, and the canvas obtained reveals the explicit results of this analysis along with a description of each building block.

Validation of the obtained results through a real simulation is necessary. A business model should be implemented as an unbundling case of a parent company, focusing on product innovation, using the presented flight pass canvas. To implement this innovative product, resources and an existing organizational structure are required. This model cannot be applied in isolation. The model presented should only be used as a means to increase the load factor of each flight. This can increase revenue and demand through product innovation, providing customers with access to a wider range of travel options. The provision of a system that falls under the category of MaaS has the potential to develop into an integrated MaaS service encompassing all modes of transportation.

The presented model enables coverage of all possible World Cup 2030 destinations in a multi-hub network system. The proposed model for the 2030 World Cup region is the 'consumables' model, where a single purchase

allows for a regular supply of trips. This model is convenient for both passengers and the company. The passengers can be leisure or business customers from a corporate structure. To cover a larger number of destinations, a hub-and-spoke network is proposed. As it stands, this Flight Pass type is not sustainable as a standalone business model that necessitates owning all resources.

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Airline choice model for domestic flights: the role of Frequent Flyer Program

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Abstract/Resumo/Resumen

This study examines the impact of Frequent Flyer Programs (FFPs) on airline choice behavior among domestic flight passengers from Medellín, Colombia, to principal coast cities. This research analyzes revealed and stated preferences data from 509 travelers from a survey conducted at Jose Maria Cordova (MDE) Airport. This research involves a model calibration to identify significant variables influencing airline choices for individuals belonging to and not belonging to FFP by employing the Multinomial Logit (MNL) model. Substantial differences were observed in the variables considered by different groups when selecting an airline alternative for domestic trips. The obtained models are useful to explain the behavior of FFP's members in contrast with non-FFP's members. Variables such as the advance time for ticket purchase, who paid for the ticket, and if the ticket was paid using FFP miles were relevant for FFP members, while these variables had no significance in the MNLs for non-FFP's members. Findings are significant as they contribute to understanding user choices and can inform strategies for enhancing or attracting more users to these programs.

Airline choice model for domestic flights: the role of Frequent Flyer Program

1. Introduction

The passenger aviation transportation industry has been one of the most affected by the COVID-19 pandemic worldwide, including Colombia. The International Air Transport Association [1] reported that global passenger traffic, as measured in revenue passenger kilometers, declined by 65.9 % compared to 2019, as international passenger demand dropped by 75.6 % and domestic demand fell 48.8 % below 2019 levels.

The high operating costs, including fuel, maintenance, and labor expenses incurred by airlines, often translate into elevated ticket prices, which can have several repercussions on air passenger demand [1]. A lack of passenger demand poses a significant challenge in the airline market. When fewer people choose to fly, airlines face increased pressure to attract customers profitably. Some airlines implement Frequent Flyer Programs (FFPs) to retain valuable customers and secure loyalty. These programs allow passengers to accumulate rewards, such as miles or points, based on their flights with the airline or its partners [3]. They act as switching barriers, enhance the airline's competitive advantage, and contribute to the airline's revenue [4].

Estimating airline choice involves analyzing the factors that significantly influence passengers' decisions. Passengers' preferences and perceptions play a crucial role in their airline choices, and these preferences can vary based on socio-demographic attributes and trip characteristics [5]. Factors such as airline reputation, frequency of flights, and in-flight staff service are essential considerations for passengers when choosing their airline [6]. Additionally, airline loyalty programs, such as FFPs, can also impact passenger airline choice [7]. Understanding these factors and their influence on passenger behavior is essential for airlines to develop effective marketing strategies and meet customer expectations [8].

Discrete choice modeling has been a mathematical tool for predicting travel choices for more than forty years [9]. The use of discrete choice models and revealed (RP) and stated preference (SP) data is integral to understanding and analyzing the complex decision-making processes involved in selecting an airline and analyzing the factors that influence air travel choice behavior [10].

The present study focuses on a compelling case in the Colombian airline industry, specifically analyzing the domestic flight market in Medellin. The primary carriers under investigation are Avianca, LATAM, and VIVA Colombia, the three airlines with the highest share in domestic passenger transportation in the country, each playing a crucial role in connecting Medellin to various domestic destinations [11]. The FFPs of these airlines, LifeMiles by Avianca, LATAM Pass by LATAM, and the low-cost carrier VIVA Colombia, are in the decision-making process of passengers departing from the Jose Maria Cordoba Airport (MDE) in Medellin. This study aims to investigate the influence of FFPs on traveler behavior in airline choice among domestic flights, using Medellin, Colombia, as a case study. An RP and SP survey was conducted in 2018, and the application of discrete choice models, specifically Multinomial Logit Models (MNL), to identify the significant factors that guide passengers in their airline selection, focusing on the impact of the FFPs. The remainder of the paper is as follows: Section 2 summarizes the relevant literature; Section 3 describes the proposed methodology, including data and modeling; Section 4 presents the main results of the case study in Medellin; and finally, section 5 summarizes the concluding remarks of the study.

2. Literature Review

In the literature, multiple studies have used discrete choice models to identify important factors in airline choice. Most of these studies have assessed various aspects of travel time and travel costs and have also identified other vital aspects outside socioeconomic determinants, such as arrival time [12], departure time [13], frequency [14], baggage fee [15], and FFPs. FFPs have a significant influence on air travelers [16], [17], [18]. However, very few studies emphasize FFPs' impact on airline choice. Fourie & Lubbe [19] investigate factors influencing business travelers' choice of airlines in South Africa and underscore the importance of frequent flyer programs that differ between full-service airlines and low-cost carriers. Factors such as company size, loyalty programs, in-flight service, and airport lounge facilities influence choice—differences in conclusions on the influence of price and flight frequency in South Africa. Business travelers in South Africa consider frequent flyer programs necessary. Seelhorst & Liu [7] quantify the impact of FFPs on itinerary choice with a latent class model. It concludes that FFP membership plays a vital role in airline choice, particularly for individuals with elite membership. Three classes of individuals with different preferences and WTP values were identified. Class 1 has average sensitivity to travel time, fare, and connections but no preference for FFP airlines. Class 2 has low sensitivity to travel time and fare but a strong preference for FFP airlines. Class 3 has high price sensitivity and moderate sensitivity to travel time and connections, with a preference for FFP airlines.

Milioti et al. [5] investigate the factors that affect passenger decisions regarding airline choice. They developed three Multivariate Probit (MP) models to analyze data for 853 respondents. This allows for modeling the simultaneous consideration of airline choice determinants, identifying fare, safety, reliability, and friendly and helpful staff during flight as the most critical determinants of airline choice. In-flight entertainment and FFPs are less important, but the significance of factors varies depending on the socio-demographic characteristics of the traveler: business and higher-income travelers have a greater tendency to consider.

Cantillo et al. [20] analyzed the choice of domestic travelers in Medellín, Colombia, focusing on airline and flight departure time alternatives. Using survey data from 2009 and Multinomial (MNL) and Nested logit (NL) models, the researchers found that Colombian air travelers exhibit highly elastic behavior towards airfares, travel time, and flight departure time, based on data collected from two airports in the city. The models did not consider the impact of FFP on airline performance despite acknowledging its significance. The data collected showed that only Avianca and Aero-República offered FFPs, which was insignificant in early models due to its correlation with non-leisure travel purposes.

Unlike our case study, the studies mentioned did not consider the impact of FFP on airline selection in developing countries. Thus, we plan to shed light on the main characteristics of passenger behavior related to FFP when selecting specific airlines in emerging economies.

3. Methodology

3.1. Data

The survey integrates RP and SP data to thoroughly explore the factors influencing airline choice among domestic flight passengers. It was conducted in 2018 at Jose Maria Cordova International Airport (MDE), a key hub serving the city of Medellin; the survey aimed to capture real-world choices corresponding to the RP section and individual preferences expressed through six hypothetical scenarios corresponding to the SP section.

In the RP section of the survey, information on travelers' characteristics, including gender, age, education level, employment status, and monthly income, was solicited. Additionally, data on air trip frequency by airline, membership in FFPs, and information related to the chosen airline for the trip were collected. This segment aimed to provide insights into the sociodemographic factors influencing choices made by passengers in their real travel decisions [10]. In the SP section, participants were presented with three choices—AVIANCA (AVA), VIVA COLOMBIA (VVC), and LATAM (LAN) —in six hypothetical scenarios. Each scenario involved variations in cost, arrival and departure times, and the frequency of each airline. This method allowed participants to express their preferences through hypothetical decision-making, providing a deeper understanding of the factors influencing their choices in controlled complete scenarios. The SP survey is a crucial instrument that asks respondents about their preferences and sensitivity in hypothetical choice scenarios. It allows the analyst to identify the independent impact of the characteristics that define each alternative and investigate the respondent's trade-offs during the SP experiment [21]. The RP and SP data combination comprehensively analyzed the multifaceted elements shaping domestic airline preferences at MDE in Medellin. The survey was conducted with 509 individuals, including 173 men and 336 women, in the boarding areas of domestic flights at MDE. This survey focused on people traveling from Medellin and its Metropolitan Area to the Atlantic coast of the country, specifically to the cities of Barranquilla, Cartagena, Montería, and Santa Marta. In this way, 326 surveys were answered by residents of Medellín and its Metropolitan Area, followed by the coastal cities of Barranquilla (51), Cartagena (31), and Santa Marta (22), while the rest of the respondents indicated varied places of residence. Most respondents were in the age range of 18 to 30 years (261), followed by individuals between 31 and 40 years old (160), then between 41 and 50 years old (61), between 51 and 60 years old (19), and those over 61 years old (8). Most respondents (459) reported having traveled by plane before. The monthly income level for most individuals (284) was between approximately USD 250 and USD 1,100, while 169 stated that they belonged to some frequent flyer program. A summary of the socioeconomic variables can be seen in Table 1.

Table 1- Demographic variables
Source: Authors

Variable	Value	Count
Gender		
	Male	173
	Female	336
	Total	509
Age		
	1. 18-30 years	261
	2. 31-40 years	160
	3. 41-50 years	61
	4. 51-60 years	19
	5. > 61 years	8
	Total	509
Income		
	1. $0 - $100.000	63
	2. $100.000 - $820.857 (1 SMMLV)	51
	3. $820.857- $2.000.000	155
	4. $2.000.001 - $3.500.000	129
	5. $3.500.001 - $5.000.000	67
	6. $5.000.001 - $6.500.000	23
	7. more than $6.500.000	21
	Total	509
FFPs Member		
	Yes	169
	No	340
	Total	509

Individuals belonging to an FFP are asked which airline program they belong to, so the results indicated that AVIANCA has the most popular FFP, with 107 frequent fliers who will fly by the airline, as shown in Figure 1.

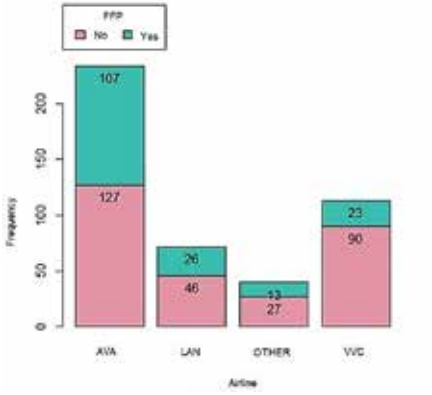

Figure 1 – Airline vs. FFP
Source: Authors

Of the 509 surveys conducted, 50 were set aside for subsequent model validation, leaving 459 surveys. An outlier data cleansing procedure was performed for this remaining sample using the Mahalanobis distance, a statistical measure that quantifies the distance between a point and a set of points, considering the covariance between variables [22]. In this case, the following five variables in the sample were calculated: approximate ticket cost, advance purchase time, desired arrival time, desired departure time, and the number of flights taken in the last year. The results indicated 22 data identified as outliers at a significance level of 0.95 based on Mahalanobis distance. These were separated and not considered for the calibration of the MNL, resulting in a final sample of 437 individuals.

3.2 Multinomial Logit Models

The discrete choice models are based on the Random Utility Theory. Mc. Fadden [23] specifies that individuals assign a utility to each alternative and, using the utility maximization behavioral rule, pick the one with the highest utility; and the consumer theory, also known as the Characteristics Model [24], establishes that products and services can be described using a set of characteristics. The utility for the alternative i for any individual is defined by q. (1). It considers the alternative systematic utility V_{iq} represented by a vector of attributes and the random error term ε_{iq} related to the unobserved attributes.

$$U_{iq} = V_{iq} + \varepsilon_{iq} \qquad (1)$$

When the ε_{iq} are independent and identically distributed (IID) extreme values can be developed in a Multinomial Logit Model (MNL). The probability P_{iq} of an individual q choice the alternative i among a set of alternatives j Eq. (2). The general scale factor of the model is represented by λ .

$$P_{iq} = \frac{e^{\lambda V_{iq}}}{\sum_{j=1}^{J} e^{V_{iq}}} \qquad (2)$$

These models allow for analyzing the determinants of airline choice behavior by considering various independent variables related to airline attributes, socio-economic aspects, and travel characteristics.

The complete dataset was used for the first phase approach to MNL model estimation in the BIOGEME open-source Python package [25]. The focus was on understanding the behavioral patterns associated with service-dependent characteristics of each of the three airline alternatives, AVA, VVC, and LAN, encompassing variables such as the approximate ticket cost, the variance between actual and desired arrival times, the difference between actual and desired departure times, and flight frequency. Additionally, the study considered variables indicative of individual characteristics and behaviors, including purchase lead time, travel purpose, employment type, ticket payment method, ticket payer, previous flights with each airline, and prior travel experiences.

A critical aspect of the analysis involved incorporating dummy variables to account for whether the user has a membership to any FFPs, specifically those affiliated with FFP LifeMiles and FFP LATAM Pass. This addition aimed to discern the impact of FFP membership on airline choice behavior.

In addition, to further understand the influence of FFP on airline choice behavior, the dataset was segmented into two distinct parts. The first segment comprised users affiliated with any FFP, while the second consisted of users without FFP membership. This segmentation allowed for a focused exploration of how FFP participation shapes decision-making in the airline selection process. The same set of independent variables, encompassing airline attributes, socio-economic aspects, and travel characteristics, was applied to both segments.

This strategic segmentation facilitated a comparative analysis, enabling a targeted examination of the impact of FFPs on distinct user groups. By utilizing consistent variables related to airline attributes, socio-economic aspects of users, and travel characteristics, the methodology aimed to isolate and evaluate the specific contribution of FFP membership to the overall choice behavior of domestic flight passengers. Table 2 shows a summary with descriptions of the significant variables found in the calibration of the utility functions for the MNL.

Table 2. Variable description
Source: Authors

Variable	Description
ANTCOMPRA	Advance time for ticket purchase in days
COSTINC	The ratio between the cost of the ticket and the individual's income range
DIFA	Difference in hours with the desired time of arrival to the coast
DIFD	Difference in hours with the desired departure time from the coast towards Medellín
VF	Dummy variable, 1 if it belongs to any FFP
VFAVA	Dummy variable, 1 if it belongs to the AVIANCA FFP
VFLAN	Dummy variable, 1 if it belongs to the LATAM FFP
ULTAVA	Dummy variable, 1 if the last flight was made on AVIANCA
VENAVA	Number of flights made in AVIANCA during the last year
VENLAN	Number of flights made in LATAM during the last year
VENVVC	Number of flights made in VIVA COLOMBIA during the last year
PMILES	Dummy variable, 1 if payment was made using frequent flyer program miles
WHOPAY	Dummy variable, 1 if the individual paid for their ticket
EMPLOY	Dummy variable, 1 if employed

4. Results

An extensive set of over 80 Multinomial Logit (MNL) models was run for the complete dataset, specifically designed to assess the impact of belonging to FFPs.

The specific variables associated with each FFP wield greater significance in influencing airline choice than the general membership status. The users enrolled in LAN FFP exhibit a higher degree of fidelity to the airline. This heightened loyalty is evidenced by the substantial coefficient accompanying the LAN FFP variable, overshadowing the importance of the coefficient associated with the AVA FFP. The discernible difference in coefficients emphasizes the unique pull of the LAN FFP, indicating that passengers are more strongly tethered to LATAM due to the specific benefits and incentives offered by this loyalty initiative. We also applied the likelihood ratio test [26] to compare the two models. The likelihood ratio test is expressed as:

$$LR = -2[LL(\beta restricted) - LL(\beta unrestricted)] \sim \chi 2\, Number\ of\ restrictions$$

The likelihood ratio test suggested that MNL1 had superior goodness of fit to that of the MNL2 model, meaning that MNL2 has the best fit and is thus the preferred model (i.e.,53.238> χ2 0.05(1) = 3.84). This indicated that the specific FFPs were included in the model, which better-estimated airline choice behavior.

For the subset of data exclusively comprising members of FFP, MNL models were run with multiple alternatives. The selection process involved choosing the most statistically significant and conceptually valid model, with the selected model presented in Table 3.

Table 3. MNL for a FFPs member.Source: Authors

Variable	Alternative	Coefficient	|t-value|
ASC_LAN	LAN	-1.6478	5.26
ASC_VVC	VVC	-2.0366	8.14
COSTINC	AVA, LAN, VVC	-0.0198	8.09
DIFA	AVA, LAN, VVC	-0.1023	3.59
DIFD	AVA, LAN, VVC	-0.1282	4.20
ANTCOMPRA	AVA	-0.0200	4.90
EMPLOY	AVA, VVC	-0.5819	2.34
PMILES	AVA, LAN	1.0839	2.85
ULTAVA	AVA	0.6837	4.20
VENLAN	LAN	0.1127	2.81
VFLAN	LAN	0.8693	4.40
WHOPAY	LAN	-0.4052	2.35
VENVVC	VVC	0.2655	5.75

The model shows that the payment method using miles emerges as the most pivotal variable influencing airline choice among FFP members. The membership in LAN FFP is closely followed in significance. However, for FFP members, the cost relative to income and the lead time for purchase prove to be the most significant variables.

For the dataset excluding members of Frequent Flyer Programs (FFP), Multinomial Logit (MNL) models were executed, incorporating numerous alternatives. The selection process involved choosing the most statistically significant and conceptually valid model, with the selected model presented in Table 4.

Table 4. MNL for NO FFPs members.
Source: Authors

Variable	Alternative	Coefficient	|t-value|
ASC_LAN	LAN	-1.6478	5.26
ASC_VVC	VVC	-2.0366	8.14
COSTINC	AVA, LAN, VVC	-0.0198	8.09
DIFA	AVA, LAN, VVC	-0.1023	3.59
DIFD	AVA, LAN, VVC	-0.1282	4.20
EMPLOY	AVA, LAN	-0.0200	4.90
ULTAVA	AVA	-0.5819	2.34
VENAVA	AVA	1.0839	2.85
VENLAN	LAN	0.1912	5.19
VENVVC	VVC	0.1061	3.61

The model shows that the most crucial variable influencing airline choice for non-members of any FFP is the number of flights taken on Avianca in the last year. However, the significance and importance of the coefficients associated with each alternative suggest that yet-to-be-discovered factors are at play.

5. Conclusions

This study provides valuable insights into the factors influencing airline choice behavior in the Medellin domestic flight market. The significant impact of FFPs on choice behavior underscores the importance of loyalty programs in the aviation industry. Understanding these dynamics is crucial for airlines to make marketing strategies effective and enhance customer satisfaction to increase the travel air demand in each airline. The comprehensive approach, integrating RP and SP data and employing MNL models, contributes to a nuanced understanding of the complex decision-making processes in airline choice behavior.

The found models help explain the behavior of FFP's members in contrast with no FFP's members; variables such as the advance time for a ticket purchase, who paid for the ticket, and if the ticket was paid using FFP miles are relevant for FFP members. At the same time, there was no found significance for these in the MNLs for no FFP's members. The estimated parameters illustrate some situations, such as the tendency of FFP's members to use low-cost airlines VVC if they have had flies with them in the last year.

Regarding the model for the general data, it can be said that some significant variables necessary for the FFP's members may not be substantial for the rest of the individuals, so it's essential to develop a new understanding of the behavior of some populational groups as the FFP's members, as it expected, belonging to an FFP increase the utility function for the alternative. However, other additional variables decrease the utility function for some alternatives.

The model was restricted to policy, time-cost, and socioeconomic variables. However, it could be essential to include other types of variables in the analysis, such as latent variables, as it is considered feasible that individuals' choices are influenced by factors like comfort, safety, and service quality, among others. Including these latent variables can generate more explanatory models of the behavior of both FFP members and non-members.

The study underscores the importance of understanding the influence of FFPs on airline choice, particularly in domestic flies at Medellin's airport MDE. Future research should delve deeper into the behavior of specific population groups, considering both FFP members and non-members. Further investigation into the factors influencing choice, especially in the absence of FFP membership, can provide

a comprehensive understanding of passenger preferences and inform more effective airline marketing strategies.

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Ciência de dados aplicada à análise de impactos econômicos regionais dos aeroportos brasileiros

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Abstract/Resumo/Resumen

A Organização da Aviação Civil Internacional (ICAO) recomenda a análise de insumo-produto (MIP) para estimar os impactos econômicos das atividades de aviação civil (ICAO, 2005). Este artigo adiciona técnicas de ciência de dados à metodologia matriz insumo-produto, estimada com base em Guilhoto (2005) para melhorar a assertividade da avaliação dos impactos econômicos gerados pelos investimentos nos setores de aviação civil. Assim, para cada setor presente na MIP brasileira, é necessário obter uma medida que indique a proporção da produção nacional desse setor em cada das Unidades Territoriais Padrão (UTPs) definidas pelas autoridades brasileiras como a unidade para planejamento do setor de transporte aéreo. Brene (2013) sugere que o valor do trabalho fornece bons resultados como estimador de regionalização. Nessa linha, foi desenvolvido um algoritmo de calibração de quocientes locacionais calculados por estatísticas nacionais de trabalho (RAIS e PNAD) de tal modo que dados referentes a empregos e salários permitam a estimativa de matrizes insumo-produtos regionalizadas de acordo com as Unidades Territoriais Padrão. Tal modelagem preenche uma lacuna significativa na análise do impacto econômico dos investimentos em aviação civil no contexto brasileiro e permite gerar informações inéditas e relevantes. A expectativa é que esses avanços beneficiem profissionais, pesquisadores e tomadores de decisão no setor aeroportuário, proporcionando uma visão mais abrangente e precisa de seus impactos econômicos

Ciência de dados aplicada à análise de impactos econômicos regionais dos aeroportos brasileiros

1. Introdução

A Organização da Aviação Civil Internacional (ICAO) recomenda a análise de insumo-produto (MIP) para estimar os impactos econômicos das atividades de aviação civil [1]. Este artigo aplica técnicas de engenharia e ciência de dados para a preparação de matrizes insumo-produto regionalizadas para ampliar a granularidade da avaliação dos impactos econômicos da aviação civil. É apresentado um procedimento de calibração e otimização de quocientes locacionais calculados a partir de estatísticas nacionais de trabalho e renda.

2. A matriz de insumo-produto e a análise de impactos econômicos

Uma matriz insumo-produto é uma representação quantitativa da interdependência entre setores econômicos em uma determinada economia. Denotada como **A**, ela é uma matriz quadrada de dimensão ***n x n***, onde ***n*** representa o número de setores. Cada elemento a_{ij} da matriz indica a quantidade de insumo do setor ***i*** necessária para produzir uma unidade de produção do setor ***j*** (Equação 1). Assim, a representação algébrica da matriz insumo-produto em termos de seus coeficientes técnicos diretos é:

$$A = \begin{bmatrix} a_{11} & a_{12} & \cdots & a_{1n} \\ a_{21} & a_{22} & \cdots & a_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ a_{n1} & a_{n2} & \cdots & a_{nn} \end{bmatrix}$$

Equação 1

A partir da matriz **A**, é possível calcular os efeitos diretos e indiretos de mudanças em variáveis do lado da demanda como investimento, consumo e exportações sobre a produção, emprego, renda e outras variáveis econômicas que funcionam como insumos das atividades econômicas. Tais efeitos são calculados por meio de multiplicadores que revelam como uma unidade adicional de demanda em um setor reverbera por toda a economia, considerando as relações de compra e venda estabelecidas entre os diversos setores produtivos [2]. A soma dos efeitos diretos e indiretos é dada pela equação algébrica (Equação 2), em que o vetor ***Y*** representa o choque de demanda, isto é, a quantidade de demanda adicional considerada na análise e ***X*** representa o incremento adicional na produção de todos setores em função do choque. ***I*** é a matriz identidade e a matriz $(I-A)^{-1}$ é a matriz de multiplicadores.

$$X = (I - A)^{-1}.Y$$

Equação 2

No Brasil, matrizes de insumo produto que discriminam as atividades econômicas em 68 setores podem ser construídas à partir das Tabelas de Recursos e Usos (TRUs) publicadas todo ano (com dois anos de atraso) pelo IBGE como parte do Sistema de Contas Nacionais [3][4][5]. Na matriz insumo-produto brasileira, dois setores são especialmente relevantes para a análise de impactos econômicos envolvendo aeroportos: *Transporte aéreo* (atividade 5100) e *Armazenamento, atividades auxiliares dos transportes e correio* (atividade 5280). A análise de impacto econômico envolve estimar o faturamento adicional nesses setores devido a, por exemplo, um aumento na demanda de passageiros, para então aplicar os multiplicadores que fornecerão a estimativa do efeito econômico indireto em todos os demais setores e insumos que participam de sua cadeia de suprimentos. Assim, a cada R$ 1,00 adicional no total faturado pelas empresas de transporte aéreo no país, os multiplicadores de impacto da matriz de insumo-produto de 2021 mostram quais os setores à montante do transporte aéreo são também impactados. A Tabela 1 mostra que a cada R$ 1,00 a mais faturado pelo setor *Transporte aéreo*, R$ 0,27 a mais será faturado pelo setor *Refino de petróleo e coquerias,* e assim por diante. O

mesmo raciocínio vale para a atividade aeroportuária, para a qual valem os multiplicadores do setor *Armazenamento, atividades auxiliares dos transportes e correio* (Tabela 2).

Tabela 1: Multiplicadores para o setor Transporte Aéreo, 2021, no Brasil, dez maiores impactos.Fonte: autores.

Multiplicador	Atividade econômica
1,0019	Transporte aéreo
0,2709	Refino de petróleo e coquerias
0,1787	Armazenamento, atividades auxiliares dos transportes e correio
0,0637	Extração de petróleo e gás, inclusive as atividades de apoio
0,0588	Comércio por atacado e a varejo, exceto veículos automotores
0,0478	Intermediação financeira, seguros e previdência complementar
0,0459	Outras atividades administrativas e serviços complementares
0,0428	Aluguéis não-imobiliários e gestão de ativos de propriedade intelectual
0,0396	Transporte terrestre
0,0342	Desenvolvimento de sistemas e outros serviços de informação

Tabela 2: Multiplicadores para o setor Armazenamento, atividades auxiliares dos transportes e correio, 2021, no Brasil, dez maiores impactos Fonte: autores.

Multiplicador	Atividade econômica
1,0489	Armazenamento, atividades auxiliares dos transportes e correio
0,0681	Transporte terrestre
0,0515	Refino de petróleo e coquerias
0,0358	Outras atividades administrativas e serviços complementares
0,0343	Serviços de arquitetura, engenharia, testes/análises técnicas e P & D
0,0336	Intermediação financeira, seguros e previdência complementar
0,0320	Atividades jurídicas, contábeis, consultoria e sedes de empresas
0,0289	Comércio por atacado e a varejo, exceto veículos automotores
0,0260	Manutenção, reparação e instalação de máquinas e equipamentos
0,0258	Atividades imobiliárias

3. Matrizes de insumo-produtos regionalizadas

O governo brasileiro emprega uma subdivisão territorial denominada Unidade Territorial de Planejamento (UTP). Este conceito foi desenvolvido pelo Departamento de Planejamento e Gestão do Espaço Aéreo (DECEA), órgão subordinado à Força Aérea Brasileira (FAB), com o objetivo de organizar e gerenciar a expansão e modernização da infraestrutura aeroportuária do país de maneira mais eficiente e integrada. As UTPs são áreas geográficas delimitadas que abrangem um conjunto de aeroportos e aeródromos próximos entre si, bem como as respectivas áreas de influência e demanda. Elas são definidas levando em consideração critérios como a conectividade entre os aeroportos, a demanda de tráfego aéreo, a infraestrutura de transporte terrestre e as características geográficas e socioeconômicas da região.[1] Para estimar os impactos econômicos focalizados em UTPs, emprega-se uma extensão do modelo de insumo-produto denominada Modelo de Isard para duas regiões [6], decompondo a matriz insumo-produto brasileira em quatro novas matrizes (Equação 3):

I. uma matriz intrarregional ***Axx*** para a região delimitada pela UTP de interesse;
II. uma matriz intrarregional ***Ayy*** para todo o restante do país;
III. uma matriz inter-regional ***Axy*** que denota o fluxo comercial da UTP para o restante de país; e
IV. uma matriz inter-regional ***Ayx*** que denota o fluxo comercial do restante do país para a UTP.

[1] https://dados.gov.br/dados/conjuntos-dados/agrupamentos-municipais-planejamento-aeroviario

$$A = \begin{bmatrix} A_{xx} & A_{xy} \\ A_{yx} & A_{yy} \end{bmatrix}$$

Equação 3

Nesta nova matriz A, com dimensões 136x136 e capaz de representar a articulação entre as atividades econômicas localizadas dentro e fora dos limites de UTP, a soma vertical dos coeficientes técnicos, por construção, deve ser igual à matriz original para o país. A construção das matrizes insumo-produtos regionalizadas para UTP e ex-UTP depende de informações que permitam calcular as matrizes ***Axx*** e ***Ayy*** para cada uma das UTPs. As matrizes ***Axy*** e ***Ayx*** decorrem das primeiras. Para estimar as matrizes intrarregionais, lança-se mão dos quocientes locacionais, descritores derivados da Geografia Econômica que visam avaliar a concentração ou dispersão relativa de uma atividade econômica em diferentes áreas geográficas [7]. Sua formulação matemática (Equação 4) envolve a comparação da participação de uma determinada atividade em uma região específica com a sua participação no total nacional [2][8]. Se o QL é igual a 1 significa que a concentração regional da atividade econômica ***i*** é igual à concentração dessa mesma atividade na escala nacional. Se for maior que 1, a região apresenta concentração dessa atividade econômica e se for menor 1, a atividade está sub representada na região.

$$QL_i^r = \frac{x_i^r}{x^r} / \frac{x_i^n}{x^n} = \frac{x_i^r}{x_i^n} / \frac{x^r}{x^n}$$

Equação 4

Com os quocientes locacionais para uma UTP, regionalizar os coeficientes da Matriz A para esta UTP significa descontar proporcionalmente os coeficientes técnicos quando o quociente locacional for menor que 1 e manter o mesmo coeficiente da produção nacional quando o quociente locacional for igual ou maior que 1 (Equação 5). Nos casos de sub-representação, assume-se que os insumos necessários para os demais setores são importados do restante do país, e nos casos de concentração que a produção excedente do setor será exportada para o restante do país.

$$a_{ij}^r = \begin{Bmatrix} LQ_i^r . a_{ij}^n & se LQ_i^r < 1 \\ a_{ij}^n & se LQ_i^r \geqslant 1 \end{Bmatrix}$$

Equação 5

A partir da matriz A de Isard obtém-se os multiplicadores para o conjunto UTP e ex-UTP. Com as informações reunidas para o cálculo do quociente locacional é também possivel estimar os demais itens de insumos e valor adicionado comumente associados à matriz insumo-produto, bem como as colunas que reúnem os dados de consumo final, completando assim todas os campos necessários para a caracterização econômica das UTPs.

4. Quocientes locacionais a partir de estatísticas oficiais

4.1. Relação Anual de Informações Sociais (RAIS)

A Relação Anual de Informações Sociais (RAIS) é um registro administrativo mantido pelo Ministério do Trabalho do Brasil. Seu principal objetivo é coletar informações sobre o mercado de trabalho formal no país. A RAIS é obrigatória para todas as pessoas jurídicas que possuem empregados. Os dados coletados pela RAIS incluem uma ampla variedade de informações sobre empregadores e trabalhadores, tais como: número de empregados, remuneração, natureza do vínculo empregatício, atividade econômica da empresa, localização geográfica, entre outros, e seus microdados são disponibilizados em tabelas indexadas por estabelecimentos e por vínculo trabalhista, atingindo facilmente a ordem de milhões de registros por tabela [9]. As principais limitações associadas à RAIS para a estimativa de quocientes locacionais são: a) sub-registros e subdeclaração; b) erros de classificação e codificação; c) ausência de informações sobre trabalhadores informais e autônomos: e d) efeito tamanho da empresa [10].

4.2. Pesquisa Nacional por Amostra de Domicílios Contínua (PNAD Contínua)

A Pesquisa Nacional por Amostra de Domicílios Contínua (PNAD Contínua) é uma pesquisa domiciliar realizada pelo Instituto Brasileiro de Geografia e Estatística (IBGE). Seu objetivo principal é fornecer informações

detalhadas sobre diversos aspectos da população brasileira, incluindo características socioeconômicas, mercado de trabalho, educação, saúde, habitação, rendimento domiciliar, entre outros [11]. Os microdados da PNAD Contínua consistem em informações individuais coletadas de cada domicílio entrevistado durante a pesquisa. Esses dados são anonimizados e disponibilizados para estudos sobre uma ampla gama de questões sociais e econômicas. Para estimar quocientes locacionais a principal informação de interesse consiste nos rendimentos do trabalho que na PNAD inclui também o trabalho informal. Assim como no caso dos dados da RAIS, os dados da PNAD Contínua também estão sujeitos a limitações [12]. As principais limitações conhecidas são: a) amostragem e representatividade; b) autodeclaração e erros de resposta; c) sub-registros e omissões; d) agregação de dados; e) padrões de resposta e vieses.

5. Regionalização a partir de microdados RAIS e PNAD

5.1. Obtenção de quocientes locacionais via RAIS

1. baixar localmente arquivos de microdados para o ano de 2021;[2]
2. extrair os dados dos campos de interesse: "Município", "CNAE 2.0 Classe" e "Vl Remun Dezembro Nom";[3]
3. consolidar os subtotais dos salários pagos por CNAE e por município;
4. agregar os totais municipais em UTPs;
5. para cada UTP, agregar as 673 classes CNAE nas 68 atividades da matriz insumo-produto;
6. obter os vetores com os totais de salários pagos por UTP;
7. obter os totais nacionais, por atividades econômicas e o total geral;
8. para cada atividade ***i***, aplicar a Equação 5;
9. obter as matrizes insumo-produtos regionalizadas (seção 3).

5.2. Obtenção de quocientes locacionais via PNAD Contínua

1. baixar localmente os resultados da PNAD Contínua para o 4º semestre do ano de 2021;[4]
2. processar o arquivo para estabelecer os campos da tabela de dados (*parser*);
3. mapear e agregar dados classificados por CNAE (variável V4013 da PNADc) em 68 atividades econômicas;
4. consolidar os dados dos estratos amostrais, somando a variável VD419 (rendimento de qualquer trabalho);
5. expandir os dados para todos os municípios brasileiros na proporção de suas populações;
6. agregar os totais municipais obtidos para UTPs;
7. obter os vetores com os totais de salários pagos por UTP;
8. obter os totais nacionais, por atividades econômicas e o total geral;
9. para cada atividade ***i***, aplicar a Equação 5;
10. obter as matrizes insumo-produtos regionalizadas (seção 3).

5.3. Obtenção de valores de referência para UTPs

A partir de dados publicados pelo IBGE para o PIB Municipal 2021, agregando-os por UTP, foi possível obter valores de referência para quatro variáveis: a) valor adicionado bruto total; b) valor adicionado bruto da agropecuária; c) valor adicionado bruto da indústria; e d) valor adicionado bruto dos serviços e administração pública

[2] disponíveis em ftp://ftp.mtps.gov.br/pdet/microdados/RAIS/
[3] A construção de quocientes locacionais a partir do valor do trabalho têm mostrado os resultados mais consistentes [8].
[4] Disponível em ftp.ibge.gov.br/Trabalho_e_Rendimento/Pesquisa_Nacional_por_Amostra_de_Domicilios_continua/Trimestral/Microdados/

5.4. Qualidade das estimativas com RAIS e PNAD

A partir da matriz insumo-produto estimada para cada UTP é possível chegar a aos mesmos valores de referência calculados via PIB Municipal, consolidando as informações de valor agregado dos 68 setores representados na matriz para os três grandes setores de agricultura (3 atividades), indústria (37 atividades) e serviços e administração pública (28 atividades). Em seguida, para cada medida de valor de referência, o resultado obtido via matriz de insumo-produto de cada UTP é dividido pelo valor de referência obtido das estatísticas oficiais (PIB Municípios). Desse modo, quando ocorre um ajuste perfeito, o índice de qualidade é igual a 1. Quando o ajuste é menor que 1, significa que o quociente locacional subestimou a realidade e quando o valor for maior que 1 significa que ele a sobre estimou. Além da proximidade do índice a 1 é relevante examinar a extensão total da distribuição das estimativas e o seu desvio padrão. As Tabelas 3 e 4 e a Figura 1 mostram os desempenhos das abordagens via quociente locacionais RAIS e PNAD para regionalização das UTPs. Observa-se que RAIS tem um melhor desempenho para as atividades industriais e PNAD para serviços. Já nas atividades de agricultura ambas apresentam dificuldades, conforme indicam os altos desvios padrões obtidos.

Tabela 3: Estatística descritiva do ajuste da regionalização com quocientes locacionais obtidos via RAIS frente aos valores de referência para as UTPs. Fonte: autores.

QL RAIS	total	agricultura	indústria	serviços
contagem	771	771	771	771
média	0,6555	1,0448	0,7971	0,5501
desvio padrão	0,3430	1,2107	0,7136	0,2549
min	0,0592	0,0002	0,0055	0,0289
25%	0,4068	0,2785	0,4248	0,3681
50%	0,6267	0,7141	0,7280	0,5097
75%	0,8519	1,3570	1,0373	0,6739
max	3,8536	10,7881	12,0361	1,7270

Tabela 4: Estatística descritiva do ajuste da regionalização com quocientes locacionais obtidos via PNAD Contínua frente aos valores de referência para as UTPs. Fonte: autores.

QL PNAD	total	agricultura	indústria	serviços
contagem	771	771	771	771
média	1,0617	1,6607	2,8676	1,0006
desvio padrão	0,4372	1,7716	4,3953	0,3420
min	0,0257	0,0229	0,0104	0,1035
25%	0,8184	0,6517	0,8505	0,7950
50%	1,0128	1,1658	1,5904	0,9621
75%	1,2758	2,0250	3,0803	1,1630
max	4,4397	20,2787	40,8502	3,6336

Uma importante propriedade dos quocientes locacionais é a sua independência setorial, de modo que os quocientes locacionais para cada setor ***i*** podem ser obtidos a partir de diferentes fontes de dados. A Equação 4 mostra duas formulações equivalentes para o cálculo dos quocientes locacionais. Na segunda delas, fica explícito que as taxas x_i^r/x_i^n de todas as regiões ***r*** somarão 1 e que diferentes fontes de dados levarão a distribuições distintas do total x_i^n entre as regiões. São essas variações que levam a diferentes estimativas de valor adicionado, o que leva a melhores ou piores ajustes frente aos valores de referência. E, desde que a soma para cada ***i*** seja 1, as variações em um mesmo setor não alteram os resultados para os demais.

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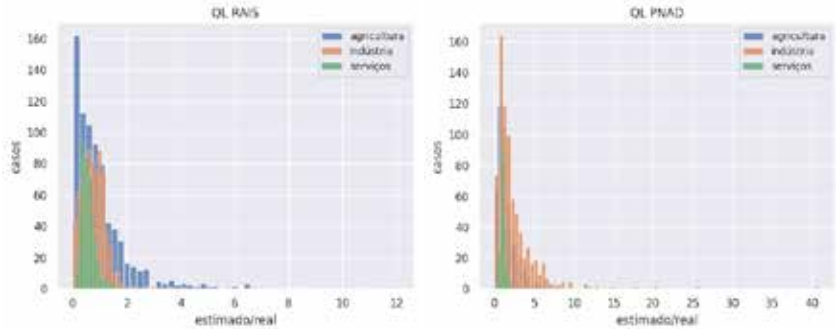

Figura 1: Histogramas da qualidade do ajuste da regionalização com quocientes locacionais obtidos via RAIS e PNAD Contínua frente aos valores de referência para as UTPs. Fonte: autores.

A propriedade de independência permite que diferentes combinações entre as fontes de dados sejam testadas. Dada a impossibilidade de se testar todas as combinações, que mesmo com duas fontes de dados já seria enorme (2^{68} combinações diferentes), foi aplicada a seguinte sequência de regras:

I. para indústria, parte-se da estimativa feita com QL RAIS e testa-se a substituição setor a setor com quocientes calculados com QL PNAD para todas as UTPs;
II. para serviços, parte-se da estimativa feita com QL PNAD e testa-se a substituição setor a setor com quocientes calculados com QL RAIS para todas as UTP;
III. para agricultura, testa-se todas as combinações, dado que são apenas 3 atividades e, portanto, apenas 2^3 combinações possíveis;
IV. se a média do ajuste se aproximar de 1 e o desvio padrão for menor, aceita-se a substituição.

6. Resultados

Os testes de permutação entre QL RAIS e QL PNAD levaram à seguinte regra de construção para o ano de 2021:

A. *Agricultura:* a melhor combinação é estimar os setores 0191 e 0280 com QL RAIS e 0192 com PL PNAD;[5]
B. *Indústria*: 34 atividades são estimadas com QL RAIS e 3 com QL PNAD (as atividades em que QL PNAD melhora o resultado são 1200, 1400 e 3300);[6]
C. *Serviços*: 26 atividades são estimadas com QL PNAD e 2 com QL RAIS (as atividades em que QL RAIS melhora o resultado são 5100, 5980);[7]

Os resultados obtidos (Tabela 5) mostram que a combinação otimizada entre RAIS e PNAD é capaz de melhorar a acurácia e a precisão da regionalização. Embora ainda imperfeita, a distribuição da qualidade dos ajustes alcançados é comparativamente superior, conforme mostra a Figura 2.

Tabela 5: Estatística descritiva do ajuste da regionalização com permutação otimizada de quocientes locacionais obtidos via RAIS e PNAD. Fonte: autores

QL MIX	total	agricultura	indústria	serviços
contagem	771	771	771	771

[5] 0191 Agricultura, inclusive o apoio à agricultura e a pós-colheita, 0192 Pecuária, inclusive o apoio à pecuária, 0280 Produção florestal; pesca e aquicultura.
[6] 1200 Fabricação de produtos do fumo, 1400 Confecção de artefatos do vestuário e acessórios 3300 Manutenção, reparação e instalação de máquinas e equipamentos.
[7] 5100: Transporte aéreo; 5980 Atividades de televisão, rádio, cinema e gravação/edição de som e imagem.

média	0,9254	1,0439	0,8469	1,0000
desvio padrão	0,3291	1,1722	0,7076	0,3415
min	0,0824	0,0173	0,0005	0,1037
25%	0,7134	0,3809	0,4846	0,7956
50%	0,9071	0,6839	0,7812	0,9614
75%	1,0806	1,2693	1,0660	1,1622
max	3,5139	10,9960	11,6825	3,6336

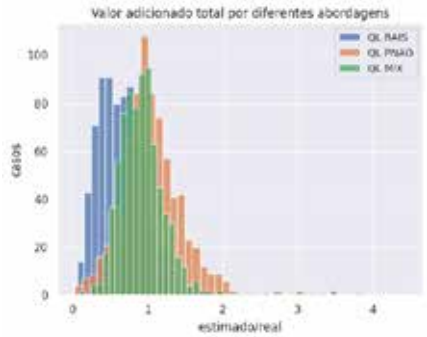

Figura 2: Comparação entre QL RAIS, QL PNAD e QL MIX quanto ao ajuste frente ao valor adicionado total. Fonte: autores.

Finalmente, a distribuição QL MIX otimizada foi comparada com as duas distribuições originais, RAIS e PNAD, por meio de teste t-Student bi-caudal, obtendo-se a confirmação de que todas são estatisticamente diferentes entre si em nível de significância $p < 0.01$ (Tabela 6).

Tabela 6: Teste t-Student para atestar as diferença entre as abordagens propostas de construção de quocientes locacionais. Fonte: autores.

Teste t-Student	t	p	graus de liberdade
RAIS x PNAD	-20,2954	2,41E-81	1540
RAIS x MIX	-15,7694	4,75E-52	1540
PNAD x MIX	6,9129	6,93E-12	1540

6.1. Aplicação na avaliação de impactos econômicos em UTPs

Com a tabela otimizada de quocientes locacionais (QL MIX) foi possível obter os multiplicadores regionalizados para uma análise focalizada em uma determinada UTP. Como exemplo de aplicação à avaliação de impactos econômicos, as Tabelas 7 e 8 trazem os multiplicadores obtidos para a UTP de São José dos Campos (SP), UTP que conta com um aeroporto (SBSJ) com capacidade de 2.700.000 passageiros/ano. São resultados coerentes com a realidade. A UTP de São José dos Campos, embora sede da fabricante de aviões Embraer, não possui empresas de transporte aéreo e, portanto, os impactos nesse setor serão ínfimos. A matriz insumo-produto captura apenas efeitos indiretos de pequena monta. Já no caso dos aeroportos e outras atividades de transportes, cada R$ 1,00 a mais de faturamento significa efeitos multiplicadores similares aos nacionais, com algumas diferenças compatíveis com o perfil regional.

Tabela 7: Multiplicadores para o setor Transporte Aéreo em São José dos Campos (SP), dez maiores impactos. Fonte: autores.

Multiplicador	Atividade econômica
1,0000	Transporte aéreo
0,0171	Refino de petróleo e coquerias

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0,0097	Armazenamento, atividades auxiliares dos transportes e correio
0,0029	Comércio por atacado e a varejo, exceto veículos automotores
0,0023	Intermediação financeira, seguros e previdência complementar
0,0023	Aluguéis não-imobiliários e gestão de ativos de propriedade intelectual
0,0018	Desenvolvimento de sistemas e outros serviços de informação
0,0017	Transporte terrestre
0,0015	Outras atividades administrativas e serviços complementares
0,0014	Fabricação de produtos de borracha e de material plástico

Tabela 8: Multiplicadores para o setor Armazenamento, atividades auxiliares dos transportes e correio em São José dos Campos, dez maiores impactos. Fonte: autores.

Multiplicador	Atividade econômica
1,0496	Armazenamento, atividades auxiliares dos transportes e correio
0,0582	Transporte terrestre
0,0530	Refino de petróleo e coquerias
0,0298	Intermediação financeira, seguros e previdência complementar
0,0295	Serviços de arquitetura, engenharia, testes/análises técnicas e P & D
0,0265	Manutenção, reparação e instalação de máquinas e equipamentos
0,0240	Atividades de vigilância, segurança e investigação
0,0236	Comércio por atacado e a varejo, exceto veículos automotores
0,0215	Outras atividades administrativas e serviços complementares
0,0211	Atividades imobiliárias

O ajuste via QL MIX em São José dos Campos mostrou os seguintes parâmetros de qualidade: agricultura 6.92, indústria 0,77, serviços: 0.99, total: 0,91. Apesar do erro elevado em agricultura, este é um setor que representa apenas 0,28% da economia da UTP, com indústria respondendo por 41,62% e serviços por 58,1%. Além disso, como os setores avaliados guardam pouca relação com atividades da agricultura, a distorção ocorrida nesse caso tem pouca influência na análise de impactos e pode ser tolerada com segurança.

7. Discussão

O uso da matriz insumo-produto nacional para a avaliação de impacto das atividades da aviação civil, consistente com a recomendação da ICAO [1], pode levar a resultados demasiado imprecisos quando se analisa casos específicos em para países grandes e de alta diversidade regional como o Brasil. Em contrapartida, a obtenção de matrizes de insumo-produto adaptadas para regiões específicas do país envolve desafios consideráveis quanto a disponibilidade de dados que permitam estimar tais matrizes sem incorrer em erros grosseiros.

Neste artigo, foram testadas duas importantes fontes públicas de dados, RAIS e PNAD, cuja desagregação viabiliza a regionalização da matriz nacional para a mesma granularidade adotada pelos órgãos planejadores da aviação civil brasileira e responsáveis por sua regulação e investimentos estratégicos. Para realizar esses testes, foi desenvolvida uma metodologia de aferição da qualidade de 771 matrizes regionalizadas para Unidades Territoriais de Planejamento (UTPs), comparando-os a referências estabelecidas por uma terceira fonte pública de dados (PIB dos Municípios), independente das duas primeiras.

A partir dos resultados de cada fonte avaliada foi possível chegar a uma combinação capaz de oferecer precisão e acurácia significativamente superiores à qualquer uma delas em separado. A combinação foi capaz de amenizar pontos fracos de cada uma das fontes de dados de modo consistente com as observações e expectativas já registradas na literatura. Ainda que a precisão não seja ideal nos casos limítrofes da distribuição, sempre é possível ao analista conhecer de antemão a acurácia e a precisão com que se está trabalhando em

cada matriz regional específica, como ficou claro para o caso de São José dos Campos, e avaliar até que ponto a adoção daquela matriz regionalizada é aceitável para os propósitos da análise.

Como continuidade desta agenda de pesquisa, seguindo o mesmo procedimento descrito neste artigo, é possível testar a inclusão de outras fontes de dados para setores específicos buscando aperfeiçoar a obtenção de tabelas de quocientes locacionais.

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The role of Advance Airline Ticket Booking on Airline choice Preference by Discrete Choice Analysis

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Abstract/Resumo/Resumen

This research is based on a discrete choice theory where it explores how passengers choose airlines for domestic flights. The found model provides crucial information for both airline strategic plans and transportation engineering research. However, beyond considering prices and onboard amenities, the model shows that advance fly ticket purchase in days is a fundamental factor in airline choice process. This variable has a significant impact on the traveler's choice behavior.

The Role Of Advance Airline Ticket Booking On Airline Choice Preference By Discrete Choice Analysis

1. Introduction

In an increasingly interconnected world, the choice of an airline has become a crucial decision for individuals seeking to explore new destinations or simply move from one place to another. It is also vital for airlines aiming to retain and attract new customers to increase their economic benefits. Therefore, how passengers choose airlines for their desired flights provides crucial information for both airline strategic plans and transportation engineering research. [1]

However, beyond considering prices and onboard amenities, a fundamental factor that often goes unnoticed is the lead time in ticket purchase. This variable can have a significant impact on the traveler's experience, from the total cost of the flight to the availability of desired seats.

This article explores how purchasing domestic flight tickets in advance affects the choice among the following airlines: Avianca (AVA), Latam (LAN), and Viva Colombia (VVC). This effect can translate not only into substantial savings but also into the possibility of accessing more convenient options tailored to individual needs, all based on constructing a discrete choice model. Smart strategies will be discovered to make the most of the lead time in purchasing airline tickets, aiming to provide insights and generate policies for airlines. This effect can translate not only into substantial savings but also into the possibility of accessing more convenient options tailored to individual needs, all based on constructing a discrete choice model. Through this analysis, conclusions can be drawn to formulate strategies for airlines.

The article will be structured as follows: a review of existing literature on discrete choice models applied in airline choice and transportation will be conducted. Following this, the data acquisition process will be explained, utilizing both revealed and stated preferences. Subsequently, the methodology, employing discrete choice models, will be presented, and finally, the models will be analyzed, reviewing the results and presenting the conclusions derived from the research.

2. Literature review

Seelhorst and Liu (2015) conducted research on itinerary preferences in air travel, focusing on understanding how membership in frequent flyer programs (FFP) affects travelers' decisions. [2] They addressed this issue by employing two models: a Multinomial Logit Model (MNL) and a Latent Class Model. Key variables included traditional flight attributes such as flight time and number of connections, along with the influence of FFP membership. In contrast to the simplicity of the MNL, the latent class model identified three segments of travelers with distinct preferences and economic dispositions. The research highlighted significant variability in participant responses, emphasizing the importance of considering discrete heterogeneity instead of relying solely on traditional models to understand the complexities of air travel itinerary choices.

Lee, et al. (2016) conducted a study to identify additional variables that could enhance the model's ability to reflect the reality of the transportation market in Korea, specifically on the Seoul-Jeju route. To achieve this, they incorporated safety and the availability of duty-free shops into the transportation mode choice model. They observed that these additional variables significantly influenced passenger choice behavior, revealing that business travelers value safety more, while leisure travelers have a marked preference for the availability of duty-free shops. This study provided a solid foundation for better understanding passenger decisions and suggested that considering these new variables is crucial for developing effective strategies in the competitive transportation market. [3]

Moreno (2006) proposed analyzing the airline choice process for passengers in the Metropolitan Region of São Paulo. A conditional logistic regression model was used, evaluating various specifications that included variables associated with flight cost, frequency of available flights, and airline performance represented by its age. After several tests, they identified that the lowest fare variable, the frequency of direct flights in the day and period of departure, and the airline's age were the most relevant in airline choice. The conclusion highlighted the importance of low fares, the frequency of direct flights, and the age of the airline in passengers' decision-making process, with specific recommendations for marketing and airport and airline management strategies. [4]

Hess and Polak (2006) formulated a model for the combined choice of airport, airline, and access mode for passengers departing from the San Francisco Bay Area. They studied the nature of interactions between these choice dimensions. The main variables included in the analysis were flight frequency, travel time, vehicle access time, waiting time, fare, aircraft size, and income. The authors also explored the influence of aircraft type (jet versus turboprop) and included airport inertia variables in utility functions. The analysis showed that factors such as flight frequency and vehicle access time had a generally significant impact on the attractiveness of a particular airport. However, factors such as fare and aircraft size only had a visible impact on some subgroups of the population. [5]

Escobari (2014) proposed a dynamic demand model using a panel dataset and analyzed how valuations change as the departure date approaches. They concluded that consumers with lower valuations become more sensitive to price as their departure day approaches, while consumers with higher valuations tend to make advance purchases. [6]

Milioti et al. (2015) presented research exploring factors influencing passengers' decisions regarding airline choice using a multivariate probit model. The main variables reviewed included fare, flight schedule, frequent flyer program presence, airline safety and accountability, overall airline image, onboard entertainment availability, staff friendliness and helpfulness during the flight, number of cities served, and independent variables related to the person boarding the flight. The research concluded that fare, safety and reliability, and friendly and helpful staff during the flight are the most important determinants when choosing an airline. Onboard entertainment and the frequent flyer program are considered less important. The results clearly show differences in the importance of these factors among passengers with different socio-demographic and travel characteristics. [1]

Cho & Dresner (2018) conducted a study on the impact of a baggage fee waiver on airline choice in the Washington-Baltimore region. A discrete choice logit model was employed. The examined variables were the number of layovers, frequency of non-stop flights, on-time performance, fares, market presence, and baggage fee extent. Three hypotheses were presented for this study. First: a baggage fee waiver positively influences a passenger's choice when traveling for a longer period. Second: a baggage fee waiver positively influences a passenger's airline choice when traveling a longer distance. Third: a baggage fee waiver positively influences a passenger's airline choice when traveling for leisure. In conclusion, a baggage fee waiver is a significant incentive for passengers who potentially have a greater need to check luggage; that is, passengers traveling on long flights, longer distances, or for leisure purposes. Confirming the hypotheses presented, it was also found that the major impact of implementing the baggage fee is to change passenger behavior in airlines that charge the fee (significantly reducing the proportion of passengers checking bags) rather than inducing passengers to switch to fee-charging carriers from the outset. [7]

3. Data

The data used in this analysis were obtained from surveys of revealed preferences (RP) and stated preferences (SP) conducted in the boarding area of José María Córdoba International Airport in the city of Medellín, Colombia, in the year 2018. The surveyed focus group consisted of passengers on domestic flights destined for the coastal cities of Colombia: Barranquilla in the Atlántico department, Cartagena in the Bolívar department, Monteria in the Córdoba department, and Santa Marta in the Magdalena department.

Regarding RP, data were collected on each individual's personal information, such as gender, age, education level, occupation, income, among others. Additionally, information about the flight they were waiting for, such

as the destination, the airline they are traveling with, the purpose of the trip, whether it is associated with any frequent flyer program (FFP), or the payment method used (cash and/or miles), etc. As for SP, six discrete choice scenarios were presented, where the alternatives were three airlines: Avianca (AVA), LAN, and VivaColombia (VVC). Attributes included ticket cost, arrival time at the destination, flight frequency, and departure time from the coastal city to Medellín.

In total, data from 509 surveys were collected, with 50 individuals reserved for model validation, which will be presented during the development of this article.

4. Methodology

4.1. Discrete Choice Models

The standard tools for modeling people's decision-making process in transportation modes are discrete choice models derived from random utility theory. Typically, these models assume that an individual selects the alternative with the highest utility, as specified in Lancaster (1966) and McFadden (1973). It is also postulated that utilities are expressed as a function of both the attributes inherent to the alternatives and the decision-makers characteristics. Additionally, this utility function incorporates a component of implicit stochastic error, for which various hypotheses can be formulated, giving rise to specific choice models, such as multinomial logit, nested logit, and multinomial probit.

The research presented in this work uses the multinomial logit discrete choice model (MNL), which is the most common choice model, proposed by McFadden (1973). The underlying fundamental assumptions of the model break down into two main aspects: first, the utility function exhibits linearity in relation to its parameters, and second, the stochastic error components are independent of each other and follow a Gumbel distribution. Additionally, the behavior of the MNL model is rigorously governed by the property of independence of irrelevant alternatives. [8]

As shown in Equation (1), Unj is a function of predictive variables that determine the choice of the j-th travel mode by the n-th individual. αj can be interpreted as an intercept term for the j-th alternative, while $\boldsymbol{\beta} j$ is a vector of model parameters (coefficients), Xnj is a vector of observable features (independent variables), and ϵnj represents the unobserved component for the specific user and travel mode. [8] Equation (2) describes the probability of choosing alternative i for individual n as:

$$U_{nj} = \alpha_j + \beta_j X_{nj} + \epsilon_{nj} \qquad \textbf{(1)}$$

$$P_{ni} = \frac{e^{\alpha_i + \beta_i X_{ni}}}{\sum_{j=1}^{J} e^{\alpha_j + \beta_j X_{nj}}} \qquad \textbf{(2)}$$

4.2. Variables.

Determining the variables that will be part of the models to be developed plays a fundamental role in the results and decisions based on them. As mentioned earlier, the research is divided into two approaches, first presenting a generic model for the entire study, and in the second part, a discrimination is made according to the time of purchase of the airline ticket. The analyzed variables are presented below:

Table 1. Description of Variables Studied in the Models.

Variable		
Cost	Cost	Cost of the air ticket
Arrival	Arri	Flight arrival time at the coastal destination
Departure	Dep	Departure time for the flight to the city of origin
Round-trip flight	RT	The flight was purchased round trip
Frequent flyer program	FFP	Enrolled in a frequent flyer program
Miles	Mls	The flight was paid with miles
Cash	Csh	The flight was paid with cash

Variable		
Traveled by plane before	TPB	The passenger has traveled by plane before
Tourist	Tour	The purpose of the trip is tourism
Business	Bnss	The purpose of the trip is business
Other reasons	Oth	The reason for the trip is medical appointments, sports competitions, congress, study, moving and resident
Low income	LIn	The passenger has income lower than 820.857 COP
Medium income	MIn	The passenger has income between 820.857 and 3'500.000 COP
High income	HIn	The passenger has income higher than 3'500.000 COP

4.3. Segmentation by Purpose

The central part of the study focuses on analyzing how behavior and the most influential variables vary depending on the advance time with which the ticket was purchased. The decision to analyze this variable was made as it is a topic that has not yet been studied in-depth in the field. Most discrete choice models for airline selection evaluate variables such as the purpose of the trip, schedule preferences, ages of individuals, type of journey, and membership or non-membership in frequent flyer programs. One study that thoroughly reviews the influence of the lead time for ticket purchase does so using a continuous logit model. [9] Therefore, it is considered highly useful to assess the impact of these variables on airline choice using a multinomial logit discrete choice model.

5. Analysis of the Model

Next, the MNL models will be presented and analyzed. This section consists of two parts. Firstly, the basic model with policy variables will be presented, defining the most representative model of airline choice considering the 459 individuals selected for model calibration. This includes statistically significant variables with 95% confidence and conceptual validity. Subsequently, the segmented models will be analyzed to determine the utility of airline choice based on the lead time of ticket purchase. Table 2 identifies the variables used in the models.

Table 2. Characteristics of the Variables Used in the Models.

	0	1
Gender (GEN)	Women	Men
	0	1
Frequent Flight Program (FFP)	No	Yes
	0	1
Traveled by Plane Before (TPB)	No	Yes
	0	1
Round Trip Flight (RT)	No	Yes
Ways to pay	0	1
Pay with cash (Chs)	No	Yes
Pay with cash (MIs)	No	Yes
Reason for trip	0	1
Tourist (Tour)	No	Yes
Business (Bnss)	No	Yes
Other reasons (Oth)	No	Yes
Income	0	1
Low income (LIn)	No	Yes
Low medium (MIn)	No	Yes
Low high (HIn)	No	Yes

5.1. Utility Functions for Airline Choice

As previously documented in the literature, the most influential variables in a discrete choice model are often cost and time (represented as arrival and departure hours). These variables were not only incorporated into the general airline choice model but also into the specific models derived from segmentation based on the anticipation of ticket purchase. As indicated earlier, efforts were made to include conceptually valid factors in each model, following a logic that supported their high probability of influencing the choice of an airline, Equation (3), (4) and (5).

$$V\ AVA = ASC_{AVA} + \beta_{Cost} * Cost_{AVA} + \beta_{Arri} * Arri_{AVA} + \beta_{Dep} * Dep_{AVA} + \beta_{FREQ} * FREQ \quad \textbf{(3)}$$

$$V\ LAN = ASC_{LAN} + \beta_{Cost} * Cost_{LAN} + \beta_{Arri} * Arri_{LAN} + \beta_{Dep} * Dep_{LAN} + \beta_{FREQ} * FREQ \quad \textbf{(4)}$$

$$V\ VVC = ASC_{VVC} + \beta_{Cost} * Cost_{VVC} + \beta_{Arri} * Arri_{VVC} + \beta_{Dep} * Dep_{VVC} + \beta_{FREQ} * FREQ \quad \textbf{(5)}$$

When running the basic model, we observed that the frequency variable was not statistically significant at 95%. Therefore, it was removed from the general model to obtain the coefficients of the other variables. Regardless of the result in this model, it will be considered in the segmented models. Among the factors considered are round-trip flights, membership in frequent flyer programs, payment method, purpose of the trip, previous experience of air travel, income, among others. The utility equations (Equation (6), (7) and (8)) of the base model are presented below.

$$V\ AVA = ASC_{AVA} + \beta_{Cost} * Cost_{AVA} + \beta_{Arri} * Arri_{AVA} + \beta_{Dep} * Dep_{AVA} + \beta_{RT} * RT + \beta_{FFP} * FFP + \beta_{Mls} * Mls + \beta_{TPB} * TPB \quad \textbf{(6)}$$

$$V\ LAN = ASC_{LAN} + \beta_{Cost} * Cost_{LAN} + \beta_{Arri} * Arri_{LAN} + \beta_{Dep} * Dep_{LAN} + \beta_{FFP} * FFP + \beta_{Mls} * Mls + \beta_{Tour} * Tour \quad \textbf{(7)}$$

$$V\ VVC = ASC_{VVC} + \beta_{Cost} * Cost_{VVC} + \beta_{Arri} * Arri_{VVC} + \beta_{Dep} * Dep_{VVC} + \beta_{TPB} * TPB + \beta_{Tour} * Tour + \beta_{MIn} * MIn \quad \textbf{(8)}$$

Significance levels of the variables in the chosen model, obtained from a Goodness of Fit Test (t-test), along with their respective coefficients (β), are presented below (Table 3).

Table 3. t-test and Coefficients of the General Model.

GENERAL MODEL		
Variable	**test-t**	**β**
ASC AVA	1,45	0,242
ASC VIVA	-4,16	-0,642
Cost	-12,49	-0,00489
Arri	-5,01	-0,0736
Dep	-7,36	-0,125
RT	4,38	0,411
FFP	3,59	0,359
Mls	2,37	0,585
TPB	3,14	0,459
Tour	2,66	0,237
MIn	2,52	0,230

5.2. Utility Functions for Segmentation by Ticket Purchase Lead Time

As mentioned earlier, in the second part, the analysis of segmented models based on the lead time of ticket purchase is performed, classified into less than a week, between one and four weeks, and more than 4 weeks. By performing this segmentation, each model analyzed 900, 1,116, and 738 scenarios, respectively.

5.2.1. Model For Ticket Purchase Lead Time Less Than A Week

In this model, some policy variables such as frequency and arrival time were discarded as they did not meet the 95% significance level. Additionally, variables mentioned in Table 4 were added, resulting in a total evaluation of 7 significant variables. The utility equations are:

$$V\ AVA = ASC_{AVA} + \beta_{Cost} * Cost_{AVA} + \beta_{Dep} * Dep_{AVA} + \beta_{Oth} * Oth + \beta_{TPB} * TPB + \beta_{Mls} * Mls \quad (9)$$

$$V\ LAN = ASC_{LAN} + \beta_{Cost} * Cost_{LAN} + \beta_{Dep} * Dep_{LAN} + \beta_{Oth} * Oth \quad (10)$$

$$V\ VVC = ASC_{VVC} + \beta_{Cost} * Cost_{VVC} + \beta_{Dep} * Dep_{VVC} + \beta_{TPB} * TPB \quad (11)$$

Table 4. t-test and Coefficients of the Model Segmented by Ticket Purchase Lead Time Less Than a Week.

MODEL		
Variable	test-t	β
ASC AVA	8,90	0,911
ASC LAN	4,01	0,922
Cost	-6,58	-0,004
Dep	-5,61	-0,166
TPB	3,05	0,716
Oth	3,13	1,628
Mls	41,70	10,257

Replacing the coefficients, the utility equations are:

$$V\ AVA = 0.911 - 0.004 * Cost_{AVA} - 0.166 * Dep_{AVA} + 1.628 * Oth + 0.716 * TPB + 10.257 * Mls \quad (12)$$

$$V\ LAN = 0.922 - 0.004 * Cost_{LAN} - 0.166 * Dep_{LAN} + 1.628 * Oth \quad (13)$$

$$V\ VVC = -0.004 * Cost_{VVC} - 0.166 * Dep_{VVC} + 0.716 * TPB \quad (14)$$

In addition to cost, the variable of payment with miles is highly significant for purchasing tickets in advance one week before Avianca flights. The coefficient directly impacts utility, so this method is an alternative that the airline should maintain due to its attractiveness.

5.2.2. Model For Ticket Purchase Lead Time Between One And Four Weeks

In this model, the frequency variable is discarded from the policy variables as it did not meet the 95% significance level. Additionally, variables mentioned in Table 5 were added, resulting in the analysis of 9 variables. The utility equations are as follows:

$$V\ AVA = ASC_{AVA} + \beta_{Cost} * Cost_{AVA} + \beta_{Arri} * Arri_{AVA} + \beta_{Dep} * Dep_{AVA} + \beta_{FFP} * FFP + \beta_{RT} * RT + \beta_{Hln} * Hln \quad (15)$$

$$VLAN = ASC_{LAN} + \beta_{Cost} * Cost_{LAN} + \beta_{Arri} * Arri_{LAN} + \beta_{Dep} * Dep_{LAN} + \beta_{FFP} * FFP + \beta_{RT} * RT + \beta_{Hln} * Hln \quad (16)$$

$$V\ VVC = ASC_{VVC} + \beta_{Cost} * Cost_{VVC} + \beta_{Arri} * Arri_{VVC} + \beta_{Dep} * Dep_{VVC} + \beta_{Gen} * Gen \quad (17)$$

Table 5. t-test and Coefficients of the Model Segmented by Ticket Purchase Lead Time Between One and Four Weeks.

MODEL		
Variable	**test-t**	**β**
ASC AVA	2,32	0,371
ASC LAN	-2,47	-0,399
Cost	-7,58	-0,00411
Arri	-4,02	-0,0950
Dep	-3,21	-0,082
FFP	3,70	0,611
GEN	3,07	0,471
RT	4,31	0,701
Hln	2,16	0,421

Replacing the coefficients, the utility equations are:

$$V\ AVA = 0.371 - 0.00411 * Cost_{AVA} - 0.095 * Arri_{AVA} - 0.082 * Dep_{AVA} + 0.611 * FFP + 0.701 * RT + 0.421 * HIn \quad \textbf{(18)}$$

$$VLAN = -0.399 - 0.00411 * Cost_{LAN} - 0.095 * Arri_{LAN} - 0.082 * Dep_{LAN} + 0.611 * FFP + 0.701 * RT + 0.421 * HIn \quad \textbf{(19)}$$

$$V\ VVC = -0.00411 * Cost_{VVC} - 0.095 * Arri_{VVC} - 0.082 * Dep_{VVC} + 0.471 * Gen \quad \textbf{(20)}$$

In these models, round trip and arrival time variables have similar significance, particularly arrival time which is present in all equations.

5.2.3. Model For Ticket Purchase Lead Time More Than Four Weeks

In this model, the frequency variable is discarded from the policy variables as it did not meet the 95% significance level. Additionally, variables mentioned in Table 6 were added, resulting in the analysis of 9 variables. The utility equations are as follows:

$$V\ AVA = ASC_{AVA} + \beta_{Cost} * Cost_{AVA} + \beta_{Arri} * Arri_{AVA} + \beta_{Dep} * Dep_{AVA} + \beta_{Mls} * Mls + \beta_{Bnss} * Bnss \quad \textbf{(21)}$$

$$V\ LAN = ASC_{LAN} + \beta_{Cost} * Cost_{LAN} + \beta_{Arri} * Arri_{LAN} + \beta_{Dep} * Dep_{LAN} + \beta_{FFP} * FFP \quad \textbf{(22)}$$

$$V\ VVC = ASC_{VVC} + \beta_{Cost} * Cost_{LAN} + \beta_{Arri} * Arri_{LAN} + \beta_{Dep} * Dep_{LAN} + \beta_{MIn} * MIn \quad \textbf{(23)}$$

Table 6. t-test and Coefficients of the Model Segmented by Ticket Purchase Lead Time More Than Four Weeks.

MODEL		
Variable	**test-t**	**β**
ASC AVA	-7,26	-0,951
ASC VVC	-6,93	-1,100
Cost	-7,73	-0,007
Arri	-3,13	-0,910
Dep	-3,77	-0,136
Mls	3,84	1,413
Bnss	4,46	0,883
FFP	3,19	0,590
MIn	2,65	0,473

Replacing the coefficients, the utility equations are:

$$V\ AVA = -0.007 * Cost_{AVA} - 0.91 * Arri_{AVA} - 0.136 * Dep_{AVA} + 1.413 * Mls + 0.883 * Bnss \quad \textbf{(24)}$$

$$V\ LAN = -0.951 - 0.007 * Cost_{LAN} - 0.91 * Arri_{LAN} - 0.136 * Dep_{LAN} + 0.59 * FFP \quad \textbf{(25)}$$

$$V\ VVC = -1.100 - 0.007 * Cost_{LAN} - 0.91 * Arri_{LAN} - 0.136 * Dep_{LAN} + 0.473 * MIn \quad \textbf{(26)}$$

Cost and the reason for business travel are the most significant variables; it is important to note that the variable that has the most impact with its coefficient is the acquisition of tickets with miles, which once again represents an advantage in Avianca's utility.

6. Conclusions

In contrast to findings in the literature, it was observed through the obtained results that the frequency variable is not representative; that is, it does not have a direct influence on users' choice of airline.

For VivaColombia, in the ticket purchase lead time model of 1 to 4 weeks, gender was significant, meaning it is more useful for the male gender. This is peculiar as it was the only utility function in which this variable is significant.

In general, for Avianca and LAN, frequent flyer programs or payment with miles are important. In all models where they are included, they are highly significant with a positive beta coefficient.

Overall, using miles makes Avianca more attractive to users, especially when tickets are purchased with short lead time.

For the ticket purchase lead time model of 1 to 4 weeks, the reason for travel is not relevant for airline choice. Both in Avianca and LAN, it is significant to purchase round-trip tickets, belong to a frequent flyer program, and have high incomes.

People traveling for business tend to purchase their tickets well in advance, while those traveling for tourism prefer Vivacolombia or LAN over Avianca.

For users engaged in different activities such as business or tourism, which are usually planned activities, they purchase tickets one week in advance and prefer Avianca or LAN airlines.

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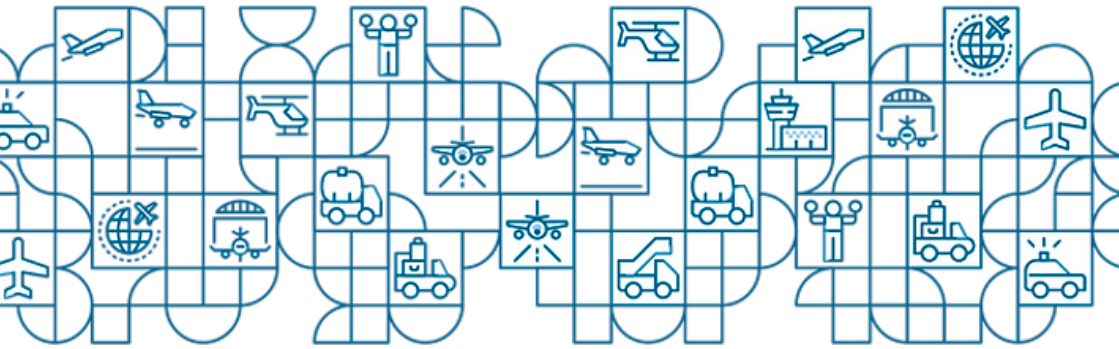
Air Transportation Sustainability and Resilience



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Integrating BIM with IoT and Artificial Intelligence for an advising tool

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Abstract/Resumo/Resumen

The aim of this paper is to explore how to take advantage of the Large Language Models' (LLM) knowledge by integrating the environment description provided by the deployed IoT sensing constellation guided by a BIM interface. By reaching the specific items of interest and the proper context, it is expected a more specific and personalized advise than just the current general rule based systems. The paper will implement a Design Science methodology. The Design principles followed in this research were influenced by the work of [1] and [2]. Their design principles involve a structured process of identifying problems, defining objectives, developing and evaluating potential solutions, and finally communicating the results. This process helps to ensure that the resulting artifacts are effective, useful, and relevant to the needs of the stakeholders in a specific context. It is expected to validate the approach as a tool to be taken into account during on-site planning interventions, both during construction but also during operation. The dynamic behavior implemented on both ends, first by setting the focus on specific items, but also by providing detailed and dynamic context can break the general application of rule-based criteria for something more specific and close to the effective conditions. LLMs gained momentum recently but they lack of application and limitation analysis of functionality for real use cases. Until now very few contributions have taken advantage of this idea [3] and [4]. This paper will explore to what end using prompting engineering and dynamic context can help in providing accurate and personalized recommendations. This work will exclude improvements coming from the fine tuning of the LLM and will run under a limited context of less than 8000 tokens for the selected models.

Integrating BIM with IoT and Artificial Intelligence for an advising tool

1 Introduction

In the context of managing Operation and Maintenance (OM) activities within complex infrastructures like those commonly encountered in the air transportation industry, there exists an ongoing requirement for intelligent asset management. This imperative facilitates optimal resource availability while endeavouring to mitigate disruptions and associated consequences [1], [2].
The advantages of integrating airport facilities into the Building Information Modeling (BIM) system and their integration with the surrounding area have been underscored [1]. Findings demonstrate that the interoperability between Geographic Information Systems (GIS) and BIM allows for a more comprehensive understanding of digital models within the broader territorial context. This, in turn, facilitates various analyses, such as assessing potential interferences with aircraft operations arising from the interaction between facilities and their surroundings.
The emergence and proliferation of BIM technology have instigated notable transformations within the Architecture, Engineering, Construction and Operation (AECO) sector [3]. BIM has progressively assumed a central role in overseeing construction information across the project lifecycle, spanning from inception and planning to utilization stages. This advancement has been instrumental in advancing the digital evolution of the built environment [4]. Moreover, BIM holds immense potential for enhancing data interoperability essential for effective building performance management [5]. Standardized concepts and principles supporting BIM-driven business processes are outlined in the ISO 19650 series [6], [7].
In recent years, a growing trend involves integrating BIM with real-time data sourced from Internet of Things (IoT) devices to enhance both construction and operational efficiencies. IoT sensor networks allow for the seamless integration of real-time data streams into BIM models, enabling a multitude of applications [8], [9], [10].
The predominant theme across published works underscores the enhanced value gained from integrating BIM with complementary technologies like IoT or GIS, thereby streamlining analysis and decision-making processes. A significant portion of these studies has interconnected these concepts through the Digital Twin (DT) framework, often likened to "digital replicas" of buildings. Experts have delved into the role of DTs in real-time simulation of physical objects via sensors, aiming to encapsulate all pertinent information throughout the lifecycle of a building [8], [11], [12], [13], [14]. However, BIM is not always enough in whole-life cycle asset management, especially in the O&M phase [15].
Regrettably, the DT concept has often been utilized in a generic manner, overlooking precise definitions and similar concepts. This oversight adds unnecessary complexity to the analysis. It is crucial to recognize a substantial disparity between DT and most existing digital 3D models and systems. A virtual model that merely mirrors the physical counterpart, with data flowing in one direction only, is typically categorized as a Digital Shadow (DS) [16]. However, in a DT, both the virtual and physical entities should communicate with each other. Addressing the integration of intelligent building data from disparate, cross-domain, and diverse sources such as BIM and IoT stands as a critical research challenge. These data sources typically operate within isolated environments, impeding seamless data interoperability. However, achieving various cognitive functions of smart building DTs, such as reasoning, learning, and decision-making, necessitates interoperable static and dynamic building data. Semantic-level interoperability, which involves describing data using explicit domain-specific terminology (i.e., ontology), represents an ideal approach for heterogeneous and cross-domain data environments [17].

The resolution of interoperability issues between static and dynamic building data, particularly derived from BIM and IoT sources, has been extensively investigated. While some studies have concentrated on integrating BIM and IoT data for creating digital twins of smart buildings, others have explored the broader BIM-IoT integration paradigm [18]. Nevertheless, existing architectures and frameworks fall short in

seamlessly integrating BIM and IoT data to enable semantic interoperability among smart building digital twin applications while preserving data integrity within their respective environments [17], [19], [20].

Based on the previous analysis, the following research question is raised: ***What are the main requirements to be considered when creating an actionable and dynamic relationship between IoT devices and BIM models, able to be used in modern Large Language Models (LLM) chatbots or similar tools?***

To address such question the hereinafter organization of the paper will present a literature review focused specifically on the related trends in Section 2. Section 3 introduces the adopted methodology, while Section 4 presents the results of the work and Section 5 discusses the implications regarding the research question. Finally, Section 5 presents the conclusions, limitations, and future research topics.

2 Literature Review

Digitalization movement within the AECO industry is, however, occurring relatively slowly and on an incremental basis. According to [21] the tools already exist to digitally transform the construction industry, but lack of will to do it is now the primary obstacle. He stated that the construction industry is often both digitally and physically chaotic with multiple companies having different agendas and mutually incompatible priorities. This is unlikely to change until disruptors introduce coordinated digitalisation on projects where stakeholders demand and apply integrated and unified data communication.
The transition toward digital processes is taking place at different rates of maturity within different organisations and sections of the industry [22]. Indeed, temporal evolution of research has also its own pacing process.
Despite the managerial issues documented in the literature and encountered during semi-structured interviews with various stakeholders, as well as the availability of different IT tools, the lack of integration tools and methodologies remains a significant factor explaining the low adoption of the technology in O&M phase, particularly for Facility Management (FM) cases [23], [24].
There are authors being much more specific and stating that while Publicly Available Specification such as the PAS1192-3:2014 (BSI 2014) broadly recommends the structured definition and consideration of the owner's requirements in building and infrastructure projects, a methodology to support the definition and compliance checking of the owner's requirements throughout the lifecycle of a building is missing [25].
Maintenance theory has established a good approach to the Asset and Asset Management (AM) concepts, with specific tools facilitating the implementation of digital tools to bring an integrated and powerful perspective for the asset and potential models facilitating the establishment of a Digital Twin.
Stated in [26] data and workflow integration across GIS and BIM enables the realization of greater efficiency, sustainability, and habitability of cities, campuses, and workplaces as well as supporting the building of a robust context model, where geographic information and infrastructure design data help in understanding that better assets interact within the context of a real place and geography, and move data seamlessly from one system to another, using data exchange models in the building industries, i.e., Industry Foundation Classes (IFC), Construction Operations Building Information Exchange (COBie), and Green Building XML schema (GBXML). Therefore, it is implicitly recognized the lack of standard integration while "data exchange" must be carried out on purpose between the different tools.
Through the specific analysis conducted in this research, a notable deficiency in coverage became apparent between the hierarchical perspective assigned to assets – wherein the reference serves as one such attribute, as per the AAS, with the goal of ensuring uniqueness across all assets – and the aspiration for the GUID of a BIM object, which aims to ensure its identity's uniqueness across all elements within the project. Consequently, due to the differing conceptual scopes, achieving automatic alignment of asset identities could prove challenging.
Another concern might arise from asset component management. The reviewed ontological implementations exhibit limited support for dynamic membership, especially in cases where non-structural (and temporal) relationships exist. This limitation could ultimately impede the necessary flexibility needed for O&M activities.

When interactions with Large Language Models (LLMs) is considered, different applications appear. In [27] the idea is to use LLM to facilitate communication between stakeholders for prefabricated and modular components of free-from buildings, as they use to require more exchanges. Prefabrication for free-form buildings requires a highly integrated and complex system depending on various ETO components, which are designed, manufactured, assembled, and even maintained by corresponding subcontractors, while the parametric configuration of the elements is handled by BIM tools. The paper proposes to have specific prompting at component level, to handle specificities between each of them. Different LLM have been tested in terms of user satisfaction.
Other authors proposed to facilitate BIM adoption during detailing of exterior walls by using an interactive LLMs based natural language approach instead of menu-based user interfaces [28].
Other interesting applications have been recently presented, where the LLM is used as natural language interface to generate heritage scenes based on language-embedded 3DGS model, without the classical training approach used in machine learning supervised training [29]. Most of the potential applications for LLMs in Construction have been analysed in recent papers, such as [30].
Nevertheless, to date, no specific applications have been identified that effectively link BIM/construction with IoT and LLMs. Furthermore, there is a lack of deeply integrated usage of data-driven models by LLMs to handle specific requests. Instead, LLMs have primarily been utilized for their proficiency in processing natural language.

3 Methodology

The main purpose of this research is not to solve all the existing gaps but focus on the capabilities provided by IoT gathered information being spatially linked to objects and represented in BIM models, to help different users in exploring alternative decisions, or anticipating decisions that increase usability or adding value to the management processes. To this end, the adopted process involves three interrelated steps in the research process, which are, theoretical analysis, framework development, and experimental verification, as suggested in [27].

3.1 Theoretical Analysis

Although not enough highlighted by the still limited number of papers found dealing with LLM applications cooperating with BIM tools, there are many challenges when working with LLMs such as domain knowledge gaps, factuality issues, and hallucination [31]. Some alternative solutions can be fine tuning and Retrieval Augmented Generation (RAG). Fine-tuning offers a precise, succinct output that is attuned to brevity. It is highly effective and presents opportunities to learn new skills in a specific domain. RAG provides a solution to mitigate some of these issues by augmenting LLMs with external knowledge such as databases. RAG is particularly useful in knowledge-intensive scenarios or domain-specific applications that require knowledge that's continually updating. A key advantage of RAG over other approaches is that the LLM doesn't need to be retrained for task-specific applications.
The design pattern known as Retrieval Augmented Generation (RAG) has gained widespread adoption for the development of grounded ChatGPT systems within specific domains. Nevertheless, the predominant emphasis has been directed towards enhancing the efficiency of retrieval mechanisms, such as embedding search, hybrid search methodologies, and fine-tuning embedding strategies, rather than the advancement of intelligent search capabilities.
The relationship between RAG and fine-tuning was clearly presented in Figure 1 by the blog of promptingguide.ai, depending on the amount of external knowledge required to complete the tasks and the particularization required from the model. The Learning through Communication (LTC) paradigm proposed by [32] becomes a training approach that enables LLM agents to continuously improve through interactions with their environment and other agents. This approach, with structured communication patterns, demonstrated versatility and efficiency across diverse domains. The problem of ”cascade of hallucinations” consequence of not including ”sanity checks” in the interaction of agents was addressed in [33].
In this work the authors aim to relay on another alternative, named Autonomous Agents (AAs) in cooperation with LLM. Autonomous agents can be likened to astute digital overseers, possessing the capacity to adapt, evolve, and streamline labor-intensive tasks within a workflow through experiential learning. Operating autonomously, these agents are capable of initiating actions driven by predefined

goals assigned to them. To complete the whole set of items, LLM function calling feature can improve the external capabilities of interaction for them, not just to suggest action but to effectively fire them. Actually, Function Calling capabilities help models to intelligently choose tools to respond to questions, becoming AAs In this way Bots can interact with internal systems for tasks like customer orders and returns, beyond providing answers to enquiries, which is the approach being tested here.

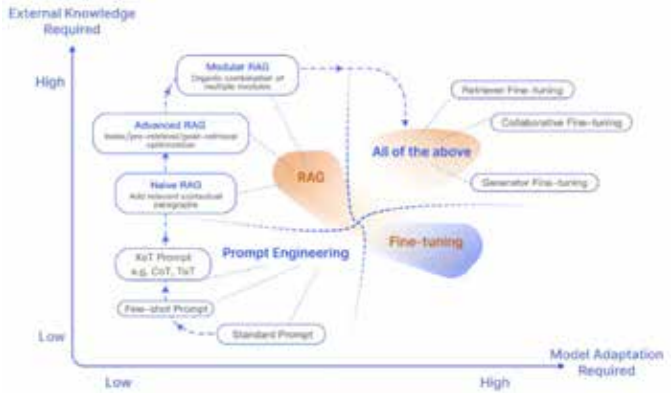

Figure 1.- RAG vs Fine-Tuning. Source: https://www.promptingguide.ai/research/rag

3.2 Framework Development

To graphically represent the integrated operative being considered in this work is presented in Figure 2.

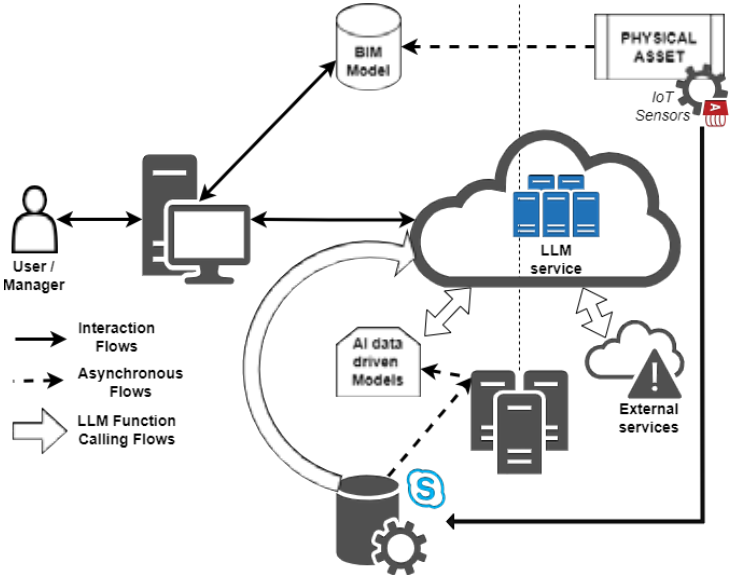

Figure 2.- Proposed Framework involving all the technologies for AAs..

In the proposed framework there are digital models created by mimicking the asset geometry in a digital BIM model, potentially enriched with specific objects having their own static properties. The application (typically a boot fired inside Revit™ by using Revit API) running in front of the user. Such application interacts with a LLM, in our case we have selected gemini-1.5-pro from Alphabet Inc.
Several autonomous agent interfaces were setup through the Function Calling, and for this setup the following were implemented:

- get_weather_for_tomorrow_morning. Having as parameters the location name. Aiming to get the forecast for weather in a given location.
- get_operating_startup_time_in_lab. Having as parameters the name of the interesting laboratory. The aim is to derive the most frequent time for starting operations based on the occupancy sensor signal for the days before, as well as considering the day of the week for tomorrow.
- get_expected_temperature_indoor_at_four_am. Having as parameters the name of he lab. The aim is to estimate the temperature of the room before starting heating it up.
- get_specific_heat_capacity_of_lab. Having as parameter the name of the lab. The functions aims to determine the type of heating system in use on that room, as well as the thermal capacity of the heating system (mass of hot water in radiators, power of fain coils, etc.) able to provide an estimation helping in determine the amount of time required to increase one degree the temperature of the room.

3.3 Experimental Verification

To develop the experimental application, a BIM model representing a educational lab has been selected, where the representation is presented in Figure 3.

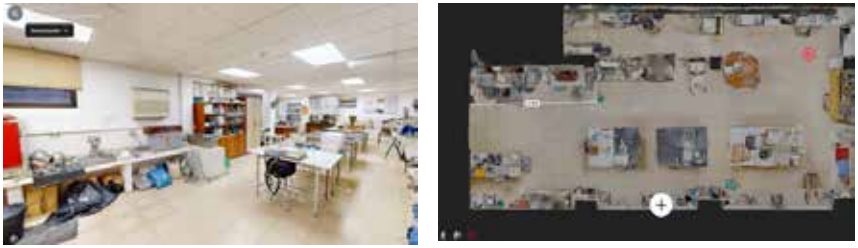

Figure 3.- Realistic BIM model with interactive metric & selection capabilities.

In the compatible setup objects having link connection to an external data source provided by different LoraWan® communication based devices were introduced.
In the integrated configuration, entities with linked connections to an external data source, facilitated by various LoraWan® communication-based devices, have been incorporated. This enables users to traverse the geometry and interact with these devices depicted in the model via a graphical tag. Activation is achieved by mouse input, allowing seamless access to external data. (see Figure 4).
Then, based on the Theoretical Analysis and the Framework development the chatbot tool was created.

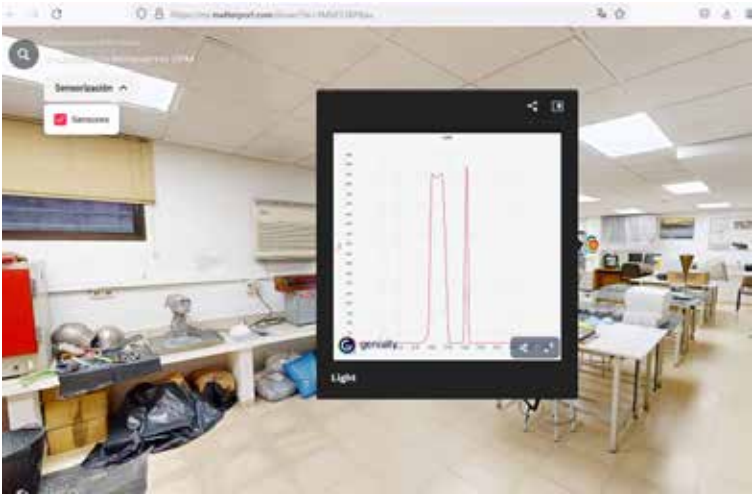

Figure 4.- IoT sensing embedded within the model.

4 RESULTS

To guide the model toward interesting solutions, and looking For best results, we have prepended the queries with specific details:

- Additional context for the model: You are a BIM API assistant to help with searching for suitable operating conditions based on user preferences.
- Details or instructions on how and when to use the functions: Do not make assumptions neither for the external weather nor for space usage timetables. Always use a future date for suggesting suitable operational conditions.
- Instructions to ask clarifying questions if user queries are ambiguous: Ask clarifying questions if not enough information is available.

Agents have the capability to access daily weather forecasts by connecting to the internet, facilitated by the utilization of a specific API KEY user identification token. Alternatively, agents can interface with the provided Information System via the functions established as a convenient interface. These functions enable the conveyance of pertinent information to the LLM, encompassing specific attributes of devices installed in the physical asset or accessing relevant data regarding the performance of said asset, leveraging the data made accessible by the IoT System.
Responsibility for calling these AAs is on the LLM itself, according to the given freedom in assuming speculative operational situations.

Tools were defined to inform the LLM about the available function calling options, therefore wheather_tool and lab_tool have been defined to incorporate the created functions, as well as the prompt function which integrates the role, the parts, and the tools. It provides the aforementioned context.
The response interface brings the convenient way to drive the model to prepare the parameters depending on the function being called. As an example, the Figure 5 shows the conversation including the question being submitted.

```
import vertexai
from vertexai.generative_models import (FunctionDeclaration, GenerativeModel,Part, Tool,)

def generate_function_call_chat(project_id: str, location: str) -> tuple:
  prompts = []
  summaries = []
  # Initialize Alphabet Vertex AI
  vertexai.init(project=project_id, location=location)
  get_weather_for_tomorrow_morning_func = FunctionDeclaration(
    name="get_weather_for_tomorrow_morning",
    description="Get weather forecast for tomorrow early in the morning",
    parameters={
      "type": "object",
      "properties": {
        "location": {"type": "string", "description": "Place name of the location for which to get the weather."} },},)
  get_operating_startup_time_in_lab_func = FunctionDeclaration(
    name="get_operating_startup_time_in_lab",
    description="Get the estimated startup time for the interesting Laboratory",
    parameters={
      "type": "object",
      "properties": {"name": {"type": "string",
            "description": "Laboratory Name"}},},)
  get_expected_temperature_indoor_at_four_am_func = FunctionDeclaration(
    name=" get_expected_temperature_indoor_at_four_am",
    description="Get the temperature of the Laboratory at 4 AM",
    parameters={
      "type": "object",
      "properties": {"name": {"type": "string",
            "description": "Laboratory Name"}},},)
  get_specific_thermal_capacity_of_lab_func = FunctionDeclaration(
    name=" get_specific_thermal_capacity_of_lab ",
    description="Get the STC of the interesting Laboratory",
    parameters={
      "type": "object",
      "properties": {"name": {"type": "string",
            "description": "Laboratory Name"}},},)
  weather_tool = Tool(function_declarations=[get_weather_for_tomorrow_morning_func],)
  Lab_tool = Tool(
    function_declarations=[
      get_operating_startup_time_in_lab_func,
      get_expected_temperature_indoor_at_four_am_func,
          get_specific_thermal_capacity_of_lab_func,],)
  # Initialize Gemini model
  model = GenerativeModel("gemini-1.5-pro",
    generation_config={"temperature": 0},
    tools=[Weather_tool,Lab_tool]  )
  chat = model.start_chat()
  # Send a prompt for the conversation
  prompt = "What will be temperature of the ETSIAE Construction Lab early tomorrow morning?"
  response = chat.send_message(prompt)
  prompts.append(prompt)
  if response.candidates[0].content.parts[0].function_call.name == "get_weather_for_tomorrow_morning":
    location = (response.candidates[0].content.parts[0].function_call.args["location"])
    api_response = requests.post(product_api_url,
        data={"location": location})
  response = chat.send_message(
    Part.from_function_response(
      name="get_product_sku",
      response={"content": api_response, },),)
  summary = response.candidates[0].content.parts[0].text
  summaries.append(summary)
  return prompts, summaries
```

Figure 5.- Example of python code implementing the AAs for Alphabet Gemini..

Other questions have been tested such as

prompt = "At what time should we start the heating system for the ETSIAE Construction Lab according to the expected human presence?"

```
response = chat.send_message(prompt)
prompts.append(prompt)
```

The answer obtained was: "For optimal comfort and energy efficiency, it is recommended to anticipate human presence estimated around 8:45 AM, taking into account past laboratory usage patterns. Considering an outdoor temperature forecasted to be 6°C at 6:00 AM, and aiming for minimum comfort conditions indoors in the ETSIAE Construction Lab spanning 86.6 square meters, it is advised to commence heating at 6:00 AM, which is two hours and forty-five minutes prior", where details about the context and the information from BIM model has been taken into account to refine the proposal.
Slight modifications in the interface, through the API subsystem, could make possible for the LLM to submit instructions to the automatic valving system for start the process at the anticipated time, which can be very relevant for Facility Management applications.

5 CONCLUSIONS

The significant capabilities that can be mobilized by the integrated cooperation between advanced geometric modelling, and live data being gathered and becoming available through the IoT system have been presented in this paper and successfully tested.
It opens a new way for doing O&M activities in FM use cases, where supervision can be described at high level in a human language and specific actions will be handled by LLMs, knowing about device and system specificities through AAs, with can also collect relevant information from external sources. This way of doing anticipates a new role for many operating actors, which will require to update their functions accordingly, mainly to supervise efficiency of the generic rules, as well as to assess the established policies. However, there is a long journey ahead to reach such point, because no robustness criteria regarding safety and security dimensions were considered.
Indeed, although possible, no real actions were delegated to the LLM system itself in this prototype, because the ambition was to test the feasibility of the integration of technologies and not to build a fully functional system.
The current implementation did not provide a free interface for the operator. Instead, navigation was through a menu of options, linked to specific requests such as the one presented in Figure 5. This choice was made to avoid questions making LLMs prone to hallucinations, mainly because of lack of the enough AAs to satisfy potential demands in terms of complementary information induced in free form dialog.
The connection between the AM perspective and the geospatial one provided by BIM is limited, therefore, progress in such dimension for organizations having facilities and assets described by different BIM projects will be challenging.
Further research is needed to facilitate the communication between the user and LLM itself, and also to increase the number of available AAs, while cost control must be a factor when the process scales up significantly. Progress in connecting suggestions to effective actions while observation of safety protocols is increased is another relevant area of work, as well as facilitate transparency on effects derived from decisions made, making them available to all stakeholders.

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Optimization of the construction quality control management in airfield pavement renovation– Integration in BIM Execution Plan

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Abstract/Resumo/Resumen

Airfield pavement renovation requires access to a dynamic integrated quality information repository in real time to meet deadlines and quality targets [1-2]. Given the large number of stakeholders involved, reports generated in different formats, the complexity of the construction management and consequences of the delays caused, having a BIM use for Construction Quality Control Management (CQCM) integrated in the BIM Execution Plans highly desirable [3]. With the support and knowledge of the activities carried out in a real construction site, a construction quality management plan, the CQCM to be integrated in the Verification Model of the BIM Execution Plan, is proposed. A brief analysis of the work being carried out and the quality plan approved and the testing plan will be made. Measures will be proposed in order to have a better control of the work, and to optimize the planning time that this entails. This study attempts to integrate a dynamic database of test measurements in quality control with the use of BIM for CQCM. This will be an objective and effective guide to make decisions about the different activities involved in the construction and quality control phase. It will also be possible to monitor and promote the planning, manage the documentation required for each of the scheduled tasks and support the feedback process between them [4]. With BIM implementation in airfield management renovation, an important step to reach a smart construction management is initiated.

Optimization of the construction quality control management in airfield pavement renovation: Integration in BIM Execution Plan

1. Introduction

New technologies and innovative frameworks are being introduced in the construction and engineering industry (AEC) to bridge the gap between project stakeholders. Building Information Modeling (BIM) is one such technology for which there is an implementation plan. From April 2024, projects with contract budgets over 5.4 M€ a BIM model must be provided at an initial level, and it is recommended for those projects with budgets over 2 M€. Efforts to enhance BIM implementation extend to renovation projects as well.

BIM is not a mere set of technologies, models and processes, but a comprehensive combination of product and process modeling. This BIM-centric approach is driving research and development in BIM servers, facilitating the adoption of technologies for more effective automated collaboration on design and construction projects. Despite the introduction of various BIM-based concepts and frameworks, the AEC industries face persistent challenges, including interoperability issues and effective adoption across countries. Interoperability between BIM dimensions, effective communication, and the implementation of national standards remain significant barriers. [1]. Addressing these challenges requires further research to optimize construction operations and ensure trustworthy quality and performance throughout the project life cycle.

Airfield pavement refurbishment demands access to a real-time, dynamic integrated repository of quality information to meet deadlines and quality standards [2] [3]. Given the multitude of stakeholders, diverse report formats, and the complexities of construction management, the use of Building Information Modeling (BIM) for Construction Quality Control Management (CQCM) is highly advantageous [4] [5].

Proposed frameworks are addressing multidimensional BIM management aim to facilitate the sharing and management of BIM infrastructure information across various stakeholders, thereby establishing a robust infrastructure network system [1] [6]. Moreover, innovative frameworks focusing on project cost management are emerging as vital elements in construction projects. The evolution of BIM dimensions is driving progress in quality, efficiency, and precision in cost estimation processes. For other dimensions, frameworks are proposed to streamline design resolutions by integrating multi-objective optimization processes with BIM-based design, thereby minimizing barriers between embodied and operational energy. These advancements underscore the critical role of BIM in delivering successful projects, particularly in post-construction energy efficiency and maintenance.

This study proposes integrating a Construction Quality Control Management (CQCM) plan into the BIM Execution Plan's Verification Model, drawing on real construction site activities and approved quality and testing plans. An analysis of ongoing work will inform proposed measures to enhance control and optimize planning. By integrating a dynamic database of test measurements into BIM for CQCM, this study aims to provide an objective guide for decision-making in construction and quality control phases. It will facilitate monitoring, promote efficient planning, manage documentation, and support feedback processes between tasks. The implementation of BIM in airfield management renovation marks a significant stride towards intelligent construction management.

This article is structured into three sections and conclusions. Following a review of some studies on the integration of construction models and quality assurance, the authors examine a specific infrastructure case. Through documentation provided by the Quality Management Plan (QMP), a framework for integrating this QMP into the 4D BIM model is poroposed.

2. Literature review

Construction progress monitoring, a complex and crucial endeavor, traditionally entails labor-intensive inspections and comparisons with planned schedules, often leading to significant resource savings through reduced construction time. However, until now, this process has consumed substantial time for construction managers and remained largely disconnected from digital, integrated management within BIM frameworks. BIM Technology for the highway sector is still in its infancy and has a lot of room for growth

To address these inefficiencies, several authors present approaches to construction progress monitoring [7] [8]. Most researchers are focusing on the integration of information acquisition, information extraction, and information transmission and management technologies in intelligent surveying technology for their research on the intelligence of pavement planning [9] [10]. Primary components of the BIM intelligence of pavement construction and maintenance technology are the Information and Comunication quality control Technology (ICT), and health monitoring and evaluation System.

Vassena et al. propose a method that integrates 4D BIM model (construction scheduling) with periodic geometric surveying using an indoor mobile mapping device (iMMS) capable of swiftly capturing point clouds and panoramic images. The acquired 3D point clouds can then be transformed into a digital construction site diary, synergizing with the 4D BIM model to monitor construction progress effectively. Employing 4D BIM during the design phase enhances stakeholders' understanding of project milestones and construction plans. Real-time insights into critical aspects of the site empower timely decision-making, ultimately reducing time and costs associated with potential delays. This integrated approach heralds a new era in construction management, where digital tools seamlessly support the entire project lifecycle within BIM-based frameworks [8].

The literature review conducted underscored the absence of guidelines and frameworks for the effective deployment of automated progress monitoring processes and technologies within the construction industry [11]. Qureshi et al. research on developing guidelines for automated construction progress monitoring by identifying and evaluating factors that could enhance the effectiveness of data-acquisition technologies and their operational performance. Through a questionnaire-based approach, feedback was gathered from industry professionals regarding various close-range technologies, including aumented reality, swarm nodes, infrared thermography, kinect sensors, videogrammetry, ultra-wideband, photogrammetry, Radio Frequency Identification, and laser scanners. Utilizing Structural Equation Modeling (SEM) analyses, a model was developed to delineate factors crucial for the successful implementation of digitized monitoring processes. The model categorizes technologies into four constructs: 'tracking & sensing', 'site video', '3D scanning', and 'site images', each supported by factors influencing data collection processes and the quality of monitoring technology outputs.

The literature review shows significant differences in the degree of BIM implementation between countries. In some countries BIM timidly appears on top of traditional management systems (integration of GIS and BIM mainly) [12] [13]; while in China for example, from year 2020, some guidelines and regulation has being developed for the application on smart infrastructure [14]. Digital construction technology, intelligent construction, information management and control, and high-quality development (as opposed to high-speed development) are now the main technical tools used in pavement construction in countries with a strong economy and development of new infrastructres.

3. Methodology

The main purpose of this research is to help different agents anticipating decisions that facilitate the quality control in the construction phase. It is not intended to solve all the existing gaps but focus on the capabilities provided by IoT to gather information spatially linked to GIS and integrated with BIM models.

The process followed was to translate the processes and methodology in use, in a more automatic process, as followed by [10]. It is not considered to get the verification in this paper.

3.1. Quality control and assessment in airfield pavement construction

The base for this study is a project at an airport with parallel runways. The execution of the project takes place in different phases, primarily based on runway closures and the routes that aircraft must follow in each case to minimize impact on airport operations. The construction company has implemented an integrated management system, with 80% of activities certified according to ISO 9001, 80% according to ISO 14001, and 69% according to ISO 50001 as of 2022. The main objective of the quality management plan (in accordance with the UNE-EN-ISO 9001 standard) is to deliver the work program meeting or exceeding the client's expectations in terms of quality, cost, and schedule.

For this study, we will focus on two process: control, and document preparation and control. The function of the first one is to identify and plan the control of activities necessary to achieve the expected quality in the project. To this end, a Process Control Plan is established, which defines Inspection Point Programs (IPPs) detailed later. The function of the second is the elaboration and control of documentation.

Integrating BIM features into Quality Control (QC) and Quality Assurance (QA) systems can enhance the functionality of the proposed quality management plan. BIM's parametric model data allows for user-defined data linking to model objects, enabling dynamic generation of site inspections and stricter control over construction activities. Figure 1 presents the schematic integration as proposed by [15]. BIM's extendibility feature allows for well-structured data to be added to model objects, facilitating performance analysis and continuous improvement in quality assurance planning across multiple projects.

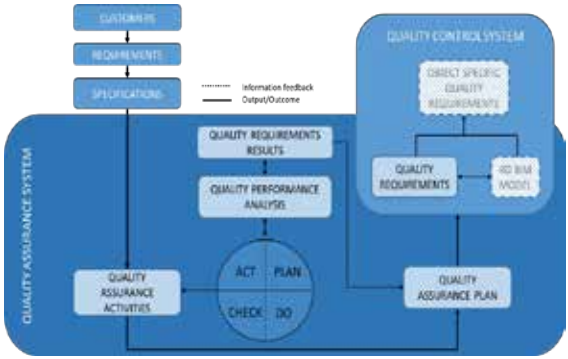

Figure 1 – Schematic integration of quality plan on company's quality managment system
Source: [15]

IPPs are satisfied as the project progresses, with each process being completed when the last defined IPP for that phase is fulfilled. Within each subprocess, various activities are incorporated, with different agents responsible for ensuring their correct execution. Depending on the subprocess, three types of control points are distinguished:

- Notification Point (N.P): an inspection point that does not require pausing the activity.
- Waiting Point (W.P): the next operation must be stopped until inspection is conducted by the designated agent.
- Stop Point (S.P): the next operation must be stopped until quality control is validated by Technical Assistance for Construction Inspection Services (CIS). Communication will be previously sent to the Works Management (control request point). The corresponding IPP (and documentation if applicable) with the checks carried out by the contractor will be attached.

IPPs may depend on the conducted and documented in the Project Testing Plan. The Testing Plan encompasses an analysis of the materials, elements, and installations to be executed, detailing the type and quantity of tests to be performed. The number of tests, defined by batches, is calculated according

to existing regulations, as well as any special requests from CIS, as deemed necessary by the project construction manager.

The project used as reference for this study considers the following construction subprocess: clearing and grubbing; excavation of the embankment; embankment; formation of embankments; crushed aggregate; hot mix asphalt; marking; lighting.

As an example of the activities and inspection points, the Figure 2 represents the flowchart of the hot bituminous mix extension, specifically for AC16 SUP 50/70 (designation according to UNE-EN 13108-1) to be used in the wearing course.

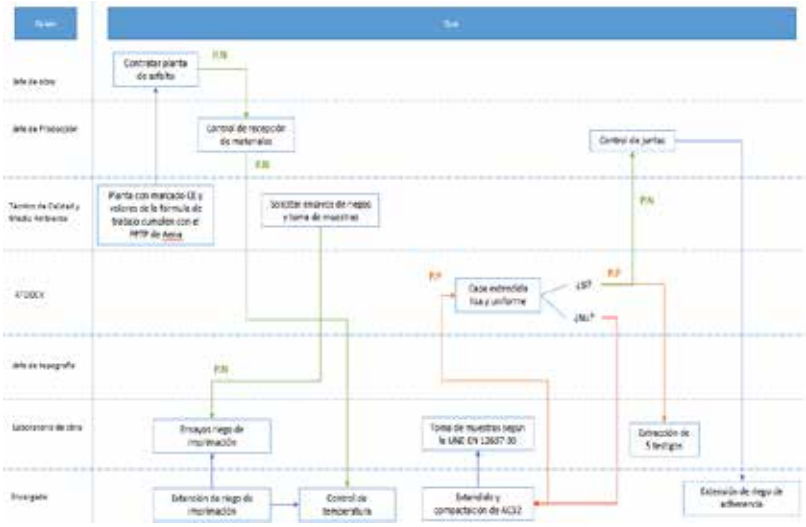

Figure 2. Flowchart of the AC16 SUP 50/70 hot bituminous mix extension
Source: Authors

The first step by the construction company is to locate a company whose asphalt plant has CE marking and whose values of the working formula comply with the Technical Specifications Particulars - Hot Bituminous Mixtures in Aircraft Movement Areas provided by the client. Once the company has been found, it will produce the bituminous mixture. Subsequently, the necessary mixture will be transported to the worksite, where the surface will have been prepared for asphalting. The production manager and the quality manager will be responsible for controlling the reception of the materials, ensuring that the material is received according to the indications in the manufacturing procedure.

When the material arrives, a temperature check is performed as the on-site placement must occur at a temperature much higher than ambient. First activity is the application of the bonding primer. Tests will be conducted following the current regulations .

Twenty-four hours after the application of the emulsified asphalt tack coat, the hot bituminous mix is extended and compacted. During extension, necessary samples are taken, and the temperature of the mix at the worksite is measured, ensuring it does not fall below the specified value in the working formula.

Upon completion of the unit, various checks are conducted based on the layer that has been extended.

- All layers: five core specimens are extracted from which density and thickness will be determined.
- Wearing course:
  - Surface Macrotexture is measured.
  - Slip resistance is determined.
  - PCN deflection index is determined according to the procedure detailed in the Technical Specifications Particulars - Hot Bituminous Mixtures in Aircraft Movement Areas (from the client).
  - The BOEING index (BBI) is measured as indicated in the FAA Advisory Circular AC No: 150/5380-9 "Guidelines and Procedures for Measuring Airfield Pavement Roughness," or alternatively, applicable specifications of the International Roughness Index (IRI).

At the end, the site surveyor must verufy that the extended layer is smooth and uniform, free from segregation or dragging, and with a thickness that, after compaction, fits within the tolerances indicated in the plans for the cross-section. If confirmed by the surveyor, this activity is considered valid, and joint control proceeds as specified in the Specific Technical Specifications.

3.2. Framework proposal

Figure 3 provides a comprehensive perspective on the process and stakeholders involved in each phase, along with the required digital products. During the design phase, a solution is developed based on owner-provided vision and requirements, often utilizing simulation models. This solution, along with technical documentation, is used to request authorization from public bodies and secure insurance coverage. Financial support and a business model presentation may be necessary. Approved solutions move to the construction phase, where BIM drives technical implementation alongside Supply Chain Management. As-built documentation is prepared, and authorization for services and exploitation is obtained. As shown in Figure 3, customized for the construction phase, it is essential to pinpoint the value created at different levels during each phases.

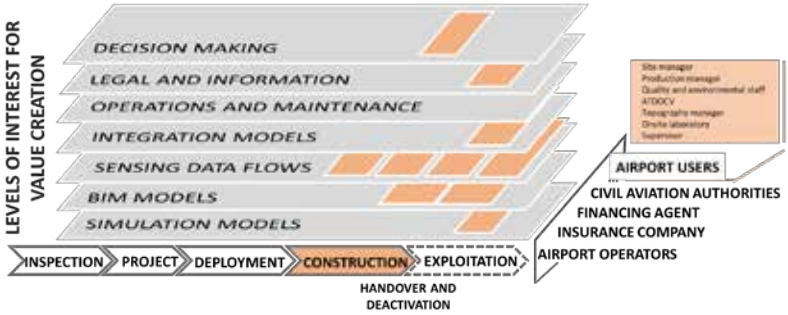

Figure 3. Reference framwork connectin agents with product phase and the layers of content management from the perspective of value creation. Source: Authors

4. Integration with BIM

As indicated in [6] a Common Data Environment (CDE) should be provided to uphold data integrity and control across the supply chain. Within this framework, a SHARED AREA is designated for information approved for sharing between companies or with clients. Once accepted, data is transferred to the PUBLISHED area, which consists of storage for data files and a database for relational objects and data models. However, the data in an APMS is distinct from the BIM model, necessitating robust integration efforts to enhance management capabilities (see Figure 4).

Construction process information exchange comprises several stages. Initially, construction data from various sections is generated on-site and recorded by technicians using for example data terminal equipment. The collected data is automatically uploaded to a data interaction and processing center deployed in a cloud database. Subsequently, a BIM model is constructed based on the design (Initially, the model contains generic design property parameters such as the number of lanes, lane width, elevation, etc) and construction transmission data. This model serves for integrating and visualizing construction data.

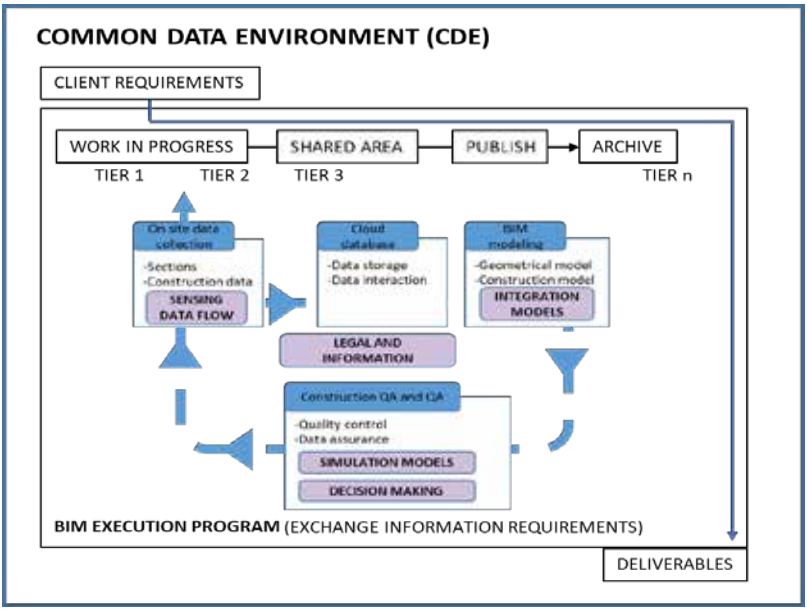

Figure 4. Integration of an Airport Pavement Management System (APMS) in the BIM process. Deployement Commont Data Environment for Construction QC and QA. Source: Authors

Ultimately, the BIM model is utilized for real-time construction quality control and assurance, providing guidance to road construction sites. A simulation method is incorporated into the model to quantitatively evaluate construction quality throughout the infrastructure construction process. Researchers have proposed using an ANN and GA combination for construction quality feedback control using real-time construction parameters. This approach enables the BIM model to guide road construction sites effectively.

To accommodate the varying access needs of different agents at different times, the proposed framework must be complemented by an strategy capable of facilitating such access. This involves granting access to legal authorizations alongside other necessary information such as construction projects or design models for traceability purposes. This perspective necessitates the storage of various object types and granting access to their respective components for different agents. Overall, this framework facilitates data interaction and closes the loop between the BIM model and the construction site.

5. Conclusion

AEC is witnessing a transformative era driven by innovative technologies like BIM. By integrating real construction site activities and quality plans into BIM Execution Plans, this study seeks to enhance control and optimize planning, marking a significant advancement in intelligent construction management.

This study centers on a project at an airport with parallel runways, executed in phases to minimize disruption to airport operations. Two key processes, control, and document preparation, are emphasized, with Process Control Plans defining Inspection Point Programs (IPPs) for quality control. Integrating BIM features enhances Quality Control (QC) and Quality Assurance (QA) systems, allowing for dynamic inspection generation and performance analysis.

The proposed framework emphasizes robust control across the supply chain, featuring designated areas for information sharing and storage. Initially, data generated onsite is recorded by technicians and uploaded to a cloud database for processing. Subsequently, a BIM model is constructed based on design and construction transmission data, serving to integrate and visualize construction data. This model then facilitates real-time construction quality control and assurance, guiding road construction sites effectively. Integration efforts between the Airport Pavement Management System (APMS) and BIM process, enhance construction QC and QA processes. Overall, this framework fosters data interaction, bridging the gap between the BIM model and the construction site, thereby enhancing management capabilities across the construction process.

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Gestão da Sustentabilidade Aeroportuária: Impacto da poluição sonora no aeroporto de Cabinda

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Abstract/Resumo/Resumen

Neste estudo será abordado a importância da sustentabilidade aeroportuária, especificamente oimpacto da poluição sonora que ocorre no aeroporto de Cabinda, em Angola.A realização deste projeto tem como base a utilização do método de pesquisa exploratória, focado na gestão da sustentabilidade aeroportuária com ênfase no impacto da poluição sonorano Aeroporto de Cabinda. A pesquisa exploratória é uma abordagem essencial para investigar ecompreender o tema, um tópico que tem crescido em relevância na gestão aeroportuária emtodo o mundo.A poluição sonora representa uma ameaça a saúde física e mental dos habitantes, oreconhecimento desta problemática irá servir para obtenção de dados, permitindo maior compreensão das adversidades e cenários da gestão da sustentabilidade nos aeroportos, visandoo equilíbrio entre o meio ambiente e a biocenose, procurando encontrar soluções que minimizem os impactos e que possam ajudar a evoluir e diminuir as fontes de poluição.Espera-se encontrar soluções que de facto ajudem a reduzir os impactos da poluição sonora do aeroporto de Cabinda, no meio ambiente e a biocenose ao redor, contribuindo para uma vida melhor e manutenção do bem estar das propriedades públicas.

Gestão da Sustentabilidade Aeroportuária: Análise do impacte da poluição sonora do aeroporto de Cabinda

1. Introdução

A gestão sustentável em aeroportos é essencial para equilibrar crescimento económico com preservação ambiental e qualidade de vida das comunidades próximas. O Aeroporto de Cabinda, crucial para a economia regional, exemplifica esse desafio ao gerar significativa poluição sonora. Esse ruído constante afeta a saúde dos moradores, causando distúrbios do sono, estresse, problemas de concentração e danos auditivos. Além disso, prejudica a vida selvagem, alterando padrões de alimentação, reprodução e migração. A gestão sustentável exige uma abordagem proativa para mitigar o impacto acústico, utilizando tecnologias e práticas que promovam o equilíbrio entre desenvolvimento económico e conservação ambiental, como demonstrado pela experiência do Aeroporto de Cabinda.

2. Enquadramento

Muitas fontes de ruído nos cercam, como a indústria, o tráfego rodoviário e ferroviário, e a aviação. O ruído da aviação é percebido como mais irritante que os outros, apesar de terem níveis de ruído equivalentes, Figura 1. Isso destaca a importância da perceção, incluindo fatores não acústicos, na definição das metas da ACARE para mitigar o ruído percebido.

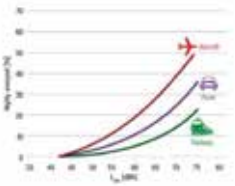

Figura 1: Impacte do ruido em % de incómodo nas deslocações com meios aéreo, rodoviários e comboio
Fonte: [1]

2.1. Fundamentos de Ruído e Som

O som é a energia transferida através do ar que nossos ouvidos detetam como mudanças na pressão do ar, sendo mais alto quanto mais energia for utilizada. "Tente sussurrar. Em seguida, grite. Você pode sentir o quanto mais energia vai para gritar[2].

Ruído é som indesejado, variando de pessoa para pessoa. Sons agradáveis, como um apito de trem distante, podem ser ruídos para outros, enquanto sons como um cachorro latindo à noite são universalmente irritantes. "O ruído tem um componente objetivo, físico; bem como um componente subjetivo que leva em conta a perceção individual, ou reação, de uma pessoa a um som[3]

2.2. Ruído Aeronáutico

A poluição sonora é definida como o excesso de som que causa incómodo, perturbação ou impacto negativo no ambiente. No contexto aeroportuário, o ruído das aeronaves é uma preocupação significativa, impactando áreas circundantes e regiões distantes devido ao sobrevoo de áreas densamente habitadas O ruído aeronáutico inclui barulhos de aterrissagem, decolagem, deslocamento em solo, circulação e testes de motores, além dos sistemas auxiliares das aeronaves [4]; [5]. Estudos recentes mostram uma ligação entre a exposição ao ruído das aeronaves e problemas de saúde como hipertensão arterial e doença cardíaca isquémica [6].

Os níveis de ruído são influenciados por fatores como o tipo de aeronave, tipo de motor, conFigurações de voo, condições meteorológicas, sistemas de captação de ruído, natureza do solo e presença de superfícies refletoras. No campo da acústica, que combina mecânica, física e neurociências, são utilizadas

grandezas como intensidade (W/m2), pressão sonora (Pa) e potência (W) para caracterizar a perceção auditiva e avaliar o incómodo [7]; [8]. As principais grandezas físicas da acústica são intensidade (W/m2), pressão sonora (Pa) e potência (W) [7].

A Agência Nacional de Aviação Civil (ANAC) de Portugal implementa regulamentações que Angola tende a seguir, como a restrição do tráfego noturno entre as 0 e as 6 horas, salvo emergências [9]. O Regulamento Geral do Ruído proíbe aterrissagens e decolagens durante a noite em aeroportos não cobertos pelo Decreto-Lei n.º 293/2003 [9]. Açores, pode haver proibição ou condicionamento dessas operações para cumprir os limites de exposição ao ruído ambiente [10].

2.3. Fontes de ruido

O ruído das aeronaves resulta da interação entre o ruído do motor e o da estrutura da aeronave [11]:

O ruído do motor provém das partes móveis e da passagem do ar, enquanto o da estrutura é gerado pelo impacto do ar. Avanços tecnológicos mostram que ambos contribuem igualmente durante a aterragem, mas na descolagem o motor ainda é a principal fonte. Dentro dos motores, há o ruído da maquinaria (partes móveis) e o ruído primário do jato (mistura do gás de escape com o ar). O ruído estrutural resulta da interação do ar com o trem de aterragem, dispositivos de sustentação e cavidades da aeronave, variando nas fases de voo.

2.3.1. Tipos de ruído

De acordo com a norma ISO 2204/1973, ruídos são classificados como contínuos (variação de aproximadamente 3 dB), intermitentes (variação rápida de 3 dB) e de impacto/impulso (picos acústicos de duração menor que um segundo). Um som tonal é identificado quando o nível de pressão sonora excede os das bandas adjacentes conforme a Tabela 1.

Tabela 1: Critério de tonalidade
Fonte: [12]

Faixa de frequência	25 Hz a 125 Hz	160 Hz a 400 Hz	500 Hz a 10k Hz
Diferença	15 dB	8 dB	5 dB

2.3.2. Contornos de ruído

Os níveis de ruído são calculados em locais específicos e representados em mapas com linhas conectando pontos de igual decibel (dBA), semelhantes a mapas topográficos. Esses contornos de ruído, como na Figura 3, comparam a exposição ao ruído em comunidades aeroportuárias, influenciados por fatores como o número de aeronaves chegando ou partindo.

Figura 2: Mapa do contorno do ruído
Fonte: [13]

2.4. Efeitos do ruído

Para a OMS, os principais efeitos adversos do ruído ambiente são: doenças cardiovasculares, comprometimento cognitivo, distúrbios no sono, zumbido (tinnitus) e incómodo [14]. perturbação do sono é destacada na Tabela 2.

Tabela 2: Efeitos do ruído na saúde
Fonte: [14]

Efeito	Dimensão	Indicador acústico	Limiar	Persistência temporal
Incómodo/Distúrbio	Psicossocial, Qualidade de vida	*Lden*	42	Crónico
Distúrbios no sono relatados	Qualidade de vida, saúde somática	*Ln*	42	Crónico
Aprendizagem, memória	Desempenho	*Leq*	50	Agudo, *crónico*
Hormônios relacionados ao estresse	Indicador de estresse	Lmax / *Leq*	Não disponível	Agudo, *crónico*

Efeito	Dimensão	Indicador acústico	Limiar	Persistência temporal
Sono	Estimulação / despertar / Qualidade do sono	L_{max} no interior	32	Agudo, *crónico*
Interrupções no sono relatadas	Sono	SEL no interior	53	Agudo
Saúde relatada	Bem-estar, saúde	*Lden*	50	*Crónico*
Hipertensão	Saúde fisiológica somática	*Lden*	50	*Crónico*
Doenças cardíacas	Saúde clínica	*Lden*	60	*Crónico*

Esses efeitos adversos levaram a OMS a propor padrões de ruído para proteger a saúde, especialmente de idosos, doentes e crianças na escola. Os valores máximos recomendados estão na Figura 3 e são mais baixos que os níveis antes considerados "ruído seguro". Essas medidas mitigam impactos negativos do ruído e promovem ambientes saudáveis e sustentáveis[15]. Embora aeroportos impulsionem o desenvolvimento regional, sua integração ao planejamento urbano deve ser completa. Grandes complexos como aeroportos exigem amplo espaço e acarretam impactos ambientais substanciais, necessitando vigilância rigoroso

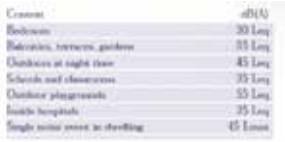

Figura 3:Valores máximos dos níveis de ruído recomendados pela WHO
Fonte: [15]

3. Metodologia e dados

3.1. Introdução

O capítulo 3 apresenta toda a metodologia de investigação, a descrição do método criado para a analisar o impacto da poluição sonora da população exposta nas redondezas do aeroporto, e por último será apresentada também a matriz do inquérito por questionário e entrevista resultante do método aplicado.

Este capítulo detalha ainda a implementação do método GSRA (Gestão da Sustentabilidade de Ruído de Aeroportos), que foi especialmente desenvolvido para este estudo, refletindo a necessidade de uma abordagem que integre tanto as métricas quantitativas do impacto do ruído quanto as respostas qualitativas das comunidades afetadas.

3.2. Investigação Mista

Esta é uma investigação mista. Este tipo de pesquisa destaca-se de outros tipos pela sua versatilidade e capacidade de análise. Este foi o método escolhido, acima de tudo, porque permite utilizar a parte quantitativa como uma aproximação do impacte e, de seguida, através da parte qualitativa analisar mais aprofundadamente esse impacte.

4. Caso de Estudo

O caso de estudo será o Aeroporto de Cabinda, localizado em Cabinda, Angola. O objetivo é analisar a Gestão da Sustentabilidade aeroportuária com enfase no impacto da poluição sonora no aeroporto de Cabinda. A escolha deste local foi estratégica, considerando suas características operacionais e seu contexto socioeconómico único, que apresentam desafios e oportunidades significativas para a implementação do modelo GSRA. Este estudo de caso proporciona uma visão valiosa sobre como as estratégias de gestão de ruído podem ser eficazes em contextos semelhantes. A criação do GSRA, Figura 4, foi inspirada pela crescente necessidade de abordagens sustentáveis na gestão aeroportuária, que não

apenas atendam às normativas de ruído, mas também considerem o bem-estar das populações afetadas. Neste estudo, é apresentada a fase 2 do modelo GSRA.

4.1. Aeroporto de estudo

A seleção do Aeroporto de Cabinda como caso de estudo foi baseada em critérios rigorosos, considerando a relevância geográfica, a singularidade socioeconômica da região e a intensidade do tráfego aéreo. Este estudo estratégico visa entender como um aeroporto em uma província rica em recursos naturais, mas com desafios de desenvolvimento, lida com a sustentabilidade ambiental. O Aeroporto de Cabinda, localizado em Angola, possui uma pista de 2.600 metros de comprimento e 30 metros de largura, permitindo a operação de grandes aeronaves como Boeing-777 e 737. O terminal tem 19 mil metros quadrados e acomoda até 900 passageiros em horários de pico[19][20].

4.2. Nível de ruido sob a população

De acordo com o Ministério do Ambiente de Angola, o limite de ruído em áreas residenciais é de 55 decibéis (dB) durante o dia e 50 dB à noite, para garantir bem-estar e qualidade de vida, evitando perturbações sonoras que afetam o sono. É crucial que todos respeitem esses limites. O aeroporto apresenta níveis de ruído entre 75 e 80 dB(A), especialmente durante decolagens, com velocidades de 110 nós
(203 km/h).
Esses níveis são considerados ruins para áreas mistas, onde não deveriam ultrapassar 55 dB(A) durante o dia, e no centro do aeroporto ultrapassam 80 dB(A), sendo intoleráveis ao ouvido humano.

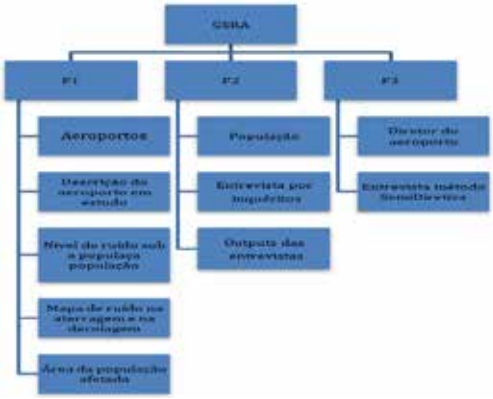

Figura 4: Modelo GSRA
Fonte: Elaboração Própria

4.3. Mapa de ruído

Para a simulação das curvas de ruído, são necessários dados de elevação, vento e temperatura. Estes devem ser obtidos de fontes governamentais ou da operadora do aeroporto, conforme Tabela 3.

Tabela 3: Dados gerais do FNCA
Fonte: Elaboração própria

Dados operacionais	Total
Número de movimentos anual (pousos + decolagens)	3.660
Percentual de operações diurnas	90%
Percentual de operações noturnas	10%

As curvas de ruído foram desenvolvidas com base na operação anual do FNCA em 2023, a considerar o período diurno das 07h às 22h e o período noturno das 22h às 7h, horário local. Para esse ano, estimou-

se um total de 5.856 (dados fictícios) operações anuais entre aterragens e decolagens, com uma média diária de 16 movimentos.

Tabela 4: Dados gerais do FNCA
Fonte: Elaboração própria

Pista	Comprimento	Cabeceiras			
		Cabeceira	Altitude (m)	Latitude*	Longitude*
1/19	2.600m	179L	20m	05 35.15S	012 11.28 E
		092P		05 36.50 S 05 35.98 S	012 11.30 E 012 11 18.50E

Observa-se nas Tabelas 4 e 5 a designação da pista, a orientação magnética, a altitude da cabeceira e dados operacionais.

Tabela 5: Dados da pista
Fonte: Elaboração própria

Nome do Aeroporto	Aeroporto de Cabinda Maria Mambo Café
Operador Aeroportuário	SGA
Cidade	Cabinda
Elevação do Aeroporto	latitude -5,59699 longitude 12,18840
Velocidade média do vento	6 km/h
Designador ICAO	FNCA
Coordenadas geográficas (WGS 84)	5°32'59" S/ 12°11'59" E
Designador IATA	CAB
Temperatura de referência	27º C

4.3.1. Questionário

O questionário demográfico teve como objetivo coletar informações sociodemográficas sobre os impactos do ruído na saúde da população estudada. Para isso, utilizou-se um questionário aplicado presencialmente, ou seja, porta-a-porta, nos bairros adjacentes ao aeroporto, como o bairro Atrás das Redes e Primeiro de Maio.

Neste projeto, para a avaliação do efeito adverso incómodo, adota-se a metodologia de avaliação da reação das comunidades expostas a uma determinada fonte de ruído ambiental, conforme indicado no ICBEN [19]. Os participantes precisavam responder o seu grau de incómodo numa escala de Likert de 10 pontos (escala de incómodo) com os limites: 0 para pouco incomodado e 10 para altamente incomodado [17] [20].

O questionário por inquérito elaborado contém perguntas sobre: dados pessoais, incómodo percebido, interferências na vida diária, impacto económico, atitude e perceções. O inquérito foi dividido em 3 duas seções.

- A Seção 1 apresenta 3 (três) questões que diz respeito à região de residência do pesquisado, à idade, sexo.
- A Seção 2 contém 10 (dez) perguntas relacionadas aos problemas de saúde, ao incómodo percebido, devido ao tráfego aeroportuário.
  A Seção 3 apresenta 4 (quatro) questões de respostas abertas que diz respeito à interação com o ruido no cotidiano, sugestões de mitigação e os planos de eficiência governamental.

4.4. Método de Aplicação

O questionário foi aplicado presencialmente, porta-a-porta, e as respostas foram digitalizadas e analisadas através do Google Forms. Isso permitiu a elaboração de gráficos para uma visualização clara das tendências e padrões nas respostas.

4.4.1. Tamanho da amostra

A presente amostra é composta por 31 respostas representativas da comunidade que reside nas proximidades do aeroporto de Cabinda, refletindo uma variedade de perspetivas e experiências em relação ao impacto do ruído aeronáutico.

4.4.2. mapa conceptual de ruído para o Aeroporto de Cabinda Maria Mambo Café

O mapa conceptual de ruído para o Aeroporto de Cabinda Maria Mambo Café foi desenvolvido para ilustrar as zonas de exposição ao ruído geradas principalmente pelas operações de Boeing 737 e 777, os modelos de aeronaves frequentemente utilizados neste aeroporto (Figura 5). Este tipo de visualização é crucial para avaliar o impacto ambiental e a qualidade de vida das comunidades ao redor do aeroporto.

Figura 5: Mapa conceitual de ruído para o Aeroporto de Cabinda Maria Mambo
Fonte: [19]

A pista do aeroporto, identificada como 1/19 com cabeceiras 179L e 092P, tem 2.600 metros de comprimento, adequada para aeronaves como Boeing 737 e 777. A orientação da pista é essencial para entender os padrões de decolagem e aterrissagem e a propagação do ruído. A zona Vermelha (75-80 dB) representa o nível mais alto de ruído, localizada ao redor da pista, prevalente durante decolagens. A zona Laranja (55 dB) corresponde ao Lmax matutino, estendendo-se além da área imediata da pista, enquanto a zona Amarela (50 dB) representa o Lmax noturno, com operações menos frequentes, mas ainda impactantes. O mapa indica que 90% das operações ocorrem durante o dia e 10% à noite, afetando diretamente as áreas residenciais nas zonas laranja e amarela.

Medidas de mitigação sugeridas incluem melhorar o isolamento acústico, planejamento de zoneamento para evitar desenvolvimento residencial em áreas de alto risco, e restrição de horários de voo. A disponibilização do mapa para comunidades afetadas é crucial para conscientização e diálogo entre comunidade, operadores e reguladores. Este mapa detalhado destaca a importância de políticas responsáveis de gestão de ruído, promovendo um ambiente mais saudável e sustentável, minimizando o impacto ambiental das operações aeroportuárias.

4.4.3. Análise da Secção 1 e dos dados sociodemográficos

A pesquisa revelou uma distribuição demográfica significativa entre os participantes, com 61,3% do sexo feminino e 38,7% do sexo masculino. Quanto à idade, 9,7% tinham menos de 18 anos, 35,5% estavam entre 18 e 25 anos, 38,7% entre 26 e 40 anos, 16,1% entre 41 e 60 anos, e nenhum tinha mais de 60 anos. Em termos de tempo de residência, 9,7% residiam há menos de 5 anos, 9,7% há mais de 5 anos, 6,4% há menos de 10 anos, 45,2% há mais de 10 anos, e 29% tinham um tempo de residência não especificado. A maioria (45,2%) vive nas proximidades do aeroporto há mais de 10 anos, indicando uma comunidade estável. No entanto, 29% da população com tempo de residência não especificado pode influenciar a compreensão total do contexto da pesquisa.

Além disso, 67,7% dos entrevistados relataram que o ruído é uma presença diária e frequente em suas vidas, indicando que o ruído aeronáutico afeta significativamente suas rotinas e qualidade de vida. Apenas 12,9% percebiam o ruído semanalmente, geralmente por não passarem muito tempo em casa. Por fim, 16,1% afirmaram que o ruído não tem mais impacto significativo, possivelmente devido à habituação ou resignação ao problema.

4.4.4. Analise da Secção 2

Na Seção 2 do questionário, as perguntas abordaram os problemas de saúde que surgem devido à exposição prolongada a ruído constante. A Figura 6 e Figura 7, apresenta os resultados obtidos, dos participantes. É notável que todos os inquiridos manifestaram algum nível de insónia e stress, representando 67,7% da população inquirida, enquanto 38,7% relataram problemas aditivos. Este dado

sugere uma correlação significativa entre a exposição ao ruído e o desenvolvimento desses problemas de saúde.

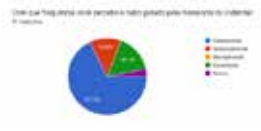

Figura 6: Perceções sobre o impacto do ruído aeroportuário
Fonte: Elaboração própria

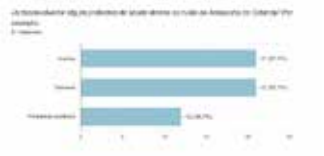

Figura 7: Perceções sobre o impacto do ruído aeroportuário
Fonte: Elaboração própria

A Figura 8 representa uma escala para avaliação do impacto do ruído aeroportuário, no qual os participantes classificaram o seu desconforto de 1 a 10. tendo considerado de 1 a 5 indicam impacto leve, e de 6 a 10, impacto relevante. Os dados ilustram que 12,9% da amostra se sente pouco impactada, enquanto 35,5% considera-se gravemente afetada pelo ruído das aeronaves, mostrando um desconforto acentuado a população s.

A Figura 9 ilustra que 77,4% da amostra nunca procuraram assistência médica por problemas relacionados a saúde auditiva, tendo 22,6% relataram ter procurado assistência. Isso significa uma subestimação dos impactos na saúde, insinuando que muitos ignoram ou minimizam os efeitos negativos do ruído constante.

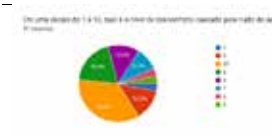

Figura 8: Níveis de desconforto com ruído aeroportuário
Fonte: Elaboração própria

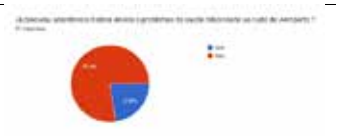

Figura 9: Assistência médica devido a ruído aeroportuário
Fonte: Elaboração própria

A procura por assistência junto às autoridades governamentais tem sido uma batalha constante para a população, frequentemente marcada pelo temor de não ser ouvida. A Figura 10 demostra que 77,4% dos participantes nunca procurou apoio ao governo para lidar com o ruído aeroportuário, porém 22,6% procuraram ajuda em organizações locais, grupos comunitários, autoridades governamentais. Estes dados representam um desafio significante na comunicação entre os cidadãos e as autoridades governamentais. Sugere o enfraquecimento ou ceticismo em relação à eficácia das medidas governamentais sobre o ruído aeroportuário. A indecisão na procura de assistência revela a necessidade urgente de reforçar a confiança e a comunicação entre os cidadãos e autoridades locais, é necessário garantir que a opinião pública seja considerada na criação de políticas e implementação de soluções para lidar com os desafios do ruído aeroportuário, visando o bem-estar e a qualidade da vida das pessoas afetadas.

A Figura 11, revela que 77,4% dos participantes compreende que o ruído aeroportuário tem impacte na qualidade de vida, outros 22,6% não referem tal interferência. Esta diferença de perceções ressalta a complexidade do problema do ruído aeroportuário e a necessidade de considerar diferentes perspetivas na criação de políticas e estratégias para melhorar a vida da população.

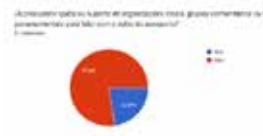

Figura 10: Assistência médica devido a ruído aeroportuário
Fonte: Elaboração própria

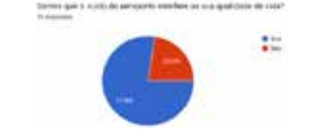

Figura 11: Ruido aeronáutico e a qualidade de vida
Fonte: Elaboração própria

A Figura 11 mostra que apenas 22,6% dos entrevistados estão cientes das medidas tomadas pelas autoridades para reduzir o impacto do ruído no Aeroporto de Cabinda. Esse número representa uma minoria que tem conhecimento das ações empreendidas pelas autoridades para abordar essa questão específica. Por outro lado, uma esmagadora maioria de 77,4% dos entrevistados declara não estar ciente das medidas adotadas pelas autoridades para mitigar o impacto do ruído no Aeroporto de Cabinda. Esses resultados indicam uma lacuna significativa na comunicação e transparência das autoridades em relação às iniciativas em curso para lidar com o problema do ruído aeroportuário. Essa falta de consciência sobre as medidas tomadas destaca a necessidade urgente de melhorar a divulgação e o engajamento público em relação às políticas e ações relacionadas ao ruído aeroportuário. Uma maior transparência e participação da comunidade podem ser essenciais para garantir que as medidas adotadas sejam eficazes e atendam às necessidades e preocupações da população afetada.

4.4.5. Analise da secção 3

Os participantes foram questionados sobre a eficácia das medidas adotadas e as razões por trás de suas opiniões. Os participantes expressaram opiniões divergentes sobre a eficácia das medidas contra o ruído aeroportuário. Alguns criticaram a falta de comunicação e implementação adequada pelas autoridades, enquanto outros reconheceram melhorias. As sugestões incluíram a restrição de voos noturnos, melhoria do isolamento acústico, otimização das trajetórias de voo, uso de tecnologias mais silenciosas, realocação dos aeroportos e criação de zonas tampão. O envolvimento contínuo da comunidade e a monitorização regular do ruído são essenciais para o sucesso destas medidas. Eles destacaram a importância de tecnologias e práticas que poderiam ser implementadas para mitigar o ruído, como isolamento acústico em edifícios residenciais próximos ao aeroporto e uso de aeronaves mais silenciosas.

Para atenuar o ruído de aeroportos e melhorar a qualidade de vida das comunidades vizinhas, é essencial adotar uma estratégia multifacetada. Restringir voos durante períodos noturnos pode reduzir significativamente a perturbação do sono dos residentes. Paralelamente, melhorar o isolamento acústico de edifícios próximos ao aeroporto, utilizando janelas de vidro triplo e materiais isolantes em paredes e tetos, pode diminuir a penetração do ruído nas residências. Adicionalmente, otimizar procedimentos de voo para que as aeronaves operem em trajetórias que minimizem o ruído sobre áreas residenciais e promover o uso de tecnologia mais silenciosa nas aeronaves são passos importantes. Considerar a realocação do aeroporto para áreas menos densamente povoadas ou o estabelecimento de zonas tampão, como áreas verdes, entre o aeroporto e as comunidades, também pode ser eficaz. O envolvimento contínuo da comunidade nas decisões e a implementação de um sistema robusto de monitorização do ruído ajudam a ajustar as medidas conforme necessário e garantem que as intervenções sejam efetivas e bem-aceitas pelos afetados.

5. Conclusões

Em suma, o mapa conceitual de ruído para o Aeroporto de Cabinda Maria Mambo Café revela a complexidade dos impactos ambientais e sociais das operações de aeronaves, como os Boeing 737 e 777, sobre as comunidades locais. A análise detalhada das zonas de exposição ao ruído, assim como a orientação e o comprimento da pista, proporcionam um entendimento aprofundado de como o ruído se propaga e afeta as áreas residenciais vizinhas. A identificação das zonas de ruído mais críticas, como as zonas Vermelho e Laranja, destaca a necessidade urgente de medidas de mitigação, incluindo isolamento acústico, planejamento de zoneamento e horários de voo restritos, para proteger a qualidade de vida dos residentes.

Os dados sociodemográficos dos participantes da pesquisa indicam que a comunidade afetada é maioritariamente feminina e jovem, residindo há longo tempo nas proximidades do aeroporto, o que sugere uma exposição significativa e prolongada ao ruído. As consequências dessa exposição são evidenciadas pelos relatos de problemas de saúde como insónia e estresse, corroborando a necessidade de uma abordagem proativa no manejo do ruído aeroportuário. Adicionalmente, os dados revelam que uma grande maioria, correspondente a 87,1% dos entrevistados, percebe o ruído proveniente do Aeroporto de Cabinda como um problema significativo, ressaltando uma preocupação comum entre os residentes sobre os impactos negativos do ruído aeroportuário em suas vidas diárias e em sua saúde. Por outro lado, a minoria de 12,9% que não considera o ruído um problema significativo para a comunidade local destaca a existência de diversas perceções sobre o assunto, o que reforça a importância de

considerar uma variedade de perspetivas ao desenvolver políticas e estratégias para mitigar esses impactos. A falta de conhecimento sobre as medidas tomadas para mitigar os impactos do ruído acentua a importância de melhorar a comunicação e o envolvimento das comunidades afetadas. É essencial que as autoridades aeroportuárias e os reguladores intensifiquem seus esforços para informar e colaborar com as comunidades locais, garantindo que as políticas e práticas adotadas sejam transparentes e efetivas. Ao fazer isso, pode-se promover um equilíbrio entre o desenvolvimento aeroportuário e a preservação da qualidade de vida e bem-estar dos cidadãos locais, assegurando que as preocupações da comunidade sejam ouvidas e levadas em consideração."

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Quantification of Bird Strike Risk in Aircraft Landing and Takeoff Operations at Major Airports in São Paulo, SP - Brazil

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Abstract/Resumo/Resumen

One of the occurrences that pose a problem for the aviation industry, is the collisions of aircraft with birds. Knowing what the main factors are, how they relate, and what most impacts this type of event, collaborates with the operational safety of air transport. Thus, this work aims to propose a general model of accident of commercial aircraft by collision with birds, able to quantifying the impact of the main factors involved in collisions in the landing and takeoff phases for the main airports in the State of São Paulo-SP, Brazil. The factors evaluated were time, cloud cover, species behavior, species mass, flight phase, altitude, speed, and part affected. The model was developed using the Bayesian Networks method, where the probabilities of the states of each factor were obtained, in scenarios with and without evidence. Comparing scenarios with and without evidence, it was identified that for both airports, SBGR, SBSP, and SBKP, the landing phase is the most critical when there is evidence of collision. On the other hand, when there is evidence of collision, is in the takeoff phase, the engine is the most critical part affected for SBGR and SBSP. Finally, the worst-case scenario for SBKP shows that two or more birds of the species behavior as the most critical situation. Accident models that quantify the impact of factors, especially during landing and takeoff phases, are rarer in the literature; therefore, this study proposes a significant contribution to the management of operational safety in airports with high annual operational movement density.Keywords: Air Transport. Accident Model. Birdstrike. Safety. Bayesian Networks.

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1. Introduction

Air transportation is essential for a nation's economic and social development, facilitating the rapid movement of goods and people, enabling the flow of business agents, and promoting commercial activities [1]. It is one of the most significant sectors for economic development and improving citizens' quality of life [2]. However, with the increase in aircraft fleet size and flight movements, there has been an increase in the number of accidents and incidents. A persistent issue within the aviation sector is accidents caused by aircraft collisions with birds [3, 4, 5].

The number of collision incidents involving fauna reported to the Center for Investigation and Prevention of Aeronautical Accidents – CENIPA has significantly increased in recent years in Brazil. Between 2016 and 2020, 42,765 events were reported, of which 5,356 were due to collisions with birds [6]. These conflicts become more significant as severe collisions that result in damages can lead to substantial economic losses, the death of crew and passengers, cargo loss, and associated costs for the aviation industry [7, 8, 9,10].

Various studies have conducted risk management analyses at aerodromes, defining the probability and severity of such incidents at specific sites or regions by scanning involved factors [7, 11-14]. Research that analyzes the scenario and factors related to collisions between aircraft and birds, approaches using different techniques and methods are utilized, such as regression analysis [15], density calculation [14], risk index [10], and Bayesian networks [16, 2], among others. Understanding the hazards or risk factors related to avian collisions is crucial for implementing management measures to mitigate collision risks.

The main airports in the state of São Paulo, Brazil, from 2011 to 2021, rank among the ten airports most critical for bird collisions. São Paulo/Guarulhos International Airport (SBGR) is ranked first, Viracopos International Airport (SBKP) third, and São Paulo/Congonhas Airport (SBSP) ninth [6]. Notably, 66.29% of bird collisions at both airports occurred during the landing and takeoff phases [6].

This paper proposes a general model for commercial aircraft accidents due to bird collisions that can quantify the impact of the main factors involved in incidents during the landing and takeoff phases at São Paulo/Guarulhos International Airport (SBGR), São Paulo/Congonhas Airport (SBSP), and Viracopos/Campinas International Airport (SBKP) in the state of São Paulo, Brazil.

2. Literature Review

As stipulated by the International Civil Aviation Organization (ICAO) [17], incidents involving collisions or near collisions with birds are termed BIRD or Birdstrike. In Brazil, CENIPA [18] classifies incidents involving birds into collision, near collision, and sighting. A bird strike refers to an event in which the crew has witnessed the collision, there is evidence of damage from the collision on the aircraft, carcasses have been located, or the presence of the bird has a significant effect on the operation of the aircraft [18].

The Safety Management System (SMS) [19] involves the organizational structure, procedures, processes, and provisions for implementing safety policies. One way to support the SMS is by developing models that can be used to evaluate accidents. Accident models help create a mental picture, facilitate questioning, and obtain physical, visual, mathematical, or descriptive information [16]. For the conception of Bird Collision Accident Model, it became crucial to investigate the factors involved in bird collisions and understand how they relate to each other.

For this purpose, academic and normative literature was used to identify the main factors involved in aircraft incidents due to bird collisions. It is emphasized that a wide range of cited factors can contribute to collisions; however, through the literature review, it became possible to observe the recurrent parameters in more than one study. In research that analyzes the scenario and factors related to collisions between aircraft and birds, approaches using different techniques and methods are utilized, such as regression analysis [15], density calculation [14], risk index [10], and Bayesian networks [2, 16], among others. There are studies analyzing the presence of species at aerodromes and their characteristics, the existence of attractive foci, historical collision analysis, and analysis aimed at improving the risk management process, among others [11-12, 20]. Table 1 synthesizes common factors cited in the literature and the presence of each of these factors in the studies analyzed and considered in this research (from academic or normative literature).

Table 1 – Selected Factors and Presence in the Literature. Source: Authors

Authors	Flight phase	Height	Time	Speed	Affect Part of the Aircraft	Cloud Cover	Species Mass	Species Behavior
Linnel *et al.* (1996)	■				■		■	■
Linnel *et al.* (1999)	■		■			■	■	■
Zakrajsek e Bissonette (2005)					■			
ALLAN (2006)							■	
Dolbeer (2006)		■	■					
Shaw and Mckee (2008)	■	■	■		■	■	■	■
Soldatini *et al.* (2010)			■				■	■
ALLAN et al. (2016)							■	■
Oliveira (2017)		■		■			■	■
CENIPA (2017)	■	■	■	■	■	■	■	■
Jeffery e Buschke (2018)							■	■
Oliveira (2018)	■			■				
Nimmagadda *et al.* (2020)	■	■	■		■		■	■
ANAC (2021)			■				■	■
GHAZAOUI *et al.* (2022)								■

It is emphasized that, due to bird strikes being one of the most recurrent occurrences in aviation, many studies have been developed that address the theme. However, a more in-depth and comprehensive analysis of the factors influencing the probability of a bird strike occurrence and how these factors interrelate is absent in many risk assessment procedures, except in [2], where the author utilized expert opinions in probability calculations. It is also noteworthy that models of accidents that can relate and/or to quantify the impact of factors, especially during the landing and takeoff phases, have not been found to date.

3. Methodology

3.1 Database

The reports of events involving fauna in Brazil are conducted using the CENIPA 15 form online through the Avian Risk Management System (SIGRA). The cases of collisions, near collisions, and sightings are reported by the aerodrome operator, wildlife management team, crew, air traffic controllers, and others. The database of these reports is made available on the Federal Government's Open Data Portal by CENIPA. The database contains 23,001 reports of collisions with fauna in Brazil between 2011 and 2021 (the data have national coverage).

The data, a result of a rigorous filtering process, was first sifted for bird collisions involving aircraft with a capacity above 30 passengers to align with our objective. From this analysis, the database included 15,033 collision reports (6,627 involved birds and 8,406 with unidentified species during the landing and takeoff phases) in Brazil. Of the total 15,033 collisions considered, 1,108 collisions occurred at SBGR, 824 at SBKP, and 524 at SBSP from 2011 to 2021. Notably, 60.92% of the collisions at SBGR and 55.73% of the collisions at SBSP involved aircraft models from the Airbus A310/318/319/320/321 family and the Boeing B737 family. For the SBKP airport, 66.02% of the considered collisions involved aircraft from the ATR 72 family.

The process of inferring the probability of a collision between an airplane and a bird is based on the universe of possible cases, which refers to the number of aircraft movements over the same period. The selected data, sourced from the Hórus system of the National Secretariat of Civil Aviation (SAC), provides a comprehensive view of the annual evolution of aircraft movements for domestic and international flights, boarding and disembarking, and regular flights from the São Paulo aerodromes considered over the period from 2011 to 2021. This data, depicted in Figure 1, shows that São Paulo/Guarulhos International Airport accounted for 2,591,393 million aircraft movements; São Paulo Airport, 1,610,582; and Viracopos/Campinas International Airport showed 1,121,393 million for the same period. From the official data of CENIPA and SAC, the a priori probabilities were calculated, and the Conditional Probability Tables - CPT were populated.

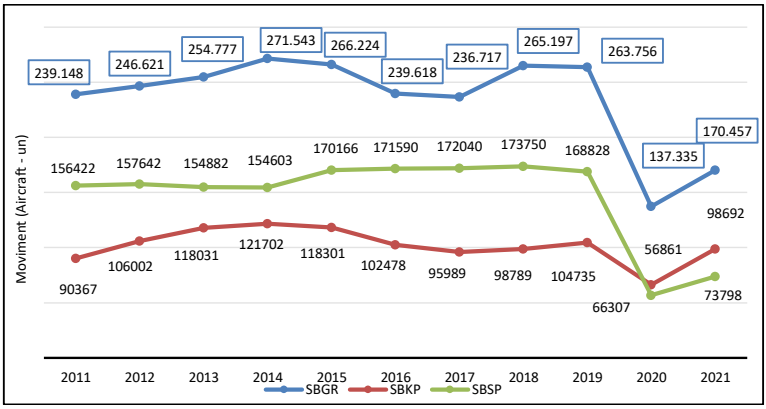

Figure 1 – Aircraft movements in SBGR, SBSP and SBKP from 2011 to 2021. Source: [21]

3.2 Selected Factors

The factors listed in Table 1 were chosen for the Accident Model because they are not just cited in the literature, but also have data collected in collision reports made to CENIPA. This dual sourcing of data ensures the robustness of the research. Based on the review of factors highlighted by the literature, four categories were defined: event, environment, birds, and aircraft.

In this case, the environment delineates factors of the external environment, including time and cloud cover. Birds is the category that defines avian fauna represented by the factors of species mass and species behavior. Although located in the environment, environmental factors directly influence the conditions of the presence and behavior of birds, as presented in the literature. Thus, the relationship between the environment and birds is direct. Finally, the aircraft category delimits specific conditions of aircraft operations that stood out in the literature and are represented by the factors: flight phase, AGL (Above Ground Level) height, speed, and parts of the aircraft affected. The states for each factor were defined by the literature and by information collected for each CENIPA report [21]. Table 2 presents the details of the categories, factors, and their states, as well as the percentage of occurrence in each state by airport.

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Table 2 – Factor and their states with percentage of occurrence per aerodrome. Source: [23]

Category	Factor	States	SBGR	SBKP	SBSP
			1108 collisions	824 collisions	524 collisions
			2591393 movements	1121393 movements	1610582 movements
Event	Event	Occurs	0.04%	0.07%	0.03%
		Not Occurs	99.96%	99.93%	99.97%
Environment	Time	Day	67.69%	62.01%	76.15%
		Night	32.31%	37.99%	23.85%
	Cloud Cover	Clear Sky	50.90%	88.47%	73.18%
		Few Clouds	22.20%	10.01%	15.58%
		Cloudy Sky	21.03%	1.52%	11.24%
Birds	Species Mass	≤ 1500 gramas	93.77%	94.05%	94.47%
		> 1500 gramas	6.23%	5.95%	5.53%
	Species Behavior	1 bird	82.13%	91.50%	82.82%
		≥ 2 birds	7.04%	2.79%	10.69%
Aircraft	Flight Phase	Landing	51.99%	64.56%	50.19%
		Take-off	43.50%	26.58%	31.87%
	AGL Height	≤ 500 ft	83.94%	87.38%	81.87%
		500 < A ≤ 3500 ft	8.94%	6.43%	8.97%
		> 3500 ft	6.50%	2.91%	7.25%
	Speed	≤ 80 kt	55.96%	72.82%	67.18%
		80 < V ≤ 200 kt	38.09%	21.12%	26.53%
		> 200 kt	3.88%	2.31%	3.82%
	Affected Part of the Aircraft	Fuselage	15.79%	17.35%	13.17%
		Engine	16.06%	20.75%	19.08%
		Radome	14.98%	12.14%	16.41%
		Windshield	9.21%	8.37%	8.97%
		Wing	5.42%	7.28%	7.06%

3.3 Bayesian Networks

The Bayesian Networks theory was used, which probabilistically estimates events of a system and represents conditional probability relationships between variables. Widely used in artificial intelligence systems, Bayesian Networks facilitate top-down and bottom-up analyses and help in understanding complex systems that depend on many factors [2].

The probability of an event is a measure of how likely or unlikely the event is to occur, hence the chances of occurrence. An event will be conditional on a second event if its probability is altered by the knowledge of the second event's state [24]. A posterior probability from prior probabilities is calculated according to Bayes' Theorem. This calculation is based on the Total Probability Law, as shown in Equation 1.

$$P(B) = P(B|A_1)P(A_1) + \cdots + P(B|A_k)P(A_k) = \sum_{i=1}^{k} P(B|A_i)P(A_i) \quad (1)$$

Where:

- $P(B)$: Probability of event B;
- $P(B|A)$: Conditional probability of B given that A occurred;
- $P(A)$: Probability of event A.

A Bayesian Belief Network (BBN) is a directed acyclic graph representing a dependency model in a domain or universe of interest. Variables can be parent nodes or child nodes. A node that is not influenced by any other is called a “parent node,” and the “child node” if another directly influences it. It should also be noted that, by

this logic, a root node has no parents, and a child node has no children [24]. In a scenario where some state of the nodes is known, it is possible to indicate the node's value to the model so that the network is updated based on the observed evidence [2].

Due to the complexity of the accident model analysis, the method that best serves an analysis from the basic elements to the main event (bottom-up) or from the main event to the basic elements (top-down) are Bayesian networks, unlike techniques such as fault tree analysis, which performs top-down analyses, and event tree analysis, which only performs bottom-up analyses. Various computational resources are used in the market to perform these analyses. The Netica® software (Norsys Software Corp.) was the computational tool used to perform the inferences in Bayesian Networks.

Subsequently, scenarios were simulated with evidence in the event and with evidence in each flight phase considered – landing and takeoff. Figure 3 shows, as an example, the network for the SBSP airport with evidence from the event and the landing. Table 3, 4 and 5 represent all the probabilities of the states of each factor in the scenarios: (i) without evidence of the event, (ii) with evidence in the event (COLLISION OCCURS) and (iii) with evidence in the flight phase (LANDING or TAKEOFF), for SBGR, SBSP and SBKP airports.

4. Results

Figure 2 displays the network—with the representation of nodes and their states—developed in the Netica® software as an example. It presents the probabilities calculated for the scenario with evidence in the event (COLLISION OCCURS) for SBGR airport. This simulation, with evidence from the event, was also performed for SBSP and SBKP airports. Figure 3, as an example, shows the network for SBSP airport with evidence in the event and during the landing phase.

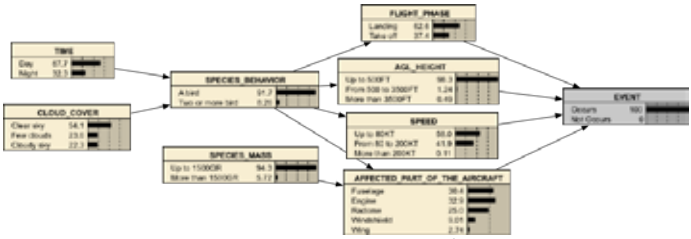

Figure 2 – BBN Netica: SBGR aiport with evidence from the event.
Source: Authors – developed in Netica®

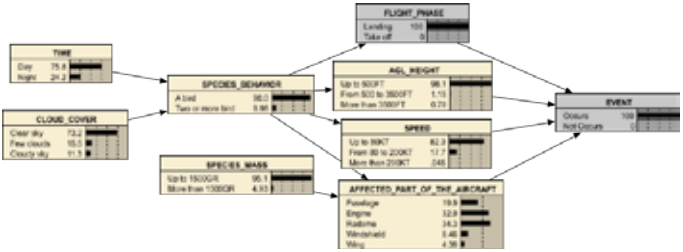

Figure 3 – BBN Netica: SBSP airport with evidence from the event and the landing.
Source: Authors – developed in Netica®

In Tables 3, 4, and 5, all the probabilities of the states for each factor are represented in the scenarios: (i) without evidence of the event; (ii) with evidence in the event (COLLISION OCCURS); and (iii) with evidence in the flight phase (LANDING or TAKEOFF) for the airports SBGR, SBSP, and SBKP. The increase in probability reveals the rise or fall in the likelihood of each occurring, measured by the ratio between the probabilities in the scenarios with evidence and without evidence. The states that showed an increase in probability in each scenario were highlighted in colors: blue in scenario (i), green in scenario (ii), and yellow in scenario (iii).

4.1 São Paulo/Guarulhos International Airport (SBGR)

In Scenario (Ci) with evidence of the collision for SBGR as per Table 3, the scenario with the most significant impact for the event to occur involves the engine as the main part affected, up to 500 feet as the most critical height, landing phase as the most critical, fuselage as the second main part affected, radome as the third main part affected, aircraft speed of 80 to 200 knots, aircraft speed up to 80 knots, two or more birds involved, mass up to 1,500 grams, daytime, sky with few clouds or overcast, in this order of importance.

For Scenario (Cii) with evidence in the event and landing as per Table 3, the simulation indicated that the critical scenario under these conditions involves the radome as the main part affected, up to 500 feet height, fuselage as the second main part affected, engine as the third main part affected, aircraft speed up to 80 knots, one bird involved, mass up to 1,500 grams, nighttime, clear sky (no clouds), in this order.

Finally, for Scenario (Ciii) with evidence in the event and takeoff for SBGR as per Table 3, the scenario with the most significant impact for the event to occur involves the engine as the main part affected, two or more birds, aircraft speed of 80 to 200 knots, fuselage as the second main part affected, up to 500 feet, daytime, sky with few clouds, mass up to 1,500 grams, overcast sky, in this sequence of importance.

The increase in probability reveals the increase or decrease in the probability of each occurring, measured by the ratio between the probabilities of the scenarios with evidence and without evidence. The states that showed an increase in probability in each scenario were highlighted by blue in scenario (i), green in scenario (ii) and yellow in scenario (iii).

Table 3 – Risk Quantification for SBGR (2011 to 2021). Source: Authors.

States	Without Evidence	With Evidence (Event)	Probability Increase (Ci)	With Evidence (Landing)	Probability Increase (Cii)	With Evidence (Takeoff)	Probability Increase (Ciii)
Up to 500ft	0.84318	9.86E-01	116.89%	9.87E-01	117.01%	9.84E-01	116.69%
From 500 to 3500ft	4.58E-02	6.19E-03	13.51%	5.86E-03	12.78%	6.75E-03	14.73%
More than 3500ft	1.11E-01	8.22E-03	7.41%	7.56E-03	6.81%	9.33E-03	8.41%
Clear Sky	5.41E-01	5.41E-01	99.98%	5.41E-01	100.12%	5.39E-01	99.74%
Few Clouds	2.36E-01	2.36E-01	100.03%	2.35E-01	99.79%	2.37E-01	100.44%
Cloudy Sky	2.23E-01	2.23E-01	100.01%	2.23E-01	99.93%	2.24E-01	100.16%
One bird	9.20E-01	9.18E-01	99.72%	9.35E-01	101.58%	8.89E-01	96.60%
Two or more bird	7.96E-02	8.21E-02	103.25%	6.50E-02	81.72%	1.11E-01	139.34%
Occurs	9.4091E-06	100%	-	100%	-	100%	-
Not Occurs	9.9999E-01	0%	-	0%	-	0%	-
Landing	5.37E-01	6.26E-01	116.68%	100%	-	0%	-
Take-off	4.63E-01	3.74E-01	80.67%	0%	-	100%	-
Day	6.77E-01	6.77E-01	100.05%	6.75E-01	99.70%	6.81E-01	100.65%
Night	3.23E-01	3.23E-01	99.89%	3.25E-01	100.63%	3.19E-01	98.64%
Up to 1500gr	9.38E-01	9.43E-01	100.54%	9.44E-01	100.64%	9.41E-01	100.38%
More than 1500gr	6.23E-02	5.72E-02	91.82%	5.63E-02	90.39%	5.87E-02	94.21%
Fuselage	2.61E-01	3.04E-01	116.37%	2.99E-01	114.33%	3.13E-01	119.80%
Engine	2.60E-01	3.29E-01	126.52%	2.97E-01	114.22%	3.82E-01	147.15%
Radome	2.35E-01	2.49E-01	105.99%	2.82E-01	119.81%	1.95E-01	82.81%
Windshield	1.61E-01	9.09E-02	56.52%	9.33E-02	58.03%	8.68E-02	53.99%
Wing	8.30E-02	2.71E-02	32.70%	2.95E-02	35.55%	2.32E-02	27.91%
Up to 80kt	5.59E-01	5.81E-01	103.91%	6.33E-01	113.12%	4.95E-01	88.46%
From 80 to 200kt	4.01E-01	4.18E-01	104.04%	3.66E-01	91.31%	5.03E-01	125.40%
More than 200kt	3.93E-02	1.22E-03	3.12%	8.27E-04	2.10%	1.89E-03	4.82%

4.2 São Paulo/Congonhas Airport (SBSP)

In Scenario (Ci) with evidence of a collision at SBSP, as outlined in Table 4, the scenario with the most significant impact on the event occurrence involves the engine as the main affected part, the landing phase as the most critical, up to 500 feet as the most critical altitude, aircraft speed up to 80 knots, the radome as the second main affected part, mass up to 1,500 grams, two or more birds involved, daytime, and sky conditions of few clouds or clear, in this order of importance.

For Scenario (Cii), with evidence in the event and during the landing phase as per Table 4, the simulation indicated that the critical scenario under these conditions involves the radome as the main affected part, aircraft speed up to 80 knots, the engine as the second main affected part, up to 500 feet, one bird involved, nighttime, mass up to 1,500 grams, and overcast and clear skies, in this order.

Finally, for Scenario (Ciii) at SBSP, with evidence in the event and during the takeoff phase, the states that showed an increase in probability are highlighted in Table 4. The scenario with the most significant impact for the event to occur under these conditions involves the engine as the main affected part, two or more birds involved, up to 500 feet altitude, aircraft speed up to 80 knots, daytime, few clouds, and a bird species mass up to 1,500 grams.

Table 4 – Risk Quantification for SBGR (2011 to 2021). Source: Authors.

States	Without Evidence	With Evidence (Event)	Probability Increase (Ci)	With Evidence (Landing)	Probability Increase (Cii)	With Evidence (Takeoff)	Probability Increase (Ciii)
Up to 500ft	8.32E-01	9.82E-01	118.00%	9.81E-01	117.87%	9.85E-01	118.40%
From 500 to 3500ft	9.12E-02	1.12E-02	12.31%	1.15E-02	12.63%	1.03E-02	11.25%
More than 3500ft	7.67E-02	7.01E-03	9.14%	7.76E-03	10.11%	4.60E-03	5.99%
Clear Sky	7.32E-01	7.32E-01	100.00%	7.32E-01	100.04%	7.31E-01	99.86%
Few Clouds	1.56E-01	1.56E-01	100.00%	1.55E-01	99.52%	1.58E-01	101.59%
Cloudy Sky	1.12E-01	1.12E-01	99.99%	1.13E-01	100.38%	1.11E-01	98.74%
One bird	8.83E-01	8.83E-01	99.99%	9.00E-01	101.98%	8.25E-01	93.48%
Two or more bird	1.17E-01	1.17E-01	100.11%	9.98E-02	85.09%	1.75E-01	149.04%
Occurs	8.2379E-06	100%	-	100%	-	100%	-
Not Occurs	9.9999E-01	0%	-	0%	-	0%	-
Landing	6.12E-01	7.65E-01	125.04%	100%	-	0%	-
Take-off	3.88E-01	2.35E-01	60.53%	0%	-	100%	-
Day	7.61E-01	7.61E-01	100.00%	7.58E-01	99.57%	7.72E-01	101.41%
Night	2.39E-01	2.39E-01	99.99%	2.42E-01	101.37%	2.28E-01	95.51%
Up to 1500gr	9.45E-01	9.51E-01	100.68%	9.51E-01	100.64%	9.53E-01	100.84%
More than 1500gr	5.53E-02	4.89E-02	88.32%	4.93E-02	89.12%	4.74E-02	85.73%
Fuselage	2.13E-01	1.96E-01	92.06%	1.99E-01	93.50%	1.86E-01	87.37%
Engine	2.75E-01	3.65E-01	132.67%	3.29E-01	119.85%	4.80E-01	174.43%
Radome	2.82E-01	3.12E-01	110.65%	3.43E-01	121.78%	2.10E-01	74.41%
Windshield	1.33E-01	8.64E-02	64.83%	8.46E-02	63.46%	9.24E-02	69.27%
Wing	9.72E-02	4.11E-02	42.31%	4.38E-02	45.02%	3.25E-02	33.48%
Up to 80kt	6.82E-01	8.02E-01	117.59%	8.23E-01	120.54%	7.37E-01	107.98%
From 80 to 200kt	2.76E-01	1.97E-01	71.36%	1.77E-01	64.14%	2.62E-01	94.87%
More than 200kt	4.16E-02	6.55E-04	1.57%	4.48E-04	1.08%	1.33E-03	3.19%

4.3 Viracopos/Campinas International Airport (SBKP)

In Scenario (Ci), a collision at SBKP is evidenced, as highlighted in the crucial data of Table 5. This data reveals that the scenario with the most significant impact on the event occurrence involves the engine as the main affected part, the landing phase as the most critical, aircraft speed up to 80 knots, the fuselage as the second main affected part, up to 500 feet, one bird involved, mass up to 1,500 grams, nighttime, and sky conditions of few clouds and clear, in this order of importance.

For Scenario (Cii), the simulation, with its precise results, indicated that the critical scenario under these conditions involves the engine as the main affected part, aircraft speed up to 80 knots, up to 500 feet, the fuselage as the second main affected part, one bird involved, mass up to 1,500 grams, nighttime, and sky conditions of few clouds and clear, in this order.

Lastly, for Scenario (Ciii) with evidence in the event and during the takeoff phase at SBKP, the states showing an increase in probability, as indicated in Table 5 suggest that the scenario with the most significant impact for the event to occur involves: two or more birds involved, the fuselage as the main affected part, aircraft speed up to 80 knots, up to 500 feet, overcast cloud conditions, mass up to 1,500 grams, and daytime, in this sequence.

Table 5 – Risk Quantification for SBGR (2011 to 2021). Source: Authors.

States	Without Evidence	With Evidence (Event)	Probability Increase (Ci)	With Evidence (Landing)	Probability Increase (Cii)	With Evidence (Takeoff)	Probability Increase (Ciii)
Up to 500ft	9.03E-01	9.98E-01	110.44%	9.98E-01	110.47%	9.94E-01	110.09%

From 500 to 3500ft	6.48E-02	2.23E-03	3.44%	1.91E-03	2.95%	5.25E-03	8.10%
More than 3500ft	3.20E-02	2.77E-04	0.87%	2.63E-04	0.82%	4.10E-04	1.28%
Clear Sky	8.85E-01	8.85E-01	100.02%	8.85E-01	100.02%	8.84E-01	99.98%
Few Clouds	1.00E-01	1.00E-01	100.15%	1.00E-01	100.18%	9.99E-02	99.80%
Cloudy Sky	1.52E-02	1.49E-02	97.87%	1.48E-02	97.36%	1.56E-02	102.75%
One bird	9.71E-01	9.84E-01	101.31%	9.87E-01	101.62%	9.55E-01	98.31%
Two or more bird	2.89E-02	1.49E-02	51.47%	1.32E-02	45.54%	4.54E-02	156.82%
Occurs	3.4124E-05	100%	-	100%	-	100%	-
Not Occurs	9.9997E-01	0%	-	0%	-	0%	-
Landing	7.11E-01	9.06E-01	127.39%	100%	-	0%	-
Take-off	2.89E-01	9.44E-02	32.65%	0%	-	100%	-
Day	6.20E-01	6.18E-01	99.67%	6.18E-01	99.60%	6.23E-01	100.42%
Night	3.80E-01	3.82E-01	100.53%	3.82E-01	100.66%	3.77E-01	99.32%
Up to 1500gr	9.41E-01	9.50E-01	101.00%	9.50E-01	101.04%	9.47E-01	100.66%
More than 1500gr	5.95E-02	5.00E-02	84.14%	4.97E-02	83.57%	5.33E-02	89.62%
Fuselage	2.64E-01	2.98E-01	112.62%	2.90E-01	109.78%	3.70E-01	139.86%
Engine	3.16E-01	4.69E-01	148.41%	4.86E-01	153.68%	3.09E-01	97.88%
Radome	1.88E-01	1.28E-01	67.78%	1.25E-01	66.49%	1.51E-01	80.23%
Windshield	1.22E-01	5.60E-02	45.99%	5.15E-02	42.29%	9.92E-02	81.48%
Wing	1.10E-01	4.96E-02	45.29%	4.75E-02	43.29%	7.07E-02	64.46%
Up to 80kt	7.53E-01	9.25E-01	122.84%	9.31E-01	123.69%	8.63E-01	114.66%
From 80 to 200kt	2.23E-01	7.49E-02	33.62%	6.85E-02	30.74%	1.36E-01	61.19%
More than 200kt	2.41E-02	3.78E-05	0.16%	1.91E-05	0.08%	2.18E-04	0.90%

It is worth noting that the worst scenario found for São Paulo/Guarulhos International Airport (SBGR) and São Paulo/Congonhas Airport (SBSP) relates to evidence of collisions during the takeoff phase. The 'engine' state of the 'affected part' node showed a significant increase in probability, highlighting the potential of the Accident Model in identifying and mitigating such risks. For Viracopos/Campinas International Airport (SBKP), the worst scenario also relates to evidence of a collision during the takeoff phase, where the state 'two or more birds' from the 'species behavior' node showed a substantial increase in probability. These findings further underscore the relevance and potential of the proposed Accident Model in managing avian risk.

5. Final Considerations

This work proposed a general model for commercial aircraft accidents due to bird collisions capable of quantifying the impact of the main factors involved in occurrences during the landing and takeoff phases for São Paulo/Guarulhos International Airport (SBGR), São Paulo/Congonhas Airport (SBSP), and Viracopos/Campinas International Airport (SBKP). The results determined which critical factors are related to the operation, categorizing them within the environment, birds, aircraft, and event, quantifying them, and identifying those with the most significant impact in a collision. The Bayesian network method allowed for a detailed analysis of the probabilities of the model's variables.

The most critical flight phase at both airports is landing. However, the worst impacts found are related to when there is evidence in the event and during the takeoff phase, with the engine state in SBGR and SBSP presenting the highest risk of being impacted, in the order of 147,15% and 174,43%, respectively; and with the state 'two or more birds' in SBKP presenting a risk in the order of 156,82%. The findings lead to an understanding that the factors and their respective states with increased probabilities in a collision, and consequently more significant impacts, can contribute to operational safety management. Furthermore, the Accident Model presented can be a new ally in managing avian risk.

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Exploring the Impact of Innovative Technologies at Ponta Delgada Airport

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Abstract/Resumo/Resumen

The advent of the fourth industrial revolution is responsible for considerable transformation of different aspects of life leading to the development of smart cities and therefore smart airports. AI, IOT, and big data analytics have been used by these airports for the purpose of improving efficiency and effectiveness in operations, customer satisfaction and optimal utilization of resources. Coupled with the growth in aviation facilities that are fitted with automated baggage handling systems. This study aims at examining how customer satisfaction, airport performance and general airport management are influenced when traditional methods are abandoned in favour of modern approaches. Through an extensive literature review, the research focuses on these advancements at Ponta Delgada Airport specifically as it looks for ways through which technological advancements have led to ongoing improvements and optimization of airport services. The findings are expected to provide directions for other airports that wish to become smart through changing technology scope and also to determine by comparison with other airports whether or not the airport would benefit from other upgrades.

Exploring the Impact of Innovative Technologies at Ponta Delgada Airport

1. Introduction

João Paulo II airport commonly known as Ponta Delgada airport (IATA:PDL, ICAO: LPPD) is located in the most populated city of the archipelago of the Azores, in the São Miguel Island. Considered the main airport for the archipelago it is the main entry for passengers and air cargo [1].

Named after Pope John Paulo II, initially named Nordela Airport, the airport was inaugurated on the 24th of August 1969, six years after its construction was planned.

The airport Is run by a private company ANA (Aeroportos e Navegação Aérea) Airports which is responsible for the management of 10 Portuguese airports both continentally and on the islands. This company was acquired in 2013 by VINCI. VINCI's airports division is considered a global leader managing over 70 airports in over 13 different countries.

In recent years, Ponta Delgada airport has undergone several improvements, most of which are in line with VINCI Airports' quality plan's three core components: digitalization, robotization, and chatbots.

2. Digital Level Transformation

In order to understand how technological improvements are being implemented in Ponta Delgada's airport it is important to understand where Portugal stands in terms of digitization. For this analysis, 3 of the most utilized and currently updated indices were utilized, these being the Network Readiness Index (NRI), the Global Innovation Index (GII) and the Digital Economy and Society Index (DESI).

The Network Readiness Index was created by the World Economic Forum and it assesses how countries use information and communication technology to increase competitiveness and growth [2]. The NRI covers ICT structure, the readiness of main stakeholders, and ICT use, addressing issues of access and socio-economic importance [3]. It allows countries to learn more about areas requiring additions or corrections to ICT infrastructure and policy. Furthermore, the framework is used by governments, businesses, and NGOs to make informed decisions regarding ICT strategies [4].

The Global Innovation Index is published once a year by WIPO and ranks countries according to their capacity and output. The GII measures several dimensions of innovation including research, technological development and transfer, human development, and creative inputs. This work gives an accurate understanding to the regulating bodies and firms about the innovation system [5].

Balanced with the usage of both qualitative and quantitative indicators, a scale from 0 to 100 is utilized to assess nations and their innovative character, with about 80 indicators broken into innovation inputs and outputs to rank world economies appropriately [6].

The Digital Economy and Society Index, or DESI, is the Annual Publication of the European Commission and is designed to observe and assess the digital performance of the European Union's 28 Member States every year. Built in 2014, DESI is an instrument which integrates the infrastructure connection, human capital, business adoption of technology and digital public services. By means of thematic chapters and country case studies, DESI highlights problematic areas and provides ways to deal with occurring challenge [7]. It uses indicators such as the percentage of households with internet access, and the number of e-government services provided, and applications for digital patents [8]. Furthermore, it gains recognition as the basis of comparison of the online performance between various EU members and worldwide [9].

2.1 Portugal's Digitization

Portugal has come a long way in terms of digital transformation, using technology to spark growth, economic development, and improve the lives of its citizens. One of the most important aspects of this is ensuring that a strong digital backbone is built, which takes the form of substantial investment in

broadband access in cities and countryside. This availability of high-speed internet service has driven broad participation in the digital economy and improved overall digital well-being, ensuring that all residents benefit and share in progress. Portugal's results in the three indicators presented above show that the country is in a continuous movement for improvement.

2.2 Network Readiness Index

The country's perfomance on the Network Readiness Index in 2022 is remarkable achieveing 29th place out of 131 economies with an average score of 65.63 [10]. The country's main categories are technology and impact as it ranks 27th place on both, as seen in Figure 1.

Portugal is a part of the high income category in the NRI rank. Here the country ranks 28th with its ratings being slightly lower than the group average except for the impact pillar where it outshines both the group average and the continent's average scores (Table 1).

Table 1 - Portugal's rankings comparison [10].

Dimension	*Portugal*	*High-income countries*	*Europe*
NRI	65.63	66.21	63.72
Technology	59.34	60.28	56.43
People	56.79	58.83	56.35
Governance	76.14	76.89	74.79
Impact	70.26	68.86	67.3

As seen in Figure 2, the country surpasses the trend line for the anticipated NRI score. This can be attributed to the country's excellence in four out of the twelve strongest indicators. Portugal secures the top rank in e-commerce legislation, women's economic opportunity, encompass internet access in schools, and privacy protection through legal content [10].

Figure 1- Portugal's rankings [10].

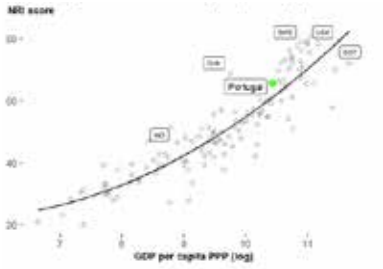

Figure 2- NRI score and GDP per capita PPP graphic trend line [10].

2.3 Global Innovation Index

In 2022, Portugal stood at 32nd place among the 132 economies featured in the GII rankings and 20th within Europe. However, this marks a slight decline from its previous rank of 31st. The assessment evaluates seven pillars, human capital and research, creative outputs, global innovation index, business

sophistication, knowledge and technology outputs, infrastructure, market sophistication, and institutions [11].

Portugal's weakest performances are evident in the institution's pillar, ranking 47th, followed by market sophistication at 42nd and infrastructure at 39th. On the other hand, the country demonstrates strengths in human capital and research, securing 22nd place, and creative outputs at 25th [11].

Although Portugal holds an overall GII rank of 32nd, it exhibits stronger performance in innovation outputs compared to inputs. Notable strengths include domestic industry diversification, software spending as a percentage of GDP and scientific and technical articles. However, significant weaknesses include labour productivity growth, gross capital formation, and cost of redundancy dismissal [11].

2.4 Digital Economy and Society Index

In the DESI 2022 ranking among European Union member states, Portugal improved to the 15th position with a score of 50.8, slightly below the average EU score of 52.3. This marks an advancement compared to previous years, which can be attributed to a strategic action plan initiated in April 2020 focusing on digital inclusion, public education, business and government digitization [12].

One of Portugal's digital transformation strategy objectives is skills enhancement, which fits with its recovery and resilience strategy plan. In 2022, the country along with the EU is working on a national strategic plan for the digital decade to align with the EU's 2030 policy agenda. The Estrutura de Misso Portugal Digital oversees the planning and implementation of the action plan and is further assisted by enhanced skills plans and the Digital Competencies Observatory. While Portugal demonstrates progress in ICT, digital disparities do exist, however, the country's share of ICT graduates is at an EU average which is reassuring. Portugal is ranked 14th in Human Capital within the EU, and more than half the population has basic digital skills, however, there is some gap to be close to the best-ranked countries. Portugal is the 18th in Connectivity which is attributed to the government and private investment in the VHCN (Very High-Capacity Network) and fast broadband cover. Notwithstanding advancements, obstacles still persist in e-commerce uptake and ICT adoption among SMEs. In the area of digital public services, Portugal is ranked 14th, slightly below the EU average and displaying some strengths in services for citizens and companies, and at the same time having as weak points the provision of open data.

2.5 Concept of a Smart Airport

Digitalization can also be seen in airports. The process of airport digitalization followed the advances of the Internet era in different waves, all in response to the needs of airlines and ground handlers to optimize resources and reduce costs. Product innovations such as Common Use Terminal Equipment (CUTE) in the 80s and Common Use Self-Service (CUSS) in the 2000s markedly improved operational efficiency and passenger satisfaction. The later development of the Common Use Passenger Processing System by the International Air Transport Association also facilitated the integration of airports and airlines. The constant overlap of digitization consisting of the use of self-service options and the adoption of open data and big data concepts displays how airport technology keeps changing. Collaboration among stakeholders is one of the most important aspects of a successful digital transformation and it requires well-thought planning, experienced leadership and broadminded acceptance of changes and innovations [13], [14].

The automation of airports from conventional manual procedures to highly technological maturity is extended into four levels. Airport 1.0 is based on manual work and traditional IT solutions for maintaining aircraft operations. In Airport 2.0 the application of CUTE indicates a certain level of self-service and, in turn, in Airport 3.0 it is completely self-service using mobile and cloud devices. Airport 4.0 is the digital transformation of its predecessor with the incorporation of big data and open data to make innovations in operations as well as the passenger experience. These shifts are triggered by challenges within the industry, for example, cost reduction, process improvement and improving passenger services [13], [15].

Smart airport is a part of smart cities, the prototype of smart cities is Industry 4.0. The goal of smart cities is to ensure comfort and sustainability with the help of technologies, such as urban transportation management and air traffic control. Intelligent airports apply these technologies to streamline procedures and operations with the highest level of customer service at the core [15].

The concept of a smart airport is grounded in Humanism and the Online-to-Offline (O2O) mode. The basic aim of Humanism is to ensure that customers have a positive travel experience and that workplace is productive for the employees in the aviation industry. The O2O model is aimed at bringing together offline and online airport services more effectively. Offline airports accomplish this by providing personal attention to those who travel, while online airports do this digitally by presenting information and digitally-based services [15].

2.6 Technologies in Ponta Delgada's Airport

Under VINCI's management, ANA's airports which also includes João Paulo II's airport in Ponta Delgada have also implemented a variety of technologies these include innovations regarding the security process, customer satisfaction through inquiries, apps and network innovations, and improving sustainability.

Since 2010, the ANA app, which is available in all ANA airports across the country, has changed the world of airports. Upon download, passengers unlock a plethora of conveniences: from booking hotels, check-ins, parking reservations, ValetXpress, and Fast Track. Users can also subscribe to flight updates, lounge reservations, and a walkthrough of airport facilities. Further, the app serves as a networking platform through BITA (Business in the Air) using LinkedIn to set up meetings during transit. In Ponta Delgada Airport the app currently only provides general information on arrivals, departures, commercial spaces, and services and an update of its contacts segment section.

Another mobile application that will be available at the airport is the Airport Community App. Created by Airport Labs, the application has been used by more than 2,500 companies and has generated more than 120 million monthly interactions. This application, according to the Airport Labs [16], is a tool for real-time collaboration, gathering data immediately to enable swift decision-making and coordination. It is also responsible for the instant spreading of emergency messages to the rest of the airport community including airport employees, authorities, airlines, ground handlers and many others. Implementation of this app in the airport is planned for March 2024.

The leading technology of airport security devices by SMITHS DETECTION is the HI-SCAN 6040-2 scanner that greatly speeds up the detection of both solid and liquid explosives from passengers' belongings or cabin baggage. Offering ECAC EDS CB C1 certification, these dual-view X-ray products are great for checked cabin baggage inspections and they also meet requirements for LEDS Standard 2 and 3 Type C. However, these scanners only provide standard resolution and are not allowed to inspect aviation cabin baggage [17].

To boost passenger processing efficiency, the airport has installed e-gates that can easily read the passport with the embedded biometric data. VINCI Airports' modernization initiative in ANA airports envisages the implementation of the so-called "The Biometrics Experience" that is progressing swiftly through the major airports of Portugal including Ponta Delgada, based on the successful pilots in Lisbon and Porto. Scheduled for introduction at the end of 2024 at Faro, Funchal, and Ponta Delgada airports, biometric boarding is already being tested on some TAP flights within the Schengen area [18].

ANA also has a detailed data security policy which is managed by a Data Protection Officer (DPO). The policy aims to educate and inform the personnel and ensure the implementation of the GDPR. The policy also includes monitoring GDPR developments, assessing compliance, supervising documentation, assessing risk exposure, and providing training. ANA uses multiple tools to handle information security and plans to implement an information safety system based on ISO/IEC25001. This security system facilitates cooperation with the stakeholders to make sure that the airport runs smoothly without passenger disruption.

The advantages for passengers are various: facial biometric recognition allows a smooth travel experience free of checkpoints or queues, accompanied by keyless boarding. Consequently, the passenger data privacy and security are held in high consideration, which means that data is deleted after every flight. Participation in this biometric identification process is voluntary, primarily targeting European flights. Passengers who qualify for self-check-in can register by using mobile devices through the Self Enrolment Mobile app or at the designated airport kiosks under 'Biometric Experience by VINCI Airports'. This fast-track process requires scanning of the boarding cards, e-passports, or Portuguese ID cards. The

passenger's selfie is then captured, signifying agreement to the conditions of movement. This process is explained in Figure 3 [19].

Figure 3 - Description of the Registration Process on the App [19].

Operating with advanced algorithms, this intelligent system verifies passengers' identities throughout their journey, eliminating the need for multiple physical or digital verification points during boarding.

In 2022, VINCI introduced the Program for Integrity, Transparency, and Compliance to halt the practice of corruption. The program contains seven mechanisms such as a risk prevention plan, an internal control system, an ethics and behaviour charter, a reporting channel, a training program, a risk assessment for third parties and an assessment system. In 2021, the 'Corruption Risk Mapping' project was introduced, which adapted corruption risk mapping to ANA's environment to be followed by the Corruption Risk Prevention and Detection Plan. Although no high or full risks were detected, corrective and preventive measures were particularly provided for in action plans. The VINCI Code and Charter, in combination with the Portuguese law, comprise the ethical framework, which is supported by a system of complaint monitoring. Staff members are encouraged to take part in online courses and conduct interactive sessions to upgrade knowledge and compliance. Clients and external service providers are scrutinized for possible corruption and internal audits are conducted annually, and externally every three years to ensure effective program implementation and schedule [20].

The airport plans to integrate a Building Management System (BMS) in order to improve its energy efficiency. A BMS is an energy-saving software system that is computer-controlled and monitors and manages the electrical components in a building. A BMS combines software and hardware playing a vital role in energy demand management and is considered critical for new development projects. It achieves this by reducing utility costs and providing a living atmosphere for occupants. Moreover, it offers remote management of heating, ventilation, and air conditioning (HVAC) systems which can be done automatically by the maintenance staff [21].

Since 1998, ANA has repeatedly shown its dedication to sustainability and has been implementing an efficient Environmental Management System. The major fields of importance are energy, CO2 emissions, air quality, professional development, and recognition. Examples of this initiative are the electrification phase for light passenger vehicles and the testing of alternative fuels for emergency vehicles which are in progress until 2030. The João Paulo II airport conducts air quality monitoring every three years and adopts waste reduction strategies through the separate collection, storage and optimization of containers, among others. ANA airports seek to reduce waste generation, increase reuse and recycling, and extend outreach to other parties. Wastewater treatment stations and the insertion of heat pumps supplied with solar panels are examples of the sustainability movement present in Ponta Delgada. The airport aims to install photovoltaic panels and an automatic lighting system which will enable the adjustment of the energy usage dynamically with the number of passengers and aircraft [22].

Table 2 - Passenger satisfaction inquiries results adapted from [23].

	Punctuality		*Security (<10 min)*	*Baggage (<20 min)*		*Passenger Satisfaction (out of 5)*
	% delays at arrivals	% delays at departure	Passenger Processing	First	Last	Overall
January	9.64%	10.29%	98.19%	96.58%	91.94%	4.19
February	6.68%	7.29%				4.23
March	12.56%	12.65%				4.25
April	23.09%	21.46%				4.39
May	22.61%	20.33%				4.17
June	31.29%	32.83 %				4.21
July	33.75%	38.67%				4.37
August	23.70%	26.96%				4.35
September	21.63%	21.63%				4.34
October	22.68%	23.74%				4.13
November	32.87%	30.35%				4.13
December	38.66%	37.27%				4.13

Since 2006 the Airport Council International's (ACI) program, Airport Service Quality, has been used for obtaining customers' reviews. The results obtained in 2022 are presented in Table 2.

3. Benefits from the Impact of Smart Technologies

The technologies implemented presented above symbolized significant improvements in efficiency, performance and wait times as it was expected. In João Paulo II's airport, this was made through the use of e-gates that have helped border control, heightening safety, while also reducing wait times and increasing passenger convenience and efficiency.

Passenger convenience is one of the most important aspects of an airport's operations and sometimes the backbone of the innovations implemented. Ponta Delgada excels at this point by making use of airport applications that change how travellers engage with the airport. Such mobile apps usually provide a wide range of features including digital boarding cards, self-check-in options, and live flight updates, and they also help assist through the airport. Customers can swiftly and easily manage their way through the airport conveniently on their smartphones using them to get relevant updates, as well as get through the pre-flight processes. The introduction of the Chatbot will not only contribute to an already existing direct and automated communication channel but also to the provision of information both operational and commercial to passengers. The release of the airport community app is evidence of the development of a dedicated staff application that strengthens collaboration and provides access to operational information while offering staff-specific benefits such as exclusive discounts in commercial areas.

The use of biometrics technologies and e-gates together helps to improve security protocols and makes identity verification easier, leading to a better traveller experience. Biometric means of identification like fingerprint verification and face recognition minimize reliance on paper documents while at the same time improving security measures.

With the current advanced technological environment, passengers may expect a smoother and more customized airport experience. These technologies ensure a smoother travel journey from arrival to boarding, allowing passengers to focus more on the excitement of their destination rather than navigating

complex airport procedures. Smart technologies have placed airports in the position to take advantage of the optimization of scarce resources. In Ponta Delgada, operational executing systems envisage expected passenger numbers per flight to reduce space wastage and anticipate needs. In such circumstances, the number of on-boarding areas can be decreased remarkably, ultimately leading to a reduction in the number of required support staff. Therefore, the staff members who are not assigned to these flights can be reassigned to other flights with more demand.

Technology is justified as an enabler and, thus, can guarantee more traffic without sacrificing the quality of services. Technological innovations lead to economic returns while also being able to reduce processing times, streamline flight turnaround times and enhance the efficient use of airport resources.

The airport makes use of innovative technologies in order to provide real-time updates and smooth communication around the globe therefore supporting global connectivity. This provides an opportunity for airport sectors to share essential information directly with airlines and authorities, making the operational process and customer experience more effective. Integrating live updates into their systems makes airports capable of changing the timetable of flights according to the latest information and consequently improving the overall efficiency and organisation of the system. In addition, these technologies provide global connectivity to airports beyond the airport perimeter, allowing real-time communication and coordination among airports, airline stakeholders and international organizations. Furthermore, real-time data availability is a determining factor for anticipating and responding to unexpected events such as weather disruptions or security incidents, allowing swift and informed decision-making in order to ensure service provision. In conclusion, these amazing innovative tools not only better the operations of airports but also promote worldwide connectivity and a smooth air transport system, establishing the foundation of modern reliable and safe air travel.

4. Drawbacks of Smart Technology Implementation

Investments in technology at airports may provide both benefits and challenges. Moreover, despite the fact that they are a useful instrument for streamlining production processes, providing security, and increasing passenger comfort, they are also a tremendous financial burden which includes buying specialized equipment, software, and worker training as well as recurrent maintenance costs.The security of digital airports can be compromised by cyber-attacks like malware and ransomware, which can ultimately lead to large financial losses and privacy violations. In view of that, the airport must develop a comprehensive cybersecurity system while also working closely with both the specialist and relevant authorities.

Furthermore, the quick spread of technology can also lead to unwanted consequences, such as fewer personal contact and more privacy problems. Consequently, the most important task for the next few years is to maintain compatibility between technology improvement and risk management.

5. Conclusion

The integration of innovative technologies at the Ponta Delgada Airport portrays a giant step toward the modernization of the aviation sector in Portugal. Located on São Miguel Island, this airport under VINCI's management has experienced drastic change led by digitalization, robotization, as well as chatbots in accordance with worldwide standards and the country's digital progress.

The digital transformation advancement Portugal has made, demonstrated by the Network Readiness Index, Global Innovation Index and Digital Economy and Society Index, highlights the country's drive to apply technology for both economic development and social enhancement.

The implementation of the latest technologies at Ponta Delgada Airport, ranging from biometric authentication technologies to mobile applications and advanced security scanners, has provided many benefits. The advancements are in the following areas: higher efficiency, better passenger experience, more comprehensive security, and powerful connectivity. It is worthy of note that e-gates, biometric boarding, and airport apps have simplified processes, reduced queues, and offered travelers more personalized and convenient journeys.

Furthermore, the emphasis on sustainability through the implementation of energy-efficient building management systems and environment management is an integral and resilient approach towards a sustainable and future-oriented business practice.

Nevertheless, the ways forward come with challenges and considerations. Financial investments, cybersecurity risks and the balance between technology and human interaction remain fundamental issues. It is of great importance that airport authorities make proactive efforts to resolve these issues while ensuring that technological advancement is done ethically and responsibly.

Finally, Ponta Delgada Airport is a signpost of technological advancement in the Portuguese aviation industry. By its constant exploitation of new tech while dealing with the obstacles, the airport will in the future reach a new level of operational rules, satisfaction of passengers and their contribution to the digital evolution of the country.

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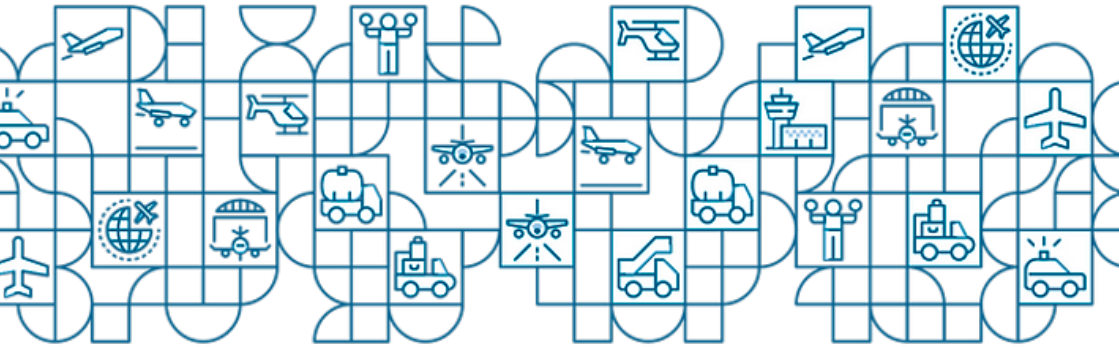

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Assessing the Conflict Between Aerodromes and Landfills from a Regulatory Perspective

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Abstract/Resumo/Resumen

This study aims to critically evaluate the spatial relationship between airports and landfills, focusing on the regulatory perspective that underpins current practices. Through an in-depth analysis of global regulations and the employment of geoinformation technology, we examine the coexistence of aerodromes and landfills, particularly in Brazil, to understand the locational dynamics involved. Expected findings suggest a fragmented regulatory landscape, characterized by inconsistencies and varying enforcement standards worldwide. This discrepancy highlights the need for policy improvements and the standardization of regulations to ensure safer and more sustainable spatial planning. Our research contributes to the field by combining technological assessments with a comprehensive review of global standards, focusing on the risk of bird strikes as a pivotal concern in the co-location of landfills and aerodromes. This novel approach not only sheds light on existing challenges but also emphasizes the necessity of risk-based decision-making in environmental and operational planning. The study's findings are poised to influence future research directions, advocating for a more integrated and evidence-based approach to managing the spatial dynamics between landfills and aerodromes.

Assessing the Conflict Between Aerodromes and Landfills from a Regulatory Perspective

1. Introduction

Landfills, particularly those that are poorly managed, are known to attract birds. However, even facilities that adhere to best management practices can host a diverse array of species, as illustrated in Figure 1. This figure showcases a facility distinguished by its exemplary management yet continues to attract various bird species. Although waste material is covered daily, it remains accessible throughout the workday. A comparison of landfills with county-level species pools reveals that scavengers and carnivores are disproportionately represented at landfill sites [1]. From an aviation safety perspective, studies consistently show that vultures are particularly associated with high risks of collisions and damage ([2], [3]), thus linking landfill management with avian risks to aviation.

Figure 1 – View of a landfill visited in Brazil
Source: Authors

Bird strikes pose a substantial risk to aviation during various flight phases, with the greatest danger arising from the proximity to airports due to the reduced altitudes. Unfortunately, the human settlements that support airport operations also necessitate destinations for solid waste disposal, typically in the form of landfills. These waste materials, which typically comprise between one-third and two-thirds organic matter as noted in [4], contribute significantly to attracting birds.

A global challenge for regulators is to define safe spatial harmonization between airports and landfills. This is crucial for the development of new airports, enhancements in infrastructure and procedures, and the establishment of new landfills. This study aims to assess, from a regulatory perspective, the existing practices regarding the spatial relationship between airports and landfills.

The remainder of this paper is organized as follows: Section 2 provides a background on bird flying patterns; Section 3 reviews the geometric buffers imposed by regulators for maintaining distance between landfills and airports; Section 4 describes the data and methods used; and the conclusions are presented in Section 5.

2. Background on Bird Flying Patterns

Arrondo *et al.* [5] conducted a study in Spain focusing on bird strikes and flight patterns of birds. For hull loss accidents they assessed the phases of flight and altitudes above ground level (AGL). The study involved GPS tracking of the most frequently involved species, providing insights into the probability of flying at various times of the day and year, as well as flight heights. Figure 2 illustrates the AGL flight heights for different species, from left to right: griffon vultures, cinereous vultures, and storks. The red marked areas in the figure indicate zones where bird strikes were reported in the study. Accidents involving storks were recorded at heights up to 1,829 meters, and up to 2,438 meters with vultures.

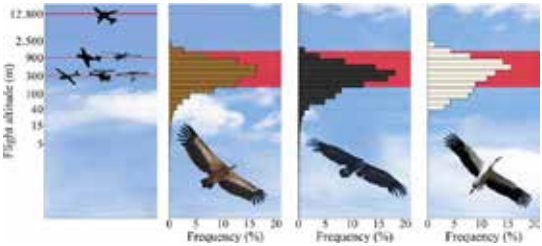

Figure 2 – Frequency of Flight Heights in a Study Conducted in Spain
Source: [5]

Utilising GPS and accelerometer data, Harel *et al.* [6] analysed the flight strategies of Eurasian griffon vultures across Israel and France, focusing on variations between short and long-range (migratory) flights. The observed Above Ground Level (AGL) flight heights of these birds typically range from approximately 200 to 700 meters. Observations revealed that both flight types exhibited increased efficiency in soaring and gliding, reduced flapping to conserve energy, and more risk-prone, steeper glides between thermals. Influential factors such as age, breeding status, meteorological conditions, and altitude were found to affect these strategies, indicating that vultures adjust their flying methods to optimise time and energy utilisation. For instance, a greater flight altitude enhances soaring efficiency. This insight could potentially allow for the prediction of flight patterns of birds in proximity to landfills.

McClure *et al.* [7] analysed the vulnerability of birds in South Africa to the hazards presented by wind turbines. They used publicly sourced datasets to identify species that frequently fly at specific altitudes. By comparing these flight patterns to the operational heights of wind turbine blades (50 to 150 metres), they assessed the collision risks and thus determined the vulnerability of each species.

In the context of the United States, Avery *et al.* [3] utilised GPS tracking technology to analyse the flight patterns of Black Vultures (*Coragyps atratus*) and Turkey Vultures (*Cathartes aura*), which are recognised as presenting significant safety risks to aviation. The maximum altitude achieved by Black Vultures was recorded at 1,578 metres, whereas Turkey Vultures reached a peak of 1,378 metres. The study revealed that Turkey Vultures are capable of spending over 60% of the daylight hours airborne during the most thermally intense periods of the day. The median flight altitudes above ground level (AGL) for Black Vultures were observed to be slightly more than 150 metres during the months of April to June. During the periods of highest temperatures, the median altitude exceeded 250 metres.

This review underscores the application of tracking bird flight patterns to evaluate collision risks associated with both human activities and natural wildlife. Soaring birds, particularly during the hottest periods, achieve significant altitudes, and cross-referencing their flight paths with aircraft trajectories can offer valuable insights into potential mitigation strategies. This approach is directly relevant to the objectives of our study, which focuses on ensuring the safe co-location of airports and landfills. By

integrating these data-driven insights, it becomes possible to develop more effective strategies for managing airspace and land use to reduce the likelihood of bird strikes and enhance aviation safety.

3. A Regulatory Perspective on Distancing between Airports and Landfills

In the US, the FAA [8] establishes criteria based on distance for the separation between airports and landfills: (i) 1,524 metres (5,000 ft) for airports serving piston-powered aircraft; or 3,048 metres (10,000 ft) for airports serving turbine-powered aircraft. For public airports that receive federal funding and cater to general aviation or operate regularly scheduled flights with aircraft seating 60 passengers or fewer, a minimum separation of six statute miles (9,656 metres) is mandated [9]. For a new landfill within five statute miles (8,047 metres) of any airport runway, the owner/operator must inform the airport and the FAA about the proposal. They must also ensure and document in the operating manual that the landfill's design and operation will not pose any aviation hazards. Local authorities such as the state of Virginia emphasise these requirements when addressing landfill siting regulations [10].

In Australia, landfill regulations can be found in Victoria State Regulations [11]. Smaller landfills catering to communities of fewer than 500 people may not require licensing. To prevent wildlife hazards that could pose risks to aircraft, stringent buffer zones are mandated for landfills serving larger populations. These landfills must maintain a minimum distance of 1,500 meters from aerodromes utilised by piston-engine propeller-driven aircraft and 3,000 meters from those accommodating jet aircraft. Similar approach can be found in Queensland state guidelines [12].

Transport Canada [13] advises that waste disposal sites (and other avian attractors) situated within a 15 km radius of any runway's should be either eradicated or obstructed, unless a bird-hazard analysis demonstrates that the site poses no significant risk. Transport Canada establishes zoning policies for bird attractive activities as shown in Table 1.

Table 1- Land Use and Bird Hazard Zoning
Source: [14]

LEVEL OF RISK	LAND USE	Primary*	Secondary**	Special***
Potentially High	Putrescible waste landfills	No	No	No
	Food waste hog farms	No	No	No
	Fish processing/packing plants	No	No	No
	Horse racetracks	No	No	No
	Wildlife refuges	No	No	No
	Waterfowl feeding stations	No	No	No
	Open or partially enclosed waste transfer stations	No	No	Yes
Potentially Moderate	Cattle paddocks	No	No	Yes
	Poultry factory farms	No	No	Yes
	Sewage lagoons	No	No	Yes
	Marinas/fishing boats/fish cleaning facilities	No	No	Yes
	Golf courses	No	No	Yes
	Municipal parks	No	No	Yes
	Picnic areas	No	No	Yes

* Generally enclose airspace in which aircraft are at or below altitudes of 1500 feet AGL (above ground level).
** 4km beyond the Primary Hazard Zone.
*** This zone is farther from the aerodrome but still relevant for safety. It includes areas where specific hazards exist, such as bird habitats, electronic signal interference, or exhaust plumes.

In Brazil, legislation 12.725/2012 [15] establishes the Airport Safety Area (ASA) as a circular region with a 20 km radius from aerodromes, subject to controls and restrictions aimed at mitigating the risk of aeronautical accidents and incidents due to collisions between aircraft and wildlife. Another risk management approach involves the environmental licensing of developments that could attract wildlife. The Basic Fauna Risk Management Plan PCA 3-3/2018 [16] required a minimum distance of 5 km for slaughterhouses, 10 km for daily covered landfills, and 20 km for open dumps. However, this plan was replaced in 2020 by a document that omits such specifics, possibly following the 2019 shift of licensing

responsibility for wildlife-attractive activities from CENIPA (Aeronautical Accident Investigation and Prevention Centre) to state agencies. Furthermore, the Fauna Risk Management Manual, MCA 3-8 [17], notes that "*landfills are the most significant type of attractive focus for the attraction of problem species at a national level and should be positioned at least 10 km from aerodromes.*"

This concise review highlights that landfills are recognized globally as aviation hazards, with considerable variance in international legislation regarding safe distances, often specified as a radius from the Airport Reference Point (ARP). An alternative approach to establishing safety buffers is to define a minimum flight altitude above ground level (AGL), tailored to expected flight procedures.

4. Methods and Data

We utilised real flight data gathered through an ADS-B platform, incorporating the variables detailed in Table 2, which represent the operations at SBSL airport in December 2019, located in São Luís, the capital of Maranhão state in Brazil. The dataset includes 771 unique flights (*indicat*), with only 8 categorised as General Aviation. This figure is representative of the traffic, closely aligning with the officially reported 1,028 movements [18]. General Aviation is underrepresented, as such operations rarely have ADS-B equipment installed. The airport's layout, including a shorter non-instrument runway, is depicted in Figure 3. Figure 4 portrays the departing and arriving flows at the airport.

Figure 3 – SBSL Airport Layout. ARP: 02 35 13S/044 14 10W.
Source: Image retrieved from Google Earth

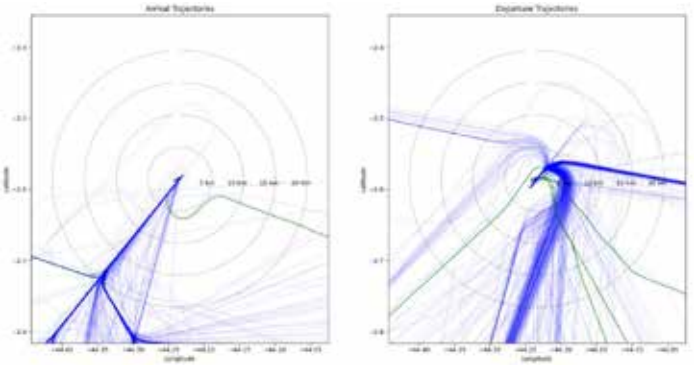

Figure 4 – Flight patterns for Dec/2019, arriving and departing SBSL. General aviation is shown in green.

Table 2- Main variables of the dataset
Source: Authors

Variable	Example	Description
indicat	587674244	A unique number for the flight
time	2019-11-30 23:21:11	Time
phase	GND_DEP	Phase of flight
lat	-15.87322	Latitude
lon	-47.91802	Longitude
alt	0	Altitude (ft)
speed	16	Speed
equip	A321	Aircraft
reg	PTMXB	Tail number
plan_dep	SBBR	Planned departure airport
plan_arr	SBSL	Planned arrival airport
real_arr	SBSL	Actual arrival airport
id_iata	LA3182	IATA ID for the flight
id_icao	TAM3182	ICAO ID for the flight
lat_dep	-15.86916733	Latitude of the departure airport
lon_dep	-47.92083359	Longitude of the departure airport
lat_arr	-2.58536005	Latitude of the arrival airport
lon_arr	-44.23410034	Longitude of the arrival airport
Class	Commercial	Class, either Commercial or General, based on aircraft model
dist2airpt	11	Distance in km (great circle) to SBSL airport

The subsequent section examines the flight altitudes in the vicinity of SBSL airport, comparing them with documented Above Ground Level (AGL) typical altitudes for vultures as reported in the literature.

5. Results and Discussion

It can be observed in Figure 5 that arrivals are confined to a relatively narrow ramp for both general and commercial aviation, particularly within up to 20 km from the airport. For departures, there is significantly greater height dispersion beyond 5 km from the airport, and general aviation exhibits notable differences in altitude gain compared to commercial aviation. Despite this higher variability, a linear trend is discernible in the altitude patterns of commercial aviation.

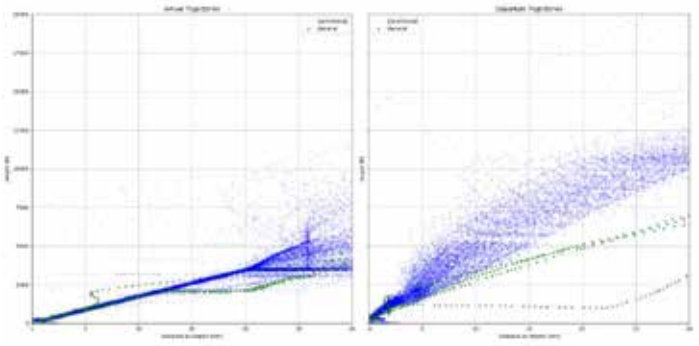

Figure 5 – Flight height patterns for Dec/2019 at SBSL.

The next three plots allow comparisons of trajectories accumulated until a given AGL height.

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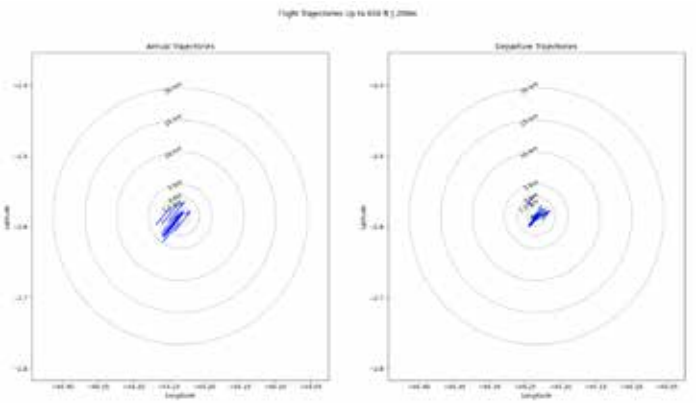

Figure 6 – Flight patterns for Dec/2019, arriving and departing SBSL up to 200m

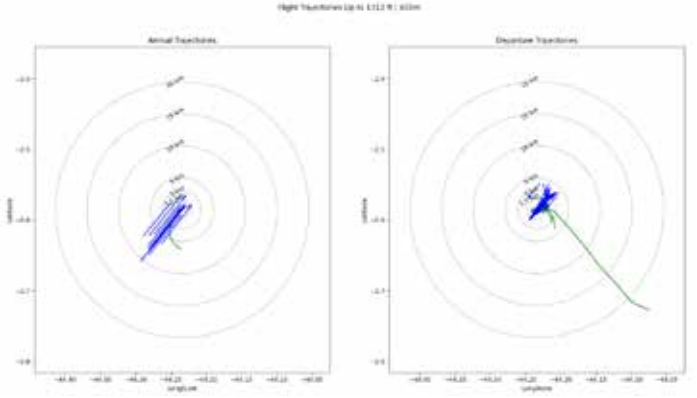

Figure 7 – Flight patterns for Dec/2019, arriving and departing SBSL up to 400m

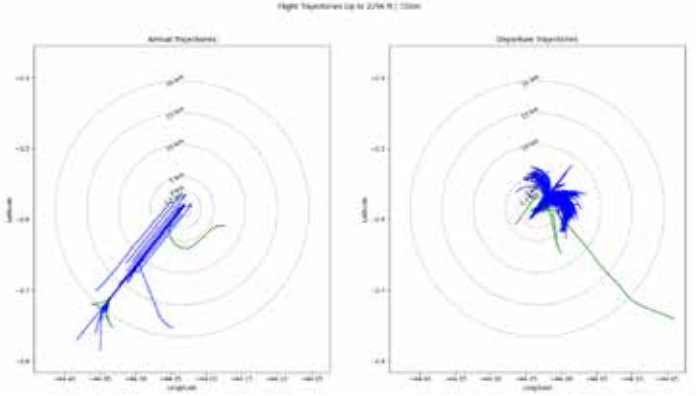

Figure 8 – Flight patterns for Dec/2019, arriving and departing SBSL up to 700m

Most bird species are unlikely to intersect with aircraft trajectories if a buffer zone of 5 km is established. However, vultures and other soaring birds can ascend to significantly higher altitudes, necessitating a larger buffer. A 20 km buffer appears essential to safeguard the approach area of the airport, whereas a 10 km buffer may suffice for other directions surrounding the airport.

6. Final Remarks

This study features the complex interplay between airport operational safety and landfill management, highlighting the distinct risks associated with arrival and departure patterns due to their varying altitudes. It reveals that current legislation concerning the proximity of landfills to aerodromes lacks uniformity worldwide and often fails to consider the specific risks posed by different flight paths, such as approaches and departures. Additionally, there is a notable gap in research regarding the tracking of bird movements near airports, which is crucial for developing effective mitigation strategies. Moreover, quantifying the impact of various landfill management strategies and procedures on wildlife attraction presents a significant challenge. This calls for a more nuanced approach to policy formulation and enforcement, ensuring that both airport safety and environmental considerations are adequately addressed in the creation of future regulations.

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Synergy between Cargo and Passenger Transport in Airport Efficiency

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Abstract/Resumo/Resumen

This study evaluates the efficiency of Brazilian airports by examining the integration of cargo and passenger operations from 2010 to 2020. Employing a Network DEA model and correcting biases in traditional DEA assessments, it aims to determine if optimizing resource allocation explains efficiency variances across airports. Preliminary findings suggest significant efficiency improvements when resources are jointly allocated for cargo and passenger services, as opposed to separate operations. This research is novel in its focus on the synergy between cargo and passenger operations within Brazilian airports, offering new insights into enhancing airport efficiency through coordinated resource management.

1. Introduction

The efficiency of airport operations directly impacts economic and logistical outcomes on a global scale, understanding how to optimize these operations is a goal to be more resilient and precise. Airports are nodes in the network of global movement, handling not only passenger traffic but significant volumes of cargo as well. The terminal can be critical to transport system and economy. The integration of these two functions—cargo and passenger transport—can potentially unlock efficiencies that are otherwise unattainable when these operations are siloed. This study delves into the synergistic potential of combining cargo and passenger operations at Brazilian airports, with the aim of uncovering actionable insights that could enhance operational efficiency. Benefit of synergy is Operational Efficiency, because effective collaboration helps eliminate redundancies and optimize processes, reducing costs and improving operational efficiency.

By focusing on the allocation of inputs between these two distinct yet interconnected airport functions, this research assesses whether such integration acts as a pivotal factor in explaining the variance in efficiency across different airports within Brazil. Employing a sophisticated methodological approach that integrates a Network Data Envelopment Analysis (DEA) model with a bias correction traditionally applied in conventional DEA models, this study provides a robust framework for evaluating the operational efficiencies of airports from 2010 to 2020. The findings are anticipated to reveal significant disparities in efficiency levels, thereby highlighting the effectiveness of integrated resource management in airport operations.

This exploration not only fills a gap in the existing literature by focusing on an under-researched area of airport efficiency but also enhances our understanding of how coordinated resource allocation can lead to more effective airport operations. Through this innovative study, we aim to contribute valuable perspectives to the discourse on optimizing airport efficiency in Brazil, potentially influencing future strategies and policies in airport management worldwide.

The structure of this paper is meticulously organized into four additional sections following this introduction, each designed to build upon the last and provide a comprehensive understanding of the study's scope and findings. The first section, Literature Review, delves into the existing research related to airport operations, specifically focusing on the integration of cargo and passenger transport to set the stage for the subsequent analysis. Next, the Methodology section outlines the specific models and analytical techniques employed in this study, including the Network DEA model and the bias-corrected conventional DEA approach, detailing the data collection process for Brazilian airports from 2010 to 2020. Following this, the Results section presents the findings from the analysis, discussing the disparities in efficiency levels and the implications of integrated versus segregated operational strategies. Finally, the Conclusion wraps up the study by summarizing the key insights, discussing the implications of the findings for airport management, and suggesting directions for future research. Each section is crafted to ensure a logical flow that enhances the reader's understanding of the study's contribution to the field.

2. Literature Review

2.1. Sinergy and Two-Side Market

The complexities of coordination and efficiency in transportation hubs, the scholarship of Van de Horst and Lengen (2008), and Pallis and Notteboom (2021) provides a critical foundation. These authors identify four main causes of coordination problems within transport networks: the presence of free riders creating unequal distribution of costs and benefits, inadequately coordinated incentive mechanisms, asymmetrical information leading to strategic divergences, and varying degrees of risk aversion that can deter long-term investments. Da Silva (2021) indicates the synergy process between ports and railway. Investigating airport operations, Ivaldi, Sokullu, and Toru (2015) extend the concept of two-sided markets to airports, defining them as bilateral platforms where the interactions between multiple products and services create a dependent relationship between different user groups. The efficiency with which an airport manages one side of its operations directly influences the service quality and pricing on the other side. This relationship mirrors Rochet and Tirole's (2002, 2003, 2006) seminal work on two-sided markets, where they highlight the interdependencies in such platforms that influence pricing strategies and service delivery.

Airports is operating as two-sided platforms serving distinct yet interconnected user groups: passengers and cargo handlers (Ivaldi, Sokullu, and Toru, 2015). Each group's efficiencies can significantly impact the other due to cross-side network effects where the value provided to one group is contingent on the level and quality of service provided to the other. Furthermore, same-side network effects, which can be either positive or negative, also play a crucial role in shaping operational dynamics. For instance, in port operations, the efficiency of loading and unloading can benefit all users on that side of the market, whereas excessive congestion can have detrimental effects.

The integration of cargo and passenger operations in airports presents unique challenges and opportunities. The coordination issues identified by Van de Horst and Lengen (2008) manifest in airports as conflicting operational priorities between cargo and passenger handling which can lead to inefficiencies unless properly managed. Incentive mechanisms need to be carefully designed to align the interests of all stakeholders involved in the airport's ecosystem, including airlines, ground services, cargo handlers, and logistics companies.

There are different models within DEA. The CCR model, developed by Charnes et al. (1978), assumes constant returns to scale, while the BCC model by Banker et al. (1984) allows for variable returns to scale, resulting in a piecewise linear efficiency frontier. Studies on airport efficiency using DEA have varied, with some focusing on output-oriented models, which aim to maximize outputs without increasing inputs.

2.2. Airport Efficiency and Measurements in Brazil

Airport efficiency is influenced by both internal and external factors. Internally, an airport might invest in new infrastructure like a runway to accommodate larger aircraft, as noted by Pels et al. (2001). The efficiency of airports is commonly measured using Data Envelopment Analysis (DEA), a nonparametric methodology that evaluates the efficiency of Decision-Making Units (DMUs) by comparing input to output. This approach was discussed extensively by Cooper et al. (2007) and involves creating an efficiency frontier against which airports are benchmarked. Airports on the frontier have an efficiency score of 1, and others are rated based on their distance from this frontier.

In Brazil, DEA has been applied to study the efficiency of airports. Fernandes & Rodrigues (2002) evaluated the efficiency of 35 domestic airports based on passenger numbers, using data from 1998 and projecting future scenarios. Silva et al. (2019) found that only 4 out of 44 airports managed by INFRAERO were efficient, using 2019 data with an output-oriented DEA-BCC model. Neto (2013) assessed the technical efficiency of 23 major airports, finding that capacity adjustments in certain areas like runway and boarding facilities were needed for less efficient airports to reach the efficiency frontier.

3. Methodology

This study employs a methodological approach that compares alternative models to the traditional DEA-CCR framework, focusing on bias-corrected models and Network DEA (NDEA) to evaluate airport efficiency. The aim is to identify any efficiency gains through these alternative models and determine whether they differ from the conventional approach.

In the first step, the methodology uses a bias-corrected DEA-CCR model based on the work of Kneip et al. (2011). This involves applying a bootstrapping procedure to correct potential bias, using resampling from the empirical data distribution. This bootstrap method involves creating two parts of the resampling sample: one "far" from the estimated efficiency frontier and the other "close" to it. The distinction between "far" and "close" is controlled by a smoothing parameter, while a second smoothing parameter controls the degree of smoothing applied to the estimated frontier. This approach ensures efficient computational requirements while providing robust results.

Next, the study employs the Network DEA (NDEA) model, an extension of the DEA-CCR concept, developed by Kao and Hwang (2008), designed to calculate the relative efficiency of decision-making units (DMUs) with internal, interrelated processes. The NDEA model assumes a multi-stage process, with each stage having its own set of inputs and outputs, and calculates efficiency through solving a Linear Programming Problem (LPP).

The NDEA model presented by Kao and Hwang uses a multiplicative approach, where overall efficiency (E_0) is determined by multiplying the efficiencies of two stages (E_0^1 and E_0^2). The weights of variables (u, v, w) and the values of inputs, outputs, and intermediate variables (x, y, z) are used in the linear programming formulations, shown in Equations (1) and (2). The resulting overall efficiency, E_0 , is calculated by multiplying the efficiencies of the two stages as in Equation (3).

$$E_0^1 = \mathrm{m}\ \frac{\sum_D}{\frac{d=1}{\sum_{i=1}^{n} v_l x_{i0}}} \quad w_d z_{d0}$$

$$\text{s.t.}\ \frac{\sum_{d=1}^{D} w_d z_{dj}}{\sum_{t=1}^{m} v_l x_{ij}} \leq 1, j = 1,2,\dots,n$$

$$w_d, v_t \geq 0, i = 1,2,\dots,m, d = 1,2,\dots,D$$

$$E_0^2 = \mathrm{m}\ \frac{\sum_{f=1}^{d} u_r y_{r0}}{\sum_{d=1}^{p} w_d z_{d0}} \qquad (2)$$

$$\text{s.}\ t \cdot \frac{\sum_{f=1}^{g} u_r y_{+j}}{\sum_{d=1}^{b} w_d z_{dj}} \leq 1, j = 1,2,\dots,n$$

$$u_r, w_d \geq 0, d = 1,2,\dots,D, r = 1,2,\dots,s$$

$$E_0 = E_0^1 x E_0^2 \qquad (3)$$

Following the calculation of efficiency scores, a comparison is made to evaluate differences in results between the traditional DEA-CCR model, the bias-corrected DEA-CCR model, and the Network DEA model. The comparison is designed to identify potential biases and assess whether the NDEA model's structure can correct these biases, indicating a possible synergy within the sequential efficiency structure proposed by Kao and Hwang (2008). If bias is found and NDEA's estimation accounts for it, this would suggest a synergy in the desired sequence of efficiencies. If not, it may imply that other factors are at play, requiring further investigation to understand the role of synergy in airport efficiency.

4. Results

The analysis was conducted using a Data Envelopment Analysis (DEA) framework, focusing on two main input characteristics and two output measures to assess the efficiency of Brazilian airports. The input variables used were the capacity of the terminal passenger services (TPS) and the length of the airport runway. For output, the study considered the total number of passengers transported and the total cargo in kilograms. This model structure was intended to investigate whether efficiencies in passenger transport and cargo operations are linked or exhibit any synergistic effects.

The initial comparison was between the results from a simple DEA model and those from a biascorrected DEA. Table 1 provides an example with the results for Brazilian airports in 2020. Columns 2 and 3 show the cargo and passenger efficiencies, respectively, without removing bias, using a simple DEA model. Column 4 shows the cargo efficiency after bias correction, while column 5 presents the corrected efficiency for passenger transport. Generally, the bias-corrected DEA values are lower than those from the simple DEA, indicating a presence of bias. This suggests that there might be unexplained factors affecting cargo and passenger efficiencies, meaning that the proposed Network DEA does not add significant insights.

Tabel 1: Standard DEA x Corrected DEA in 2020

	DEA Simples (DEAs)		DEA corrigido (DEAc)		DEAc - DEAs	
	Carga	Pax	Carga	Pax	Carga	Pax
SBBE	17%	4%	16%	4%	-1%	-1%
SBBR	20%	9%	18%	13%	-2%	4%
SBCF	25%	9%	23%	7%	-2%	-1%
SBCG	25%	4%	23%	3%	-2%	-1%
SBCT	10%	5%	10%	4%	-1%	-1%
SBEG	12%	48%	11%	43%	-1%	-5%
SBFL	10%	5%	10%	14%	-1%	9%
SBFZ	17%	15%	14%	13%	-2%	-2%
SBGL	9%	8%	8%	7%	-1%	-1%
SBGR	41%	68%	37%	59%	-4%	-9%
SBKP	37%	100%	35%	88%	-2%	-12%
SBMO	14%	1%	14%	1%	-1%	0%
SBPA	22%	15%	20%	13%	-2%	-2%
SBRF	26%	17%	24%	15%	-3%	-2%
SBSL	19%	1%	18%	1%	-1%	0%
SBSP	32%	5%	28%	5%	-4%	-1%
SBSV	13%	11%	11%	27%	-2%	16%

It is worth noting that the results for other years showed similar patterns. However, for passenger efficiency, airports in Brasília, Florianópolis, Maceió, São Luís, and Salvador had higher corrected DEA values than the simple DEA. Additionally, another interesting observation is that the bias was more pronounced in the early years and has decreased over time. The Network DEA results for 2020 are presented in Table 2. Column 2 shows the cargo efficiency when associated with passenger efficiency, which means that when cargo efficiency is 100%, the corresponding passenger efficiency is given in column 3. Columns 4 and 5 reverse the relationship, showing passenger efficiency when associated with cargo efficiency. As observed, the values are identical in both directions. Global efficiency can be calculated by multiplying the values in columns 3 and 5, and the fact that they are the same indicates that there is no improvement in passenger efficiency with efficient cargo transport.

Tabel 2: Network DEA in 2020

	Network DEA			
	Carga/Pax	Pax	Pax/Carga	Carga
SBBE	100%	4%	100%	4%
SBBR	100%	9%	100%	9%
SBCF	100%	9%	100%	9%
SBCG	100%	4%	100%	4%
SBCT	100%	5%	100%	5%
SBEG	100%	48%	100%	48%
SBFL	100%	5%	100%	5%
SBFZ	100%	15%	100%	15%
SBGL	100%	8%	100%	8%
SBGR	100%	68%	100%	68%
SBKP	100%	100%	100%	100%
SBMO	100%	1%	100%	1%
SBPA	100%	15%	100%	15%
SBRF	100%	17%	100%	17%
SBSL	100%	1%	100%	1%
SBSP	100%	5%	100%	5%
SBSV	100%	11%	100%	11%

Finally, the results in columns 3 and 5 of Table 2 do not differ significantly from the simple DEA efficiencies in columns 2 and 3 of Table 1, suggesting that cargo transport does not significantly influence or impact passenger transport efficiency.

The results of the DEA model did not reveal any significant correlation between the efficiencies of cargo and passenger operations. While individual airport efficiency varied across the dataset, there was no clear pattern indicating that high efficiency in cargo handling would lead to or result from high efficiency in passenger transport. This lack of observed relationship suggests that these two operational areas may function independently, with efficiencies in one domain not necessarily impacting or reflecting efficiencies in the other. The Figure 1 is a summary of the results and the efficiencies in airports passengers' operations as maximus does not relates with the airports cargo operations in blue line.

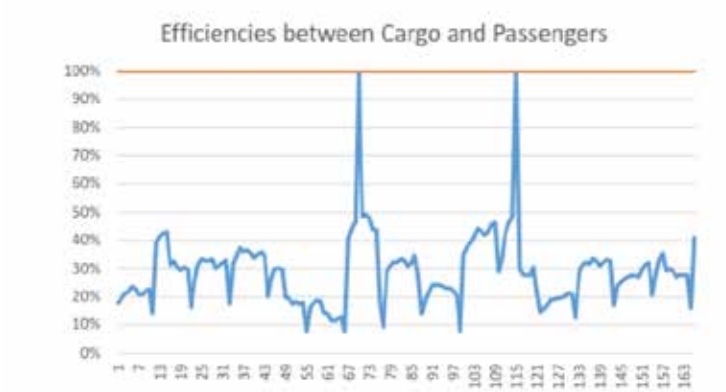

Figure 1: Efficiency cargo in blue line and passenger in red line – Does not indicate, with the model, a robust relationship.

The finding is not robust but suggest the absence of synergy or relationship between cargo and passenger transport efficiencies implies that different management strategies and operational processes could be at play for each domain. Thus, airports may need to address cargo and passenger operations as distinct components when aiming to improve overall efficiency. These findings indicate that efforts to enhance airport efficiency should consider a tailored approach to cargo and passenger services rather than expecting improvements in one area to translate to gains in the other.

Further analysis and studies might be needed to better understand the factors contributing to efficiency in each domain and to determine whether there are any other underlying elements that might influence the potential for synergy between cargo and passenger operations in airports. However, the current results suggest that, at least within the scope of this study, efficiencies in cargo and passenger operations do not show a clear relationship or synergistic effect.

5. Final Remarks

This study aimed to evaluate the efficiency of Brazilian airports by examining cargo and passenger operations. Using a Data Envelopment Analysis (DEA) framework, the research utilized two primary inputs—the capacity of terminal passenger services (TPS) and the length of the airport runway— along with two outputs: the total number of passengers transported and the total cargo in kilograms. The objective was to determine whether there exists a synergy between cargo and passenger transport efficiency or if these operational areas are independent.

The results from the analysis indicated no significant correlation or synergy between cargo and passenger transport efficiency. While individual airports demonstrated varying levels of efficiency, there was no clear evidence to suggest that high efficiency in cargo handling would lead to or result from high efficiency in passenger transport. This suggests that the operations of cargo and passenger services at airports may be influenced by different factors and require unique management strategies.

Given these findings, airport managers and policymakers should consider treating cargo and passenger operations as distinct components, each requiring focused attention and resources. The lack of observed relationship between the efficiencies of cargo and passenger operations highlights the need for tailored approaches to enhance overall airport efficiency. Future research may delve into specific factors driving efficiency in each domain or investigate broader datasets to uncover potential synergies, but the current results suggest that a one-size-fits-all approach may not be effective in improving airport performance.

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Forecasting Model to Assess the Impact of Extreme Weather Events Interconnection on Aviation

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Abstract/Resumo/Resumen

The need of a comprehensive analyses to face challenges associated to aviation in a climate context which is evolving continuously, as the changes in Hadley and Ferrel cells that has been seen in formation of jet stream in the troposphere can increase the risks in air safety. Thus, this study intend to evaluate the impact of the arrangement of extreme climate events through the development of algorithmic technical models that can impact in aviation operations, influenced by phenomena as El Niño, La Niña and Windshear. The analyses will be done in 10 airports in a period of 10 years, embracing the periods of El Niño and La Niña, noticing the possible influence of the alignment of the runway in the operability index, which should remain above 95%. The study proposes an evaluation of the alterations in the alignment of the runway in a time lag of 5 years. The changes that negatively impact this index due to extreme events will indicate the influence of these phenomena in the airport operation and security. The results will be divided in two sections: the first one approaches the results of the changes encountered in the alignment of the runway in the airports, whereas the second approaches the difference encountered in the factor of operability of the runway. These results will allow assessing the magnitude of the changes in the alignment of the runway and the impact of the factor of operability during El Niño and La Niña seasons. The study presents a model capable to observe the interaction between the climate phenomena and its possible interferences in aviation security and it develops a forecast model to assess the impact of these events. It correlates the increase of turbulence in the last years and the climate changes, demanding essential adjustments to maintain the operational security and efficiency, emphasizing the urgency of innovative strategies in front of constant changes, which represent a crucial challenge for the contemporary aviation.

Modelo de Previsão para avaliar o impacto da Interconexão de Eventos Climáticos Extremos na Aviação

1. Introdução

O universo da aviação está intrinsecamente entrelaçado com os fenômenos climáticos complexos que caracterizam a dinâmica atmosférica global. A compreensão abrangente desses elementos climáticos é fundamental para garantir não apenas a eficiência operacional, mas também a segurança das operações aéreas [1]. Este artigo busca explorar a interconexão vital entre El Niño, La Niña, Jet Stream, e o modelo tricelular atmosférico (Células de Hadley, Ferrel e Polar) para o Hemisfério Sul, destacando a necessidade de uma análise abrangente para enfrentar os desafios associados à aviação em um contexto climático em constante evolução.

As mudanças climatológicas tendem a tornar os voos futuros mais turbulentos, principalmente as CATs - turbulências de céu claro, resultando em enorme perigo para a segurança de voo e um custo elevado para as companhias aéreas. As ações antrópicas têm causado inúmeras modificações climáticas ampliando anomalias nos agentes principais da equação dentre elas, podemos citar o constante aquecimento global e o efeito estufa onde, a cada 100 unidades de radiação solar apenas 30 são refletidas de volta ao espaço e as 70 unidades não refletidas ficam presas na atmosfera influenciando toda a nossa cadeia climática de maneira significativa [2].

Nesse contexto intrincado de interconexões climáticas, é imperativo compreender não apenas os efeitos isolados de El Niño, La Niña, Jet Stream, WindShear, Vórtice Polar, Ondas de Rossby e Células de Hadley, mas também suas interações complexas. O desafio é desenvolver estratégias operacionais e tecnologias avançadas que permitam à aviação adaptar-se de forma dinâmica a essas condições climáticas variáveis, garantindo assim a segurança e eficiência contínuas das operações aéreas em um mundo onde o clima é cada vez mais imprevisível [3].

O objetivo geral deste trabalho é relacionar os principais efeitos climáticos causados pelo El Niño e La Niña e suas interconexões com o JETSTREAM. Pretende-se entender como as alterações climáticas estão impactando a segurança das operações aeronáuticas ao longo do tempo, especialmente devido aos incidentes envolvendo WindShear. Também são analisados os possíveis efeitos dessas alterações nas células de Hadley, nos JET STREAMS Subtropicais, nas células de Ferrel, nos JET STREAMS polares e seus impactos na troposfera, e, consequentemente, na segurança da operação aeronáutica [4].

2. Revisão da Literatura

Um estudo realizado por pesquisadores do Instituto de Meteorologia da Universidade de Reading no Reino Unido, constatou que viajar de avião atualmente é uma experiência mais turbulenta do que há 40 anos atrás. A pesquisa constatou que as CATs – turbulências de céu claro aumentaram em várias regiões

do mundo, onde rotas sobre o Atlântico Norte que são as mais movimentadas do planeta tiveram um aumento de 55% na duração de turbulência severa (saindo de 17,7h em 1979 para 27,4 horas de duração), 37% na moderada (de 70 para 96,1h) e 17% na turbulência leve, indo de 466,5 para 546,8 horas de duração [4].

Estes aumentos são consistentes com os efeitos das mudanças climáticas que têm intensificado principalmente o efeito *windsher* ou tesoura de vento, tornando o voo irregular e perigoso e as companhias aéreas precisam pensar em como administrar esses efeitos, pensando principalmente na segurança da operação mas também no impacto econômico, pois cada minuto viajando pela turbulência aumenta o desgaste da aeronave, o consumo de combustível e as possíveis lesões aos passageiros e comissários de bordo, dado que esta turbulência já custa à indústria entre U$ 150-500 milhões anualmente [4].

Juntamente ao efeito estufa podemos citar também o El Niño, conhecido pelo aquecimento das águas oceânicas no Pacífico Equatorial, que desencadeia uma série de efeitos climáticos globais. Nas camadas mais altas da atmosfera, as mudanças na temperatura da superfície do mar durante o El Niño podem influenciar a posição e intensidade do Jet Stream. Esta corrente de vento de alta altitude, que flui de oeste para leste, exerce uma influência significativa nas rotas aéreas, particularmente em voos de longa distância. A alteração na trajetória do Jet Stream durante o El Niño pode impactar diretamente o consumo de combustível e o tempo de voo, exigindo uma adaptação contínua por parte das companhias aéreas para manter a eficiência operacional [5].

Por outro lado, a La Niña, caracterizada por águas oceânicas mais frias, também desencadeia uma série de efeitos climáticos notáveis. Durante esse fenômeno, a alteração nos padrões de vento e temperatura pode criar condições atmosféricas desafiadoras para as aeronaves. Os ventos intensificados e as variações na temperatura do oceano durante a La Niña podem influenciar o Jet Stream de maneira única, apresentando desafios adicionais para a aviação. A compreensão profunda dessas interações é imperativa para que as companhias aéreas ajustem suas estratégias operacionais, garantindo segurança e eficiência mesmo em condições climáticas adversas [6].

Além do Jet Stream, o WindShear, uma variação abrupta na velocidade e direção do vento, emerge como uma preocupação crítica na aviação. Durante eventos de El Niño, as alterações nos padrões de WindShear podem ter impactos diretos nas condições de decolagem e aterrissagem. A presença de ventos mais fortes e instáveis durante esses períodos exige uma abordagem cautelosa dos pilotos para assegurar a segurança operacional. Similarmente, durante a La Niña, as condições de WindShear também podem ser significativamente afetadas, intensificando ainda mais os desafios enfrentados pelos profissionais da aviação durante as fases cruciais do voo [6].

Ao nos debruçarmos sobre estes elementos, não é possível desconectá-los do Vórtice Polar, um sistema de baixa pressão situado sobre os polos que exerce uma influência marcante nas condições meteorológicas globais. Suas flutuações sazonais podem desencadear mudanças nas trajetórias do Jet Stream, impactando diretamente as rotas aéreas. A influência combinada do El Niño, La Niña, Vórtice Polar com o aquecimento global pode resultar em condições meteorológicas extremas, exigindo uma abordagem estratégica para garantir a segurança e eficiência nas operações aéreas [3].

As Ondas de Rossby, por sua vez, representam perturbações nas correntes de ar de grande escala, contribuindo para a formação de sistemas climáticos complexos. Durante eventos de El Niño e La Niña, as Ondas de Rossby desempenham um papel crucial na propagação das anomalias de temperatura e pressão atmosférica, influenciando a distribuição de calor ao redor do globo. Essas ondas atmosféricas, quando interagem com as Células de Hadley, sistemas de circulação atmosférica que transportam calor equatorial em direção aos polos, podem moldar os padrões climáticos em altitudes mais baixas, afetando diretamente as condições encontradas pelos voos comerciais [6].

As Células de Hadley, representando uma parte essencial do sistema climático global, desempenham um papel central na circulação atmosférica. Durante eventos de El Niño e La Niña, as alterações nas temperaturas da superfície do mar podem influenciar a intensidade e a posição dessas células, impactando a distribuição de calor e umidade na troposfera. Essas mudanças podem, por sua vez, afetar

as condições meteorológicas em altitudes mais baixas, onde as aeronaves operam, apresentando desafios adicionais para a aviação com os deslocamentos na célula de Hadley na ZCIT - Zona de Convergência Intertropical [4].

2.1. El Niño, La Niña e o Modelo Tricelular Atmosférico

O El Niño é um fenômeno climático complexo caracterizado pelo aquecimento anormal das águas superficiais do Oceano Pacífico Equatorial, principalmente na região central e leste. Durante um evento de El Niño, as mudanças nas temperaturas da superfície do mar afetam os padrões de vento, levando a alterações nos regimes de chuva e temperatura em várias partes do mundo. Os impactos do El Niño incluem secas intensas, inundações, tempestades mais intensas e efeitos na agricultura e pesca. Similarmente, a La Niña, caracterizada por águas oceânicas mais frias, também altera os padrões climáticos, causando condições atmosféricas desafiadoras para as aeronaves devido aos ventos intensificados e variações na temperatura do oceano [6].

Dados encontrados em sites especializados em climatologia nos trazem uma dimensão do preocupante aumento da temperatura da superfície terrestre e oceânica como ilustra a Figura 1 [7]. A Figura 2 ilustra a probabilidade de turbulência no sistema de ventos entre 1979 e 2020 [8].

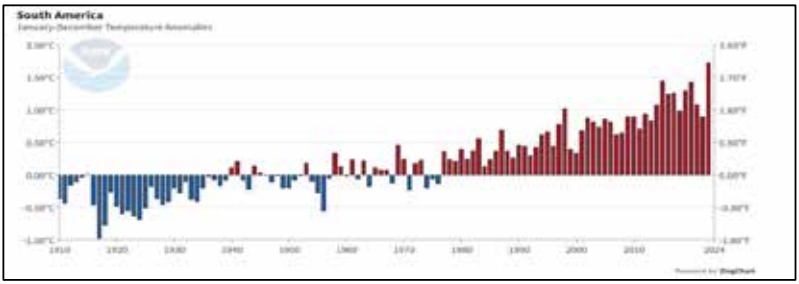

Figura 1 – Anomalias na temperatura da superfície do mar e terrestre. Fonte: [7]

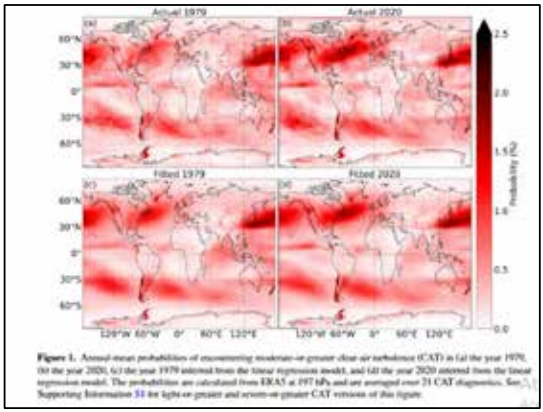

Figura 2 – Probabilidade anual de grandes turbulências. Fonte: [8]

O El Niño - ENSO, aquecimento das águas oceânicas no Pacífico Equatorial desencadeia uma série de efeitos climáticos globais principalmente mudanças na temperatura da superfície do mar durante e que podem influenciar a posição e intensidade dos ventos e do Jet Stream nas camadas mais altas da atmosfera como ilustram as Figuras 3 e 4.

Figura 3 – Inverno típico durante El Niño. Fonte: [7]

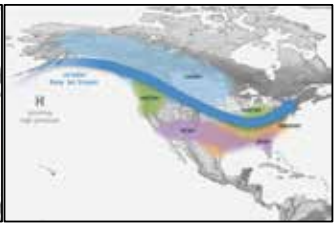

Figura 4 – Inverno típico durante La Niña. Source: Fonte: [7]

A Figura 5 ilustra o comportamento do El Niño e La Niña.

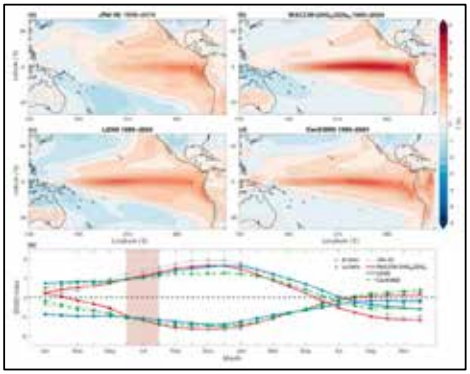

Figura 5 - Junho–Agosto ENSO: diferentes composições (El Niño − La Niña) temperaturas da superfície para (a) JRA-55, (b) WACCM-GHGHODSH, (c) LENS, e (d) CanESM2. (e) A sazonalidade de Junho–Agosto do evento ENSO. Fonte: [8]

O efeito do aquecimento global sobre o jet stream subtropical tem recebido atenção na literatura recente, onde sabe-se que mudanças na temperatura impactam nas células de Hadley em força e extensão meridional, isso acontece porque a circulação de Hadley controla a força do jet stream subtropical por meio da advecção meridional de momentum na troposfera tropical superior, e o gradiente térmico da assimetria de temperatura intertropical induz mudanças causando deslocamentos na zona de convergência intertropical (ZCIT) [9] ilustrado na Figura 6, enquanto a Figura 7 ilustra o modelo tricelular atmosférico [10].

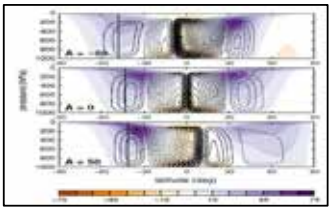

Figura 6 – Deslocamento na célula de Hadley e a ZCIT
Fonte: [9]

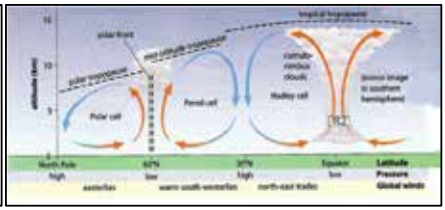

Figura 7 – Modelo tricelular atmosférico
Fonte: [10]

3. Metodologia

A metodologia adotada, de natureza investigativa, embasa-se em procedimentos bibliográficos e documentais, e suas fontes incluem dados de sites especializados em meteorologia [7], [11] e [12] para observação de dados globais, além de artigos e trabalhos de conclusão de curso para dados relacionados

ao Brasil englobando os passos necessários para alcançar os resultados por meio de uma análise comparativa entre cenários de El Niño, La Niña e Fase Neutra em 10 aeroportos comparando-se com o projeto atual in loco.

As principais etapas são:

(i) Definição dos aeroportos de análise - foram selecionados dez aeroportos internacionais do Brasil;
(ii) A obtenção dos dados - considerou-se estações de coletas de dados que apresentassem um histórico de coletas de até 10 anos,
(iii) As variáveis em análise e a orientação de pista que será avaliada dentro dos cenários El Niño e La Niña comparadas com pista atual do local;

Este artigo busca explorar a influência dos fenômenos climáticos El Niño, La Niña e Fase Neutra buscando mensurar possíveis alterações na direção, frequência, intensidade e módulo de direção dos ventos. O horizonte temporal escolhido para esta análise é de 10 que busca contribuir com estudos e desafios associados à aviação em um contexto climático antropogênico em constante alteração, identificando a variação percentual dos ventos de través e o impacto nas condições de segurança operacionais de pouso e decolagem dos aeródromos existentes diante das variações climáticas constantes durante os fenômenos climáticos supracitados.

3.1. Obtenção de dados

Historicamente os períodos de El Niño e La Niña desde 1950 em diante catalogado mensalmente, tal informação foi usada para filtrar os dados dos ventos dentro do cenário somente com ventos de El Niño, La Niña e Fase Neutra [7]. Para exemplificar este filtro foram escolhidos os anos de 1976 e 2009 com fins didáticos. Ao passo que se percorre cada ano de análise, seus meses em questão são alocados em seu respectivo grupo sendo: vermelho o El Niño, branco a Fase Neutra e azul La Niña como ilustra a Figura 8.

Figura 8 - Exemplo de série histórica série de dados trimestrais de fase: El Niño, La Niña e Fase Neutra. Fonte: [7]

Após a o agrupamento dos dados em seus respectivos grupos, foi identificado que em cada grupo havia tamanhos distintos, portanto, foi escolhido o grupo com menor quantidade de meses alocados para realizar o recorte dos outros grupos, assim todos ficaram com a mesma quantidade de meses, esse processo foi repetido para cada aeroporto em análise para seus respectivos dados meteorológicos.

Para este estudo foram utilizados dados meteorológicos abertos existentes para análise dos ventos e disponibilizados através da plataforma BDMEP [13]. Obtidos no mês de março/2024, os dados trazem uma vasta série de registros das estações meteorológicas nacionais categorizados por cidade e tipo de estação meteorológica - automática e/ou convencional com 25 tipos de variáveis climáticas coletadas incluindo as relacionadas ao vento: *direção, frequência e velocidade horária* ilustradas na Tabela 1 e utilizadas neste estudo.

Tabela 1 - Estações Meteorológicas e destaque das variáveis selecionadas. Fonte: [13]

1.	***** Data da medição***	14.	Temperatura do ar - bulbo úmido, horária (âºC)
2.	*Hora da medição*	15.	Temperatura do ponto de orvalho (âºC)
3.	Ch (nuvens altas) (código)	16.	Temperatura máxima hora anterior (aut) (âºC)
4.	Cl (nuvens médias) (código)	17.	Temperatura mínima na hora anterior (aut) (âºC)
5.	CM (nuvens baixas) (código)	18.	Umidade relativa máx. hora anterior (%)
6.	Nebulosidade horária (décimos)	19.	Umidade relativa mín. hora anterior (%)
7.	Precipitação total, horário (mm)	20.	Umidade relativa do ar, horária (%)
8.	Pressão atmosférica ao nível da estação, horária (mb)	***21.***	***** Vento, direção horária (º (graus))***
9.	Pressão atmosférica ao nível do mar, horária (mb)	*22.*	*Vento, rajada máxima (nó/s)*
10.	Pressão atmosférica máx. na hora ant. (aut) (mb)	23.	Vento, velocidade horária (m/s)
11.	Pressão atmosférica máx. hora anterior (aut) (mb)	***24.***	***** Vento, velocidade horária (nó/s)***
12.	Radiação global (kj/m2)	25.	Visibilidade, horária (código)
13.	Temperatura do ar - bulbo seco, horária (âºC)		

A Tabela 2 apresenta as estações meteorológicas, seus nomes, códigos e demais informações e, que foram a fonte de dados para o presente estudo.

Tabela 2 - Estações meteorológicas dos aeroportos analisados. Fonte: [13]

Nome	Cidade	ICAO	Código estação	Latitude	Longitude	Altitude (m)	Data Inicial	Data final
BRASÍLIA	Brasília - DF	SBBR	A001	-15.78944444	-47.92583332	1160.96	2000-05-06	2024-04-09
CURITIBA	Curitiba - PR	SBCT	A807	-25.4486111	-49.23055554	922.91	2003-01-27	2024-04-09
FLORIANÓPOLIS	Florianópolis - SC	SBFL	A806	-27.6025	-48.61999999	4.87	2003-01-21	2024-04-09
FORTALEZA	Fortaleza - CE	SBFZ	A305	-3.81583333	-38.53777777	29.55	2003-02-17	2024-04-09
MIRANTE DE SANTANA	Guarulhos - SP	SBGR	A701	-23.43555556	-46.47305556	785.64	2006-07-24	2024-05-03
JOÃO PESSOA	João Pessoa - PB	SBJP	A320	-7.16527777	-34.81555555	33.5	2007-07-20	2024-04-09
MACAPÁ	Macapá - AP	SBMQ	A249	0.03499999	-51.08888888	16.62	2013-12-11	2024-05-03
MACEIÓ	Maceió - AL	SBMO	A303	-9.55111111	-35.77027777	84.12	2003-02-24	2024-04-18
PORTO ALEGRE	Porto Alegre - RS	SBPA	A801	-30.05361111	-51.17472221	41.18	2000-09-21	2024-05-03
PALMARES	Recife - PE	SBRF	A357	-8.66666666	-35.56805554	164.01	2008-09-03	2024-05-03

Buscando uma melhor acurácia na qualidade das análises, foram realizados tratamentos no banco de dados oficiais brutos, conforme descrito, assim foi possível suprimir erros de digitação, valores incongruentes que poderiam impactar e distorcer as análises realizadas. Após o tratamento dos dados foram obtidos 1.373.356 de linhas de dados. A Tabela 2 descreve os dados tratados para cada aeroporto.

Tabela 3 - Locais de estudo e respectivas linhas de dados brutos e processados. Fonte: [13]

Aeroportos de Estudo	Município - UF	ICAO	Horizonte temporal		Nº Linhas da análise	
Presidente Juscelino Kubitschek	Brasília - DF	SBBR	2000-05-06	2024-04-09	209.760	*203.882*
Afonso Pena	Curitiba - PR	SBCT	2003-01-27	2024-04-09	185.856	*112.805*
Hercílio Luz	Florianópolis - SC	SBFL	2003-01-21	2024-04-09	186.000	*173.230*
Pinto Martins	Fortaleza - CE	SBFZ	2003-02-17	2024-04-09	185.352	*125.487*
Governador André Franco Montoro	Guarulhos - SP	SBGR	2006-07-24	2024-05-03	95.949	*91.478*
Presidente Castro Pinto	João Pessoa - PB	SBJP	2007-07-20	2024-04-09	146.616	*120.498*
Alberto Alcolumbre	Macapá - AP	SBMQ	2013-12-11	2024-05-03	91.128	*72.593*
Zumbi dos Palmares	Maceió - AL	SBMO	2003-02-24	2024-04-18	185.400	*158.901*
Salgado Filho	Porto Alegre - RS	SBPA	2000-09-21	2024-05-03	207.024	*198.798*
Aeroporto Int. de Recife - Guararapes	Recife - Pernambuco	SBRF	2008-09-03	2024-05-03	137.328	*115.684*
					1.630.413	***1.373.356***

É importante ressaltar que os dados não puderam ser processados diretamente pela biblioteca *Pandas* devido à sua codificação desconhecida, que diferia do padrão *UTF-8* (8-bit Unicode Transformation Format) [13]. Para contornar essa questão, foi necessário desenvolver uma função específica para ler essas informações, utilizando ferramentas nativas, capazes de lidar com arquivos com limitações de codificação de caracteres [14]. Isso permitiu o pré-processamento e as análises subsequentes, garantindo a correta leitura dos dados. Essa adaptação possibilitou a integração dos dados com a referida biblioteca.

As análises e o pré-processamento dos dados foram conduzidos em ambiente computacional, com o auxílio da biblioteca *Pandas*, que é responsável por gerar os anemogramas e analisar a direção e a velocidade dos ventos [14]. Esses dados foram tratados em um *dataframe* para padronizá-los, pois apresentavam títulos e tipos de dados diversos. Posteriormente, as velocidades dos ventos foram convertidas de metros por segundo (m/s) para nós (kn).

4. Escolha dos Aeroportos

Foram escolhidos 10 (dez) aeroportos internacionais no Brasil que tiveram relatos de incidentes de ventos de través durante operações de pouso e decolagem em suas pistas [15]. Porém, durante o tratamento do banco de dados foram identificadas divergências em algumas estações de coleta, como por exemplos direções de ventos incoerentes, ausência de determinadas variáveis (leituras nulas), histórico de coletas abaixo de 20 anos entre outros. A Figura 9 ilustra o mapa de localização dos aeroportos selecionados.

Figura 9 - Mapa de localização dos aeroportos propostos. Fonte: [16] adaptado pelos autores.

A Tabela 4 descreve as principais informações dos aeroportos de estudo, são dados abertos contendo todas as informações operacionais dos aeroportos civis públicos brasileiros [17].

Tabela 4 - Dados dos aeroportos selecionados. Fonte: [17]

Nome	Município / UF	ICAO	Orientação atual Pista 1	Comprimento Pista 1	Orientação atual Pista 2	Comprimento Pista 2	Altitude (m)
Presidente Juscelino Kubitschek	Brasília - Distrito Federal	SBBR	11L – 29R	3200 m 10499 ft	11R – 29L	3300 m 10827 ft	1066
Afonso Pena	Curitiba - Paraná	SBCT	15 – 33	2218 m 7277 ft	11 – 29	1798 m 5899 ft	908
Hercílio Luz	Florianópolis - Santa Catarina	SBFL	14 – 32	2400 m 7874 ft	03 – 21	1320 m 4331 ft	5
Pinto Martins	Fortaleza - Ceará	SBFZ	13 – 31	2755 m 9039 ft	-	-	25
Governador André Franco Montoro	Guarulhos - São Paulo	SBGR	10L – 28R	3700 m 12139 ft	10R – 28L	3000 m 9483 ft	750
Presidente Castro Pinto	João Pessoa - Paraíba	SBJP	16 – 34	2515 m 8251 ft	-	-	66
Alberto Alcolumbre	Macapá - Amapá	SBMQ	08 – 26	2100 m 6890 ft	-	-	17
Zumbi dos Palmares	Maceió - Alagoas	SBMO	12 – 30	2602 m 8537 ft	-	-	117
Salgado Filho	Porto Alegre - Rio Grande do Sul	SMPA	11 – 29	3200 m 10499 ft	-	-	3
Aeroporto Internacional de Recife - Guararapes	Recife - Pernambuco	SBRF	18 – 36	2751 m 9026 ft	-	-	10

5. Resultados e Discussões

Para os resultados vale ressaltar que em todos os casos, para os ventos de través é possível observar uma redução significativa, entretanto, tal comparação é de um agrupamento de dados de ventos ocorridos num horizonte temporal de 10 anos contrapostos com dados dos fenômenos climáticos El Niño, La Niña e Fase Neutra. Tais comparações não indicam que seja necessário mudanças na orientação de pista, e sim que durante estes períodos de climatologia extrema os operadores devem redobrar os cuidados durante os procedimentos de pouso e decolagem, pois a mudança dos ventos pode ser significativa trazendo maiores riscos à operação.

Pode-se observar também uma perceptível diminuição nos ventos de través e um aumento no fator de operação. Somente um dos casos, Guarulhos SBGR em sua pista atual na Tabela 5 atingiu o mínimo aceitável de 95% determinado em norma, os demais aeroportos que não atingiram os 95% em sua pista atual precisam de intervenções, pois, se o FO é baixo, observamos uma tendência no aumento dos ventos de través, acarretando maiores incidências de “pouso-caranguejo” ou pousos abortados [18]. Os dados obtidos na análise são apresentados na Tabela 5.

Tabela 5 - Resultados encontrados na análise. Fonte: Autores

AEROPORTOS		PISTA ATUAL 1				PISTA MODELADA					MUDANÇAS PERCENTUAIS		
ICAO	FATOR DE OPERAÇÃO (FO)	CABECEIRA	ORIENT.	VENTO DE TRAVÉS	PERÍODO	FO	CABECEIRA	ORIENT.	VENTO DE TRAVÉS	FO	CABECEIRA	VENTO DE TRAVÉS
SBBR	87%	85	11-29	13%	LA NIÑA	97%	12	03-21	3%	11%	-86%	-77%
					EL NIÑO	96%	21	04-22	4%	10%	-75%	-69%
					NEUTRA	98%	7	03-21	2%	13%	-92%	-85%
					10 ANOS	97%	3	03-21	3%	11%	-96%	-77%
SBCT	93%	135	16-34	7%	LA NIÑA	98%	7	03-21	2%	5%	-92%	-71%
					EL NIÑO	98%	7	03-21	2%	5%	-92%	-71%
					NEUTRA	98%	3	02-20	2%	5%	-96%	-71%
					10 ANOS	98%	7	03-21	2%	5%	-92%	-71%
SBFL	93%	122	14-32	7%	LA NIÑA	99%	72	09-27	1%	6%	-15	-86%
					EL NIÑO	99%	72	09-27	1%	6%	-15	-86%
					NEUTRA	99%	81	10-28	1%	6%	-5%	-86%
					10 ANOS	99%	74	09-27	1%	6%	-13%	-86%
SBFZ	68%	105	13-31	32%	LA NIÑA	99%	29	05-23	1%	46%	-66%	-97%
					EL NIÑO	99%	25	05-23	1%	46%	-71%	-97%
					NEUTRA	99%	41	06-24	1%	46%	-52%	-97%
					10 ANOS	99%	29	05-23	1%	46%	-66%	-97%
SBGR	96%	73	09-27	4%	LA NIÑA	96%	66	09-27	4%	0%	0%	0%
					EL NIÑO	96%	51	07-25	4%	0%	0%	0%
					NEUTRA	98%	44	07-25	2%	2%	-50%	-50%
					10 ANOS	96%	51	07-25	4%	0%	0%	0%
SBJP	78%	135	16-34	22%	LA NIÑA	99%	44	07-25	1%	27%	-48%	-95%
					EL NIÑO	99%	26	05-23	1%	27%	-69%	-95%
					NEUTRA	99%	59	08-26	1%	27%	-31%	-95%
					10 ANOS	98%	44	07-25	2%	26%	-48%	-91%
SBMQ	79%	100	12-30	21%	LA NIÑA	97%	3	03-21	3%	23%	-96%	-86%
					EL NIÑO	98%	1	02-20	2%	24%	-99%	-90%
					NEUTRA	98%	23	05-23	2%	24%	-73%	-90%
					10 ANOS	97%	3	03-21	3%	23%	-96%	-86%
SBMO	87%	57	08-26	13%	LA NIÑA	98%	141	16-34	2%	13%	66%	-85%
					EL NIÑO	96%	153	17-35	4%	10%	80%	-69%
					NEUTRA	98%	155	17-35	2%	13%	82%	-85%
					10 ANOS	97%	153	17-35	3%	11%	80%	-77%
SBRF	94%	162	18-36	6%	LA NIÑA	98%	25	05-23	2%	4%	-71%	-67%
					EL NIÑO	98%	21	04-22	2%	4%	-75%	-67%
					NEUTRA	99%	41	06-24	1%	5%	-52%	-83%
					10 ANOS	98%	25	02-23	2%	4%	-71%	-63%
SBPA	91%	91	11-29	9%	LA NIÑA	98%	33	05-23	2%	9%	-61%	-78%
					EL NIÑO	99%	44	06-24	1%	9%	-48%	-89%
					NEUTRA	99%	29	05-23	1%	9%	-66%	-89%
					10 ANOS	99%	33	05-23	1%	9%	-61%	-89%

6. Conclusões

Para cada aeroporto em questão, nos cenários comparados apresentados na Tabela 5, a Fase Neutra é onde ocorre a maior variação nos dados analisados, alterando o rumo e a orientação de pista em virtude da variação da direção e dos módulos dos ventos, apresentando os maiores impactos no cenário analisado, sendo o El Niño representado pela cor laranja, La Niña pela cor azul e a Fase Neutra representada na cor cinza, para o período de análise de 10 anos representado pela cor verde. Assim, faz-se necessário a observação constante das mudanças climáticas principalmente no que tange à segurança das operações aeroportuárias, de maneira para que se possa mitigar os impactos antropogênicos aliados aos causados pelos fenômenos climáticos principalmente o aquecimento global que interfere diretamente no mecanismo de circulação atmosférica causando anomalias que comprometem a operação e a segurança do sistema aeroviário.

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Economic Impacts and Operational Efficiency of Brazil's Major Airports: An Input-Output Analysis

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Abstract/Resumo/Resumen

This study examines the interregional air transportation network among Brazil's three largest airports, focusing on their economic impacts and operational efficiency using input-output economic tables. Utilizing an input-output model, we simulate the economic effects of investments in airport infrastructure on Brazil's GDP, employment, and tax revenue. This approach integrates data from the Civil Aviation Secretariat and national transportation databases to analyze passenger and cargo flows and their economic contributions. Our findings indicate that investments in airport concessions can significantly boost Brazil's GDP, create hundreds of thousands of jobs, and enhance tax revenue. The study highlights the critical role of São Paulo's Guarulhos, Rio de Janeiro's Galeão, and Brasília's Juscelino Kubitschek airports in promoting regional development and connectivity. This research contributes to understanding the economic impacts of airport infrastructure investments in Brazil. By applying an input-output economic analysis, it provides insights into optimizing air transport networks to support regional development.

Economic Impacts and Operational Efficiency of Brazil's Major Airports: An Input-Output Analysis

1. Introduction

The rapid expansion of air transportation has underscored the need for improved airport demand forecasting models. These models aim not only to accommodate growth expectations but also to ensure operations are efficient and sustainable. Serving as a cornerstone in airport management, these complex and multifaceted models influence key strategic decisions, from infrastructure development to coordination with airlines and regulatory bodies. The process begins with data collection and preprocessing, where data from various sources are validated, integrated, and formatted appropriately [1]. This is followed by exploratory data analysis to understand the data set's basic characteristics, explore variable interrelations, and spot trends [2].

Input-Output analysis has been a valuable tool in economic evaluations within the airport sector and is recommended by the International Civil Aviation Organization [3]. The outcome generated include economic multipliers that depict how variables such as income, output, and employment respond to changes in the air transport sector, aiding managers in strategic planning and fostering sustainable economic growth in both the airport and its surrounding area.

The economic influence of airports on their regional development is increasingly recognized in urban planning and public management. This paper introduces an innovative decision-making tool designed to assess the economic impact of airports, combining input-output methodology with an efficiency evaluation analytic tool. We propose a framework to study airports' relative efficiency based on their economic benefits to Society [4].

The practical application of this tool is demonstrated through a case study examining several airports within a specific region, focusing on ten Brazilian airports. The aim is to assess whether investments in these airports are yielding societal economic benefits. The analysis underscores the tool's effectiveness in identifying and quantifying each airport's economic contributions, covering aspects like passenger traffic, employment generation, and direct and indirect economic impacts [5]

Furthermore, the paper discusses the practical implications of these findings, suggesting ways to enhance airport operations and strategies for regional economic development. This discussion is vital for public managers and investors aiming to maximize the economic benefits of airports, thereby contributing to the sustainable development of their locations [6].

However, the paper also acknowledges the current limitations of the proposed tool and outlines directions for future research. The goal is to enhance its accuracy and applicability across different regional contexts, making it a more robust reference for strategic decision-making related to airport infrastructure investments.

Therefore, this study offers a significant contribution to the field of airport infrastructure management, providing insights for the evaluation and planning of public investments in airports. By emphasizing the importance of an input-output approach in assessing airport efficiency, the paper establishes an understanding of these infrastructures' economic impact, encouraging the development of more effective strategies for economic growth and regional development.

2. Literature Review

The application of Data Envelopment Analysis (DEA) in optimizing airport performance has garnered considerable attention in recent years. DEA, a robust non-parametric linear programming method, evaluates the efficiency of decision-making units (DMUs) by comparing their input-output productivity. The following synthesis of studies illustrates the diverse applications of DEA in assessing and enhancing airport operational efficiency across different contexts.

Roghanian and Foroughi [7] focused on the efficiency of Iranian regional airports, employing a robust DEA methodology capable of handling data uncertainties. Their analysis indicated that many Iranian airports operated inefficiently, highlighting a significant opportunity for the government to implement regulatory adjustments to enhance performance. This study underscores the potential of DEA to inform policy and regulatory decisions aimed at improving airport efficiency.

Suzuki et al. [8] addressed DEA's methodological and substantive weaknesses in a study of European airports' comparative performance. By incorporating lumpy inputs like runways into their extended DEA model, they highlighted the importance of detailed, process-level data for a more discriminative and valid efficiency evaluation. Their approach sheds light on the need for a more nuanced application of DEA that considers the specific operational and infrastructural characteristics of airports.

Storto [9] explored the efficiency of Italian airports by evaluating their cost-revenue production cycle using a Network Slack-Based Measure DEA (NSBM-DEA) approach. This innovative analysis provided a granular view of airport efficiency at different stages of the production cycle, offering valuable insights for policy makers and airport concessionaires interested in improving industry performance and airport management.

Iyer and Jain [10] conducted a comprehensive review of 61 articles published between 2009 and 2017 that assessed the performance of airports worldwide using DEA. Their study categorized the objectives of these articles beyond merely calculating efficiency scores into themes such as analyzing efficiency variation due to exogenous factors, mapping efficiency changes over time, and comparing DEA with other efficiency measurement tools. One critical insight from their review is the identified gap in the practical application of DEA-derived efficiency scores for actual performance improvement in airports, suggesting an area ripe for future research and application.

Ripoll-Zarraga and Lozano [11] applied a centralized DEA approach to Spanish airports, which are centrally controlled by the Spanish airport authority, as opposed to being managed by individual airport managers. Their study utilized a non-oriented Slack-based inefficiency (SBI) DEA model to reallocate two transferable inputs—labor and operating costs—across various airports. The results demonstrated the feasibility of increasing the total amount of passengers, cargo, and aircraft movements without increasing total inputs, merely by reallocating resources efficiently. This finding is particularly relevant for centrally managed airport systems, offering a pathway to enhanced operational efficiency through strategic resource distribution.

These studies collectively highlight DEA's versatility in analyzing airport efficiency across different contexts and methodologies. They underscore the importance of selecting appropriate inputs and outputs based on available data and the potential of DEA not only to assess current performance but also to guide strategic improvements in airport operations.

3. Methodology

Data Envelopment Analysis (DEA) is a non-parametric technique used to evaluate the efficiency of production units, known as decision-making units (DMUs). When applied to the analysis of airports in a country, DEA helps identify how well each airport utilizes its resources (inputs) to generate services and facilities (outputs).

In airport analysis, the inputs can include variables such as the number of employees, size of facilities, number of runways, and operational costs. The outputs, on the other hand, can be represented by indicators such as the number of passengers served, amount of cargo handled, number of flights, and other services offered to users.

The application of DEA involves the following steps:

1. Selection of Inputs and Outputs: Clearly define the resources consumed (inputs) and the services or products generated (outputs) by each airport.
2. Construction of the DEA Model: Based on the selected inputs and outputs, construct a model that allows comparing the relative efficiency of the DMUs. There are different DEA models, such as CCR (Charnes, Cooper, and Rhodes) and BCC (Banker, Charnes, and Cooper), which can be chosen depending on whether the scale of return is constant or variable.
3. Analysis and Interpretation of Results: After executing the model, each airport is evaluated on a scale from 0 to 1, where 1 indicates maximum efficiency. Those with efficiency less than 1 are compared with the most efficient to identify areas for improvement. DEA also allows identifying benchmarks or reference airports for those less efficient, offering a clear direction for operational enhancements.
4. Recommendations for Improvement: Based on the results, formulate specific recommendations for each inefficient airport, aiming to optimize resource use and improve the quality of services provided.

The application of DEA in the context of airports is particularly useful for managers and regulators of the aviation sector, as it provides a detailed understanding of how resources are being used and identifies opportunities to improve operational efficiency and service quality. This analysis can be fundamental for strategic planning, resource allocation, and evidence-based decision-making.

3.1. CCR Model (Charnes, Cooper and Rodes)

The CCR model, proposed in 1978, assumes constant returns to scale (CRS). This means it is most suited for analyzing DMUs that operate at their optimal capacity or when the goal is to assess overall efficiency without considering the size or scale of the operation.

Advantages of the CCR Model:

- Simplicity: The model is relatively simple to understand and apply, making it accessible to researchers and managers.

- Overall Assessment: It is useful for evaluating the overall efficiency of DMUs, offering a comprehensive view of performance.
- Benchmarking: It allows identifying efficiency leaders among DMUs, serving as a benchmark for other units.

Disadvantages of the CCR Model:

- Ignores Size of Operations: By assuming constant returns to scale, the model may not be suitable for DMUs that do not operate at the optimal scale, overlooking the effects of the size of operations on efficiency.
- Limitations in Diverse Environments: It may not adequately reflect the efficiency of DMUs operating under varying scale conditions.

Consider a set of n decision-making units (DMUs), each using m inputs to produce s outputs. Let's represent the inputs by x_{ij} (where i = 1, 2, ..., m and j = 1, 2, ..., n) and the outputs by y_{rj} (where r = 1, 2, ..., s and j = 1, 2, ..., n). The CCR model can be formulated as a linear programming problem in the following way:

One should maximize:

$$Z_0 = \sum_{r=1}^{s} u_r y_{r0} \tag{1}$$

to satisfy the following conditions:

$$\sum_{r=1}^{s} u_r y_{rj} - \sum_{i=1}^{m} v_i x_{ij} \leq 0, \quad j = 1, 2, ..., n \tag{2}$$

$$\sum_{i=1}^{m} v_i x_{i0} = 1 \tag{3}$$

$$u_r, v_i \geq 0, \; r=1, 2, ..., s; \; i = 1,2, ..., m \tag{4}$$

where u_r and v_i are the weights assigned to outputs and inputs, respectively, and the index 0 represents the DMU being evaluated. The goal is to maximize the quotient of the weighted outputs by the weighted inputs, ensuring that no DMU is more than 100% efficient under the chosen set of weights.

3.2. BCC Model (Banker, Charnes e Cooper)

The BCC model, introduced in 1984, assumes variable returns to scale (VRS), allowing for the assessment of efficiency in situations where DMUs do not necessarily operate at their full or optimal capacity.

Advantages of the BCC Model:

- Flexibility: By considering variable returns to scale, the model is more flexible and suitable for analyzing DMUs of different sizes and at different stages of growth.
- Pure and Scale Efficiency: It allows the decomposition of total efficiency into pure efficiency (related to management) and scale efficiency (related to the size of the operation), providing more detailed insights.
- Applicability: More suitable for analyzing efficiency in environments where the size or scale of operations varies significantly among DMUs.

Disadvantages of the BCC Model:

- Complexity: The analysis can become more complex, especially in decomposing efficiency into components of pure and scale efficiency.
- Interpretation Difficulties: The results can be more difficult to interpret, especially for those not familiar with DEA methodology and the concepts of variable returns to scale.

The BCC model, which assumes variable returns to scale (VRS), modifies the CCR model by adding a condition that allows for variability in returns to scale. This is achieved by introducing an additional

variable, θ, which adjusts the orientation for technical efficiency. The basic form of the BCC model can be expressed as follows:
One must maximize:

$$Z_0 = \sum_{r=1}^{s} u_r y_{r0} \tag{5}$$

satisfying the following conditions:

$$\sum_{r=1}^{s} u_r y_{rj} - \sum_{i=1}^{m} v_i x_{ij} \leq 0, \quad j = 1, 2, \ldots, n \tag{6}$$

$$\sum_{i=1}^{m} v_i x_{i0} = \theta \tag{7}$$

$$\sum_{i=1}^{m} v_i = 1 \tag{8}$$

$$u_r, v_i \geq 0, \quad r = 1, 2, \ldots, s; \; i = 1, 2, \ldots, m \tag{9}$$

Here, in addition to the weights u_r and v_i, the model introduces the variable ϑ to capture the technical efficiency of the DMU under analysis. The constraint from Eq (8) is added to ensure variable returns to scale.

3.3. Collected Data

The results section of this study focuses on analyzing the operational efficiency of airports using the Data Envelopment Analysis (DEA) method, based on collected data that encompasses both input and output variables. This data was gathered and organized from information available in reports and financial statements of the studied airports, including details on operational expenses and revenues generated by the airports during the year 2022. The input variables comprise the resources consumed by airport facilities to facilitate their operations. The collected data includes:

- Personnel Costs: This variable reflects the expenses related to the airport staff, including salaries and social charges, essential for the efficient functioning of airport activities.
- Conservation and Maintenance Costs: Represent the expenses with the maintenance of airport infrastructure and equipment, crucial for safety and operational efficiency.
- Operational Expenses: Include all variable operational costs associated with maintaining airport activities, such as logistics services and utilities.
- Administrative Expenses and Other Expenses: Encompass administrative and financial costs, in addition to other expenses not directly related to airport operations.
- Concession Payments: Reflect the amounts paid to the government or private entities for the right to operate the airport, influencing the operational margin.

The output variables comprise the financial returns received by airport facilities. They are indicators of the financial performance generated by airport operations, including:

- Adjusted Gross Revenue: The total revenues generated, adjusted for deductions and allowances, reflecting the airport's revenue-generating capacity.
- Adjusted Net Revenue: Represents gross revenue after subtracting costs and operational expenses, offering a more accurate perspective of operational efficiency.

Table 1 presents the collected input data for the DEA analysis for the 4 analyzed airports, SBGR (São Paulo/Guarulhos International Airport – Governor André Franco Montoro), SBKP (Viracopos/Campinas International Airport), SBRJ (Santos Dumont Airport), and SBBS (Brasília International Airport – President Juscelino Kubitschek). The data represents annual balance sheet data presented in 2022.

Table 1. Inputs for the 4 analyzed airports in 2022 in millions of BRL.

	DMU1	DMU2	DMU3	DMU4
	SBGR	SBKP	SBRJ	SBBS
Personnel	R$ 113.90	R$ 137.90	R$ 107.20	R$ 76.95
Conservation and Maintenance	R$ 112.90	R$ 224.50	R$ 34.10	R$ 136.76
Operational	R$ 202.60	R$ 46.47	R$ 140.00	R$ 99.82
Administrative Expenses	R$ 50.10	R$ 90.29	R$ 48.10	R$ 40.61
Concession Payments	R$ 261.90	R$ 333.82	R$ 140.40	R$ 51.17

Table 2 presents the collected output data for the DEA analysis for the 4 analyzed airports, SBGR, SBKP, SBRJ, and SBBS. The data represents annual financial data presented in 2022.

Table 2. Outputs for the 4 analyzed airports in 2022 in millions of BRL.

	DMU1	DMU2	DMU3	DMU4
	SBGR	SBKP	SBRJ	SBBS
Adjusted Gross Revenue	R$ 2736.20	R$ 1516.62	R$ 485.4	R$ 170.37
Adjusted Net Revenue	R$ 2333.50	R$ 991.17	R$ 670.8	R$ 279.48

4. Results

4.1. CCR Model

The DEA applied to the provided airport data allows for the evaluation of the operational efficiency of these units considering multiple inputs and outputs. This method, based on the work of Charnes, Cooper, and Rhodes, adopts a non-parametric approach to estimate production frontiers and determine how efficiently each decision-making unit (DMU) operates in relation to an efficiency frontier. The provided data includes information on various airports in the year 2022, covering expenses on personnel, conservation and maintenance, operational, administrative, as well as adjusted gross and net revenues.

The DEA model was executed using a toolbox developed by Álvarez [12]. Thus, DEA models were run to assess the relative efficiency of the DMUs. The results show the efficiency of the DMUs considering different orientations and returns to scale (crs - Constant Returns to Scale and vrs - Variable Returns to Scale), based on the defined inputs and outputs. The analysis of the results obtained through the application of the DEA model provides a quantitative view of the operational efficiency of four decision-making units (DMUs), represented by different airports. This model, oriented to inputs under a constant return to scale (crs) approach, allows the evaluation of the relative operational efficiency among the analyzed DMUs, based on three input variables and two outputs. Table 3 presents the results of theta and slacks for the 3 variables and two outputs presented.

Table 3: Input-Oriented analysis, return to scale: crs.

DMUs	Theta	Slack X1	Slack X2	Slack X3	Slack Y1	Slack Y2
1	1.00	0.00	0.00	0.00	0.00	0.00
2	0.46	0.00	40.65	13.74	0.00	302.24
3	0.95	69.23	0.00	31.38	301.16	0.00
4	0.18	0.00	10.72	1.20	157.34	0.00

4.2. BCC Model

DMU 1 achieved an efficiency score of 1.000, indicating that this airport operates on the efficiency frontier, without any excesses in any of the inputs and achieving the expected outputs. There are no

positive slacks, implying that there is no waste in the input variables and that the outputs are at optimal levels.

DMU 2 presented an efficiency of 0.4598, meaning that this airport operates well below the efficiency frontier. There is a significant positive slack in X2 (Conservation & Maintenance) and X3 (Administrative Expenses), indicating specific areas where a reduction in inputs can contribute to an improvement in efficiency. The positive slack in Y2 (Adjusted Net Revenue) suggests an opportunity to increase this output to achieve efficiency.

DMU 3 had an efficiency of 0.9518, positioning it close to the efficiency frontier. The slack in X1 (Personnel) and X4 (Administrative Expenses) indicates opportunities for adjustments in these inputs. The positive slack in Y1 (Adjusted Gross Revenue) suggests the possibility of increasing this output to achieve total efficiency.

DMU 4 showed the lowest efficiency among the analyzed DMUs, with a value of 0.1773. This indicates a large margin for improvement. Positive slacks in X2 (Conservation & Maintenance) and X4 (Administrative Expenses) point to critical areas where reductions are necessary. The slack in Y1 (Adjusted Gross Revenue) highlights the capacity to increase revenue to improve efficiency.

The revised analysis of the results, using the output for the DEA model with input orientation (io) and variable returns to scale (vrs), offers a detailed perspective on the operational efficiency of four DMUs. This model assesses relative efficiency by considering the inputs used against the outputs generated, allowing for the identification of potential areas for operational and strategic improvements. Table 4 presents the results of slacks for inputs X1, X2, and X3, and for outputs Y1 and Y2.

Table 4: Input-Oriented analysis, variable returns to scale: vrs.

DMUs	Theta	Slack X1	Slack X2	Slack X3	Slack Y1	Slack Y2
1	1.00	0.00	0.00	0.00	0.00	0.00
2	0.70	0.00	33.28	0.00	0.00	366.02
3	1.00	0.00	0.00	0.00	0.00	0.00
4	1.00	0.00	0.00	0.00	0.00	0.00

DMU 1 achieved an efficiency of 1.000, indicating it operates on the efficiency frontier for the dataset analyzed under the model with variable returns to scale. This means that, given the inputs used, DMU 1 generates an optimal volume of outputs, without presenting excesses or deficiencies in the variables considered.

DMU 2 obtained an efficiency of 0.7017, suggesting there is a considerable margin for efficiency improvement. The slacks found in X2 (Conservation & Maintenance) and X4 (Administrative Expenses) indicate specific areas where the airport can reduce resource consumption to improve its efficiency. Additionally, the positive slack in Y2 (Adjusted Net Revenue) shows that there is an opportunity to increase this output.

DMU 3 reached an efficiency of 1.000, thus operating on the efficiency frontier. This demonstrates optimized management of its inputs to produce the expected outputs, without the need for immediate adjustments in the variables analyzed.

DMU 4 also recorded an efficiency of 1.000, indicating efficient operation within the parameters established by the DEA vrs model. This result points to the proper use of available resources to achieve the desired outputs, not presenting excesses in inputs.

These results highlight significant differences in operational and scale efficiency among the analyzed airports. While some operate at maximum efficiency, others demonstrate significant areas for improvement. Specifically, DMUs 2 and 4 present opportunities for improvement both in operational efficiency and scale. The analyses suggest the need for strategic reviews of operations and scale to improve the efficiency of these airports.

5. Conclusions

The article presents an innovative tool designed to assess the economic impact of airports. Using the input-output methodology along with an analytical tool for efficiency evaluation, the work proposes an instrument to study the relative efficiency of airports in terms of the economic benefits they bring to society. This work, by illustrating its applicability through a case study involving four Brazilian airports, seeks to observe whether the investments made in these infrastructures are generating significant economic impacts for the community.

The analysis conducted demonstrates the utility of the tool in identifying and quantifying the economic contributions of each airport, considering aspects such as passenger movement, job creation, and direct and indirect economic impacts. The results reveal the effectiveness of the tool in offering pointers for the improvement of airport operations and strategies for regional economic development.

The study contributes in a meaningful way to the field of airport infrastructure management, providing a robust means for the assessment and planning of public investments in airports. Furthermore, it highlights the importance of an input-output approach in the efficiency analysis of airports, establishing a deep understanding of the economic impact of these infrastructures, and encouraging the development of more effective strategies for economic growth and regional development.

Lastly, the article recognizes the current limitations of the proposed tool and suggests directions for future research, aiming to enhance its accuracy and applicability in different regional contexts. Thus, the study not only offers practical results for the allocation of investments and regulation of private airports but also provides a solid foundation for strategic decision-making related to airport infrastructure investment, with the potential to positively impact the sustainable development of the regions where airports are located.

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Towards Sustainable Aviation: Assessing Airport's Progress Towards Net Zero Emissions by 2050

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Abstract/Resumo/Resumen

Nowadays there's a big challenge in the aviation industry in order to reach the goal of having net zero emissions of GHG's by 2050. This research aims to determine whether or not the airports can reach this goal.This research is based on the articles and reports analysis by authors, international commissions and airports of a global dimension, as well as investigations, projects, news and applications for the sustainability perspective in the airport segment. A quantitative methodology will be developed in order to measure and predict if the airports are putting as much effort as needed to reach the goal of the 2050 Net Zero emissions.Nowadays the environmental protection in one of the main drivers for some of the biggest organizations in the world. The aviation industry looks at decarbonization as a big challenge but also as a opportunity in a lot of domains. Some airports have already adopted several methodologies, philosophies, and technologies to reduce their emissions. However, it is expected that their effort it's still not enough to reach the 2050 goal.Even though, nowadays the environmental sustainability is a crucial factor for the aviation industry and for the airport segment it's important to understand and measure if we can actually reach the 2050 Net Zero emissions goal. By adopting a mathematical way to measure and predict the future, this research will demonstrate if the nowadays efforts are enough or not to the airport segment 2050 goal.

Towards Sustainable Aviation: Assessing Airport's Progress Towards Net Zero Emissions by 2050

1. Introduction

This research seeks to determine the progress of a particular airport infrastructure, in this case Changi Airport, towards reducing its emissions of polluting gases, with a view to achieving the 2050 Net Zero goal.

Environmental sustainability is one of the three pillars of sustainability as a whole. As a result, it is imperative to take action and set goals as we see the deterioration of environmental sustainability. The goal of Net Zero by 2050 arises from this and seeks to reduce polluting gas emissions to acceptable levels for environmental preservation. With this in mind, and focusing on the aeronautics sector, this reduction is really important and must be carried out in the most varied areas of the sector. Above all, it is necessary to reduce the emissions of polluting gases from airlines, with airport infrastructures appearing as a secondary, but considerable, priority.

Airport infrastructure emissions can be measured in a number of ways, but the ACI methodology is used for segmenting emissions by source, which is divided into scopes.

This research develops a methodology that seeks to make predictions and thus determine whether the future for any airport infrastructure in terms of emissions is bright. The Airport Progress Scope Emissions, the name adopted for the methodology, has a quantitative aspect, with the collection and mathematical processing of data, and a qualitative aspect with the justification of why there has been an increase or decrease in emissions, as well as what the airport infrastructure has planned for the future in order to contribute to a reduction in emissions, across the three Scopes.

2. Literature Review

2.1. Environmental Impact

Rupcic et al. (2023) [1] point out that the aeronautical sector has an impact on the environment at three main moments, which are subdivided into the manufacturing of aircraft, the operation of aircraft and ground operations to support the transportation of passengers by air. Each of these moments impacts the environment in a different way and with a different severity, with the most notable being the impact through the emission of polluting gases, the emission of noise, the use of land and destruction of habitats, soil contamination, water contamination, among other methods of pollution and environmental impact [2].

More specifically, with regard to emissions of polluting gases, which turns out to be the environmental impact that most fleetingly seeks to be combated, in 2022 there was an increase of 0.9%, or 321 megatonnes, compared to 2021, in the amount of carbon dioxide emitted globally, reaching 36.8 gigatonnes [3]. More specifically for the air transport sector the International Energy Agency (2023b) says that in 2022 the sector emitted around 785 megatons of CO2, which means a 15% increase in the sector's emissions compared to 2021, which is largely due to the increase in the number of movements compared to the pandemic period, when there was a decrease. However, compared to 2019, the pre-pandemic period, the sector only emits 80% of the emissions it used to emit, representing an overall share of 2.14% of global emissions [4]. In more detail, these 2022 emissions from the aviation sector show that 44.3% result from domestic operations, while the other 55.7% result from international flights.

Due to the fact that these pollutant gas emission figures are constantly increasing year after year [5] a number of initiatives have emerged that set certain objectives while suggesting various methods for achieving these objectives [6], [7].

In addition to CO2, aviation also emits, among other gases, carbon monoxide, sulphate aerosols, nitrogen oxide, water vapour, non-combusted hydrocarbons and non-volatile black carbon in its operations [8]–[10]. Emissions from airport operations account for only 2% of overall emissions from the passenger, cargo and mail air transport sector, with the most polluting share being linked to aircraft operation itself, where the combustion of CAF is proving to have a significant environmental impact [11]. According to Statista (2022) [12] in 2019 the 10 airports that emitted the most CO2 were, from the most polluting to the least polluting, Dubai International Airport (DXB),

London Heathrow Airport (LHR), Paris-Charles de Gaulle Airport (CDG), Changi Singapore Airport (SIN), Hong Kong Airport (HKC), Incheon Airport (ICN), Frankfurt Airport (FRA), John F. Kennedy Airport (JFK), Los Angeles Airport (LAX) and Bangkok Airport (BKK). Kennedy Airport (JFK), Los Angeles Airport (LAX) and Bangkok Airport (BKK). However, more important than mentioning the most polluting airports is to analyze why they are the most polluting and what solutions they have already implemented and are trying to implement to reduce their environmental impact. The reason why these airports may be the most polluting can be linked to the number of passengers transported, because there is a strong correlation between the more passengers transported and the greater the tendency to emit polluting gases.

However, not all the environmental impacts caused by airport infrastructures are related to the emission of polluting gases, as mentioned for the sector as a whole, Nunes et al. (2011) [13] studied the impact of airport infrastructures on soil and groundwater contamination and concluded that this contamination derives from:

i. from fuel storage;
ii. from the rainwater drainage system;
iii. from hydrant fuel systems;
iv. from the transportation and supply of fuel;
v. atmospheric deposition;
vi. firefighting and rescue training areas;
vii. winter operations;
viii. electrical substations;
ix. storage of chemical products; and
x. maintenance of green spaces.

In addition to the emission of polluting gases and the contamination of soil and water, airport infrastructures also produce a lot of noise that impacts the surrounding populations [14]. Miedema (2007) [15] believes that noise pollution at airports can lead to severe sleep disturbance, inevitably affecting the quality of life and health, both physical and mental, of those who work or live in the area surrounding airport infrastructures. Wolfe et al. (2017) [16] found that noise pollution from Gatwick and Heathrow airports in 2010 was associated with 57 myocardial infarctions that resulted in at least 17 deaths considered premature.

2.2. Airport Sustainability

The concept of a green airport can be defined as an airport that complies with the latest sustainability criteria, reduces the effects of airport activities on the environment and mitigates the impact of climate change resulting from related facilities and operations [17].

The concept of airport sustainability incorporates the "triple bottom line" concept with a fourth pillar focused on operational efficiency, as shown in Figure 1.

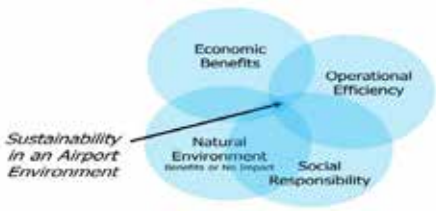

Figure 1 – Airport Sustainability
Source: [18]

Some authors define airport sustainability according to multiple categories of environmental impact [19]–[22], and others are limited to environmental impacts such as emissions of polluting gases and noise [23]. Unlike other studies that examine the sustainable practices of a specific airport [24]. Greer et al. (2020) [25] carried out a more comprehensive review, from which two of the five research objectives were to summarize the existing literature on airport environmental sustainability indicators and metrics and to recommend which indicators and metrics should be used at airports based on the results of the data survey, as shown in Figure 2.

Figure 2 – Themes and categories collected
Source: [25]

The first domain related to Energy and the Atmosphere comprises energy management, renewable energy and energy-related emissions.

Energy management is the process by which airports are able to monitor and characterize their energy consumption and act to reduce it [25]. Alba & Manana (2017) [27] studied Seve Ballesteros-Santander Airport in Spain and realized that most of the energy is consumed in the airport terminals in activities such as heating, ventilation, air conditioning and lighting. Kiyak & Bayraktar (2015) [28] concluded that in Turkey the activity that consumes the most energy in an airport is lighting. An airport that implements an energy management system is considered sustainable in this category [28].

Airports are the perfect candidates for the adoption of a large renewable energy network, mainly due to their usually large terrain [29]. One of the main advantages of using renewable energies is that there is no need to use fossil fuels, thus reducing the amount of polluting gases emitted [30].

Annual GHG emissions from energy consumption are a metric for assessing environmental sustainability [31], [32]. ACI mentions in its annual reports the amount of natural gas, energy consumed and fuel used to power the airport's ground vehicles [33].

The topic of Comfort and Health includes indoor air quality, air quality in the environment around the airport and the comfort of airport users.

Exposure to pollutants has significant impacts on human health, including increasing the likelihood of developing respiratory diseases, cardiovascular diseases and even leading to death [34], [35]. Wang et al. (2015) [37] studied eight Chinese airports and concluded that customer satisfaction increases the lower the amount of CO2 in the airport's indoor air.

Air quality in the airport's external environment is influenced by operations involving aircraft and by operations not involving aircraft [25]. Sources that influence air quality and are not related to aircraft operation include equipment used to clean, load and reposition aircraft, GSE's, or equipment to supply power to parked aircraft, GPU's [37]. Other sources of air contamination are the airport building itself and vehicles traveling on the apron, such as emergency vehicles [38]. Targino et al. (2018) [40] also concluded that the area of the airport where there is the greatest air contamination is in the apron.

Passenger comfort is important for the airport's sustainability, as aspects related to comfort such as ventilation and lighting are directly related to each airport's energy consumption [40]. Kotopouleas & Nikolopoulou (2017) [42] carried out a study in the UK's main airports and concluded that passengers prefer natural light, which has implications for airport energy consumption.

The third element is related to Water and Wastewater, containing water conservation and water quality.

Airports use water for indoor operations such as flushing toilets, preparing food, among others, and for outdoor operations such as washing and maintaining aircraft and infrastructure [42]. The amount of water used by a large airport is not insignificant and is on a par with many small and medium-sized cities [43]. It is therefore important to find alternatives for this water, as, for example, Mildura Airport in Australia uses a mechanism to conserve rainwater for later use [44].

Water quality concerns due to an airport's operations can be categorized as persistent, seasonal and accidental [45]. The fluid used in de-icing aircraft can have a negative impact on water quality and even marine fauna [46], [47].

The green element focuses on the Site and Habitat surrounding the airport and its sub-themes are the habitat itself, the transport used to and from the airport, and finally the resilience of the site.

The impacts of airport operations on wildlife is another area of research with the aim of finding specific strategies to discourage and accommodate wild populations at airfields, terminals, control towers, among others [48]. Research has already been carried out to identify the factors that make birds attracted to green roofs [49]. on the effects of airport expansions on bats [50], among others.

Sustainable transport, as far as airports are concerned, refers to the means of transport used to take passengers from the terminals to the aircraft and also the means of transport used from point X to the airport and from the airport to point Y [25]. Solutions from the terminal to the aircraft include, for example, the use of electric transport and the implementation of a policy whereby the number of journeys with completely empty transport is reduced [51]. For transportation to and from the airport, there are solutions such as encouraging passengers to use public transport, preferably low-emission transport [52], and also the possibility for airports to include electric vehicle charging platforms in their infrastructure [53].

Airport resilience is a topic with little research [25]. Some of the problems that some airports will face include rising sea levels and an increase in the frequency of flooding events [54]–[56].

The last theme is Materials and Resources used in an airport and its sub-themes are the management of airport materials, the materials used to build airports and waste management.

The soil on the airside of airports is usually composed of cement or tar, which are known to be a major source of polluting gas emissions [57]–[59].

Usually when airports are built, expanded or renovated, they try to obtain a green certification. This certification is given by certain groups, where airports usually have to follow a certain checklist. One of these groups, in this case in the United States, is the U.S. Green Building Council's Leadership and Energy in Environmental Design, which today has more than 200 certified airports [60].

Waste management at an airport includes the management of wasted food, building waste and aircraft-related waste [61]. Some metrics used to measure waste include the amount of waste, the source of the waste and the amount of waste per operation [62].

2.3. 2050 NetZero Target

The European Comission (2024) [64] defines this 2050 NetZero Challenge as a challenge that seeks to achieve carbon neutrality in an economically sustainable way by 2050, in line with the Paris Agreement. Carbon neutrality does not mean eradicating the emission of polluting gases from business activities, but rather ensuring that the amount of emissions emitted is fully reabsorbed [64].

For aviation there is a long way to go to achieve this goal, but some forecasts are optimistic and believe that by optimizing both airline and airport operations it is possible to achieve this goal.

3. Methodology

This research is mixed, involving both quantitative and qualitative methodology. Quantitative research is a systematic process of collecting observable and quantifiable data, based on the observation of objective facts, phenomena and events that exist independently of the researcher [65]. Qualitative research allows us to understand the origin of some quantitative results by interpreting them and giving them practical meaning [66].

This study includes bibliographical research and is mainly carried out using scientific articles. Leong and Austin [67] believe that reading, understanding and analyzing research that has already been carried out helps researchers to create a better-supported study base, because they have a better idea of what is already known and what has yet to be discovered. This research also analyzes annual reports published by airports, processing this data and applying the methodology presented. A case study is also taken into consideration in this study,

especially because by using a case study it is possible to answer questions relating to the "how" and the "why" of a particular reality or development [68].

The method created by the authors makes it possible to determine the evolution of GHG emissions by airport infrastructures towards achieving Net Zero 2050. The name adopted for the development of this method is APSE (Airport Progress Scope Emission).

In the first phase of this method, it is necessary to collect certain data which will then be processed and analyzed for a better interpretation.

The various three scopes were defined by Airports Council International [18] in order to segment each emission source in an airport infrastructure:

- Scope 1: emissions owned and controlled by the airport operator, such as energy production and airport vehicles;
- Scope 2: emissions from external energy production purchased by the airport operator;
- Scope 3: emissions owned and controlled by airport users and other stakeholders (companies, GSEs, GAVs, among others).

Once the data has been collected, APSE defines that a Scatter Graph needs to be created for each of the first two Scopes, because these are the ones that the airports actually directly control. After this it is necessary to obtain the number of passengers movements and the number of aircraft movements in order to have a better ratio to analyse and compare results. Using a Scatter Plot it is possible to obtain a number of outcomes such as analyzing the dispersion of the data, checking linearity, observing correlation and its strength, identifying outliers, among others [69].

After creating a Scatter Graph for each of scopes 1 and 2 as a function of passenger and aircraft movements, it will be necessary to check what the linear trend line will be and once this has been determined, it is necessary to collect the equation of the line y=mx+b. By identifying the linear trend line it is possible to extrapolate the data collected to a future reality, in this case to the year 2050.

By having the equation of the line it is possible to forecast how many emissions from each scope, depending on the existing reality, will exist in a given chosen period, which in this case for APSE is 2050, due to the goal of Zero Net Emissions for this year.

4. Results (Case Study, Sydney Airport (SYD))

By collecting the data on the Scope 1 and Scope 2 emissions, as well as passenger and aircraft movements from 2013 to 2019 of Sydney's Airport activity, it is possible to construct the following table, in tCO2 for the Scopes meaning. For this study in particular the Covid years were disconsidered because of the expected disruption and influence on the end results, mostly derived from the lack of movements, either passenger and aircraft ones.

Table 1 – Data Collected
Source: Self Elaboration (Based in [70]–[76])

	2013	2014	2015	2016	2017	2018	2019
Scope 1	5364	5024	5349	5746	5826	5569	5755
Scope 2	85350	85425	82999	79898	82062	81347	77865
Total Emissions	90714	90449	88348	85644	87888	86916	83620
Passenger Movements	37900000	38500000	39700000	41900000	43300000	44400000	44400000
Aircraft Movements	326228	327190	335001	346437	348522	344149	346182

Based on the data collected on Table 1, it is then possible to create the following two figures, where a Scatter Graph is created for each Scope and Total Emissions in order firstly on the Passengers Movements and secondly on the Aircraft Movements. In addition, each graph will have its own linear trend line, as well as its own equation so that forecasts can later be made for the year 2050.

For the following Figures it is important to retain the following caption:

- Blue Line: Scope 1 Emissions;

- Orange Line: Scope 2 Emissions;
- Green Line: Total Emissions.

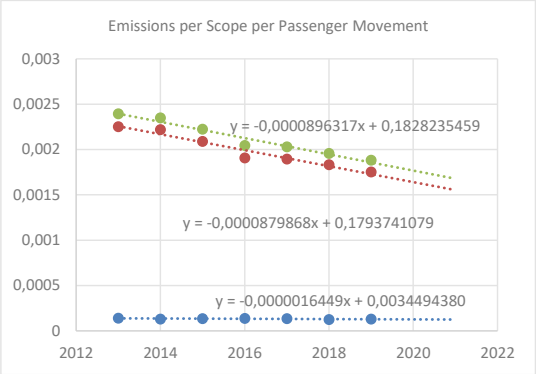

Figure 3 – Emissions per Scope per Passenger Movement
Scope – Self Elaboration

Looking at Figure 3, it can first be seen that its dispersion is significantly low for each of the three lines, where the maximum value shown and the minimum value for each one have a considerably low amplitude. The trend lines show that the dispersion is low due to the reduced slope, by analyzing the equation of the line.

In Table 2 is shown fow each equation the prevision of emissions by year 2050, for Scope 1, Scope 2 and Total Emissions, and also the prevision of the year where emissions will be zero by Passenger Movement.

Table 2 – Forecasting Emissions
Source: Self Elaboration

	Scope 1 (-2E-06x + 0.0034)	Scope 2 (-9E-05x + 0.1794)	Total Emissions (-9E-05x + 0.1828)
Emissions by 2050	7.7393E-05	-9.98832E05	-9.21439E05
Zero Emissions Year	2097	2038	2039

Analyzing Table 2 there are some key results to retain. Firsly it is possible to understand that maintaining this ritm of reducing emissions per passenger, Syney's Airport will be able to, per passenger, achieve the Net Zero goal earlier then 2050. In this case the Scope 1 is actually the one that this Airport in specific needs to do a better job in reducing it, however by the constant increase in the number of passengers transported its hard to do it mostly because it is necessary to maintain the business sustainability, economically talking. By looking at Table 2 it is possible to understand that the Scope 2 and the Total Emissions that congregate Scope 1 and Socpe 2, per passenger will be 0 by 2038 and 2039 respectively, if the Sydney's Airport maintain their efforts.

Analyzing Figure 4 it is again possibly to retain the low amplitudes of the emissions values as well as observe that the slope of the equations are negative which means that Sydney's Airport is actually working towards emiting less GHG's per Aircraft Movement in this case in specific, with the exemption of Scope 1 (blue line).

In Table 3 is shown how each equation the prevision of emissions by year 2050, for Scope 1, Scope 2 and Total Emissions, and also the prevision of the year where emissions will be zero by Aircraft Movement.

By analysing Table 3 its easy to understand that mainting this ritm of GHG's reduction at Sydney's Airports, by aircraft movement, they will not achieve the Net Zero goal by 2050. Mathematically talking the neutral carbon emissions will be obtained in Scope 2 and Total Emissions by 2056 and 2060 respectively. In case of Scope 1 by aircraft movement the perspectives are not ideal because the ritm is against the desired and the Sydney's Airport will need to change their paradigm otherwise they will not obtain the Net Zero Goal in this scope by any means in the future.

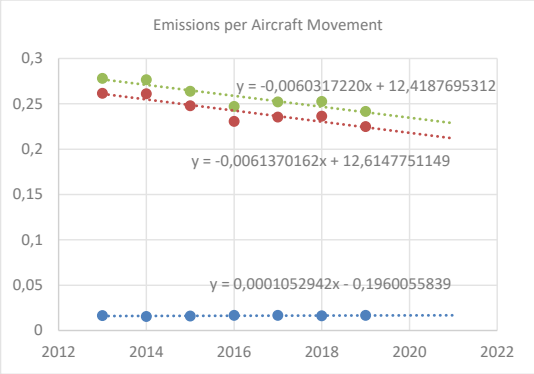

Figure 4 – Emissions per Scope per Aicraft Movement
Scope – Self Elaboration

Table 3 – Forecasting Emissions
Source: Self Elaboration

	Scope 1 (0.0001x – 0.1960)	Scope 2 (-0.0061x+12.615)	Total Emissions (-0.0060x+12.419)
Emissions by 2050	1.984753E-02	3.3891905E-2	5.3739431E-02
Zero Emissions Year	-	2056	2060

5. Conclusion

The environmental sustainability is one of the three pilars of the business sustainability paradigm. The aviation industry is one of the industries that have shown more concerns in battling against pollution. The various stakeholders have been working with the same goal of reducing GHG's emissions. There are two key actors on decarbonising the aviation industry, the airlines and the airports. Specially about the airports it is important to understand what can the infraestrutures do, in the various aspects, to be more sustainable and to achieve the industry main goal of the Net Zero emissions by 2050.

This method mathematically addresses and forecasts whether or not a specific airport will achieve the 2050 goal. By the specific case of Sydney's Airport it was possible to understand that depending on the ratio, if it relates to passenger movements or aircraft movements, the airport can obtain the Net Zero goal. With the exception of the emissions related to aircraft movements that delay this goal by a couple of years in Scope 2 and Total Emissions however in Scope 1 needs to increase their efforts.

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O impacto social da operação do eVTOL no funcionamento das cidades

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Abstract/Resumo/Resumen

O estudo examina os impactos sociais da operação de eVTOLs em ambientes urbanos, integrando teorias de mobilidade urbana aérea com regulamentações europeias. Utiliza uma metodologia documental, analisando documentos da EASA e índices de infraestrutura para avaliar vertports na Europa, confrontando com a literatura científica. Os resultados esperados incluem uma análise das normativas da EASA, destacando a evolução no tratamento dos impactos sociais, como segurança, ruído, poluição visual e privacidade. Apesar da ênfase inicial na segurança cibernética, menos atenção é dada aos ruídos e à privacidade. Regulamentações específicas para mitigar os impactos dos pólos geradores de tráfego afetarão o projeto e a construção de vertports, indicando a necessidade de uma abordagem integrada na inserção desse novo modal na malha urbana. O artigo propõe uma análise abrangente das normas da EASA e da literatura especializada em UAM, destacando a urgência de uma regulação mais eficaz dos impactos sociais e a integração da UMA às normas de zoneamento urbano para enfrentar desafios e explorar oportunidades de pesquisa em um contexto decompetição territorial e crescente demanda por soluções multimodais.Palavras-chave: mobilidade urbana aerea, impactos sociais, integração.

O impacto social da operação do eVTOL no funcionamento das cidades

1. Introdução

Este estudo visa identificar os impactos sociais da operação dos eVTOLs no espaço urbano terrestre, analisando modelos teóricos relevantes e definições de mobilidade urbana aérea (UAM), bem como seus efeitos no transporte de pequenas cargas e passageiros. A pesquisa revisou a literatura científica para classificar e dimensionar os impactos sociais percebidos pela população em cidades específicas. Com a maturidade do desenvolvimento europeu em utilizar baixas altitudes urbanas para o transporte aéreo, foi realizada uma análise documental de documentos recentes da Agência de Segurança da Aviação da União Europeia (EASA). Esta análise focou em como as regulamentações iniciais da UAM abordam a mitigação de impactos relacionados à segurança, ruído, poluição visual e privacidade. Os resultados foram comparados com abordagens científicas dos mesmos temas, destacando como as normas regulatórias tratam esses impactos e as diretrizes científicas sugeridas para sua gestão.

2. Revisão de literatura

O artigo examina a Mobilidade Urbana Aérea (UAM), que é destacada como um avanço disruptivo nos transportes urbanos, facilitando o deslocamento aéreo por meio de veículos elétricos que operam verticalmente (eVTOL) e são gerenciados por aplicativos, conforme indicado por Garrow et al. (2021). A UAM é vista como parte da Mobilidade Aérea Avançada (AAM), operando principalmente em espaços aéreos de baixa altitude que, até então, eram subutilizados. Thipphavong et al. (2018) destacam que esta nova modalidade inclui o transporte não tripulado de pequenas cargas e passageiros, um conceito ainda emergente na indústria de transportes.

Tang et al. (2021) e Bauranov et al. (2021) detalham como a UAM ocupa a camada G do espaço aéreo, faixa abaixo de 1200 pés, tradicionalmente reservada para drones e UAVs. Eles propõem a criação de uma nova faixa aérea dedicada à UAM, com regulamentações específicas para esse fim, uma ideia que poderia resolver as complexidades operacionais desse novo ambiente aéreo.

A pesquisa aponta a saturação dos modos de transporte terrestres e a necessidade de um uso mais equilibrado do espaço urbano como motivadores para a exploração da UAM, segundo Straubinger et al. (2021). No entanto, a mesma pesquisa indica uma contradição: apesar do rápido desenvolvimento de eVTOLs por mais de 200 empresas globalmente, com previsão de operação comercial nesta década, ainda há uma forte concentração acadêmica e prática nos modos de transporte tradicionais.

Os eVTOLs são projetados para pouso e decolagem verticais, eliminando a necessidade de pistas longas e possibilitando o acesso a áreas urbanas densas, uma inovação destacada por Bauranov et al. (2021). Essa praticidade se estende ao acesso dos usuários, que podem ativar os eVTOLs via aplicativos móveis, integrando-os ao sistema de mobilidade sob demanda (ODM), uma prática já em teste por empresas como a Ehang, conforme registrado por Yun et al. (2021).

Melo et al. (2020) descrevem as capacidades operacionais dos eVTOLs, que incluem uma sustentação de voo com velocidades de cruzeiro de até 200 nós e uma autonomia de até 200 milhas náuticas, adequadas para viagens curtas abaixo de 35 km. Os vertports, essenciais para a operação da UAM, e devem ser planejados para serem integrados nas malhas urbanas, levando em consideração fatores como densidade populacional e acessibilidade, como observado por Fadhil et al. (2019). Este estudo também nota que a UAM não busca necessariamente reduzir o congestionamento, mas sim oferecer um transporte rápido e eficiente para usuários economicamente privilegiados e para serviços especializados, como o transporte de pessoas com mobilidade reduzida.

Além de seu uso convencional, os eVTOLs são vistos como soluções potenciais para desafios geográficos específicos, como regiões montanhosas ou isoladas, conforme apontado por Pukhovay et al. (2021). No entanto, a implementação efetiva dos vertports ainda enfrenta incertezas, especialmente na escolha de locais apropriados, o que Fadhil et al. (2019) sugerem ser mitigado pelo uso de softwares baseados em sistemas de informação geográfica (GIS).

Os impactos sociais da UAM, como ruído e privacidade, ainda são uma preocupação, conforme explorado por Straubinger et al. (2019) e Airbus UTM (2019). Yedavalli et al. (2019) enfatizam que a segurança e o ruído são os principais desafios a serem endereçados. Ahuja et al. (2022) propõem soluções para mitigar o ruído, sugerindo que eVTOLs com múltiplas hélices podem operar a velocidades mais baixas, reduzindo o impacto acústico. Em conclusão, percebe-se que a viabilidade de operação da UAM depende não apenas da inovação tecnológica, mas da adequada integração dessa nova dimensão logística com os ecossistemas já existentes.

Jeong at al. (2021) explicam que, com o uso de um programa de design ambiental de aviação (AEDT) foi possível criar o conceito de rota prioritária de ruído, que desenha o deslocamento do eVTOL sob superfícies pouco povoadas e com baixo impacto sonoro, comparando com as rotas de prioridade comercial, as quais ponderam menor tempo de deslocamento e consumo de bateria, independente do impacto gerado, conforme ilustra Figura 1, na aplicação da região metropolitana da cidade de Seul.

Figura 1 – Uso de rotas alternativas para mitigação de ruídos UAM
Fonte: [9]

Avaliando os dois modelos, citados acima, constata-se que o uso da rota desenhada por prioridade de ruído apresentou uma redução de 76,9% no número de pessoas afetadas por altos níveis de ruído em comparação com as rotas operadas por prioridade comercial, evidenciando ser essa uma alternativa eficaz na mitigação dos ruídos de operação da UAM.

Analisando o mesmo contexto, Bauranov et al. (2021) alertam que o ajuste nas rotas de voo dos EVTOLs, poderão ser feitos de forma proativa, com o planejamento do espaço aéreo pelos órgãos de controle, de modo a considerar a mitigação do impacto social dos ruídos ou, o mesmo resultado será perseguido pela população das localidades atingidas, por meio de ações judiciais em defesa do bem estar coletivo, condição que pode influenciar no êxito ou não da recém exploração da UAM.

Como forma de instrumentalizar essa proatividade, Eissfeldt (2020) sugere que o controle de ruído seja feito de forma colaborativa, por meio de canais de comunicação instalados nos próprios aplicativos de transporte aéreo por demanda, de maneira a convidar os próprios residentes que se sentirem impactados a informar e gerar a detecção dos ruídos gerados pelos eVOTLs, criando a oportunidade dos ajustes de rotas por parte das operadoras, de maneira a garantir que os taxis aéreos urbanos operem de forma sustentável e bem sucedida.

Quanto a segurança da UAM, frisa-se que o presente estudo busca estudar o aspecto da percepção social de tal condição, e não os aspectos técnicos específicos da operação, nesse contexto, vê-se que a sensação de poluição visual pela comunidade, ocasionado pela rápida transformação da paisagem de baixa altitude já causada pelas aeronaves não tripuladas (UAS) em seus já diversos serviços conforme constataram Lascara et al. (2018).

Corroborando com esta percepção Bauranov et al. (2021) constataram que o sentimento geral da população em relação aos drones e potencialmente com os eVTOLS é de incômodo com as aeronaves, em razão da sobrecarga do campo de visão da paisagem das cidades e criação de sombras próximas a superfície com a operação em baixa altitude, conforme se sugere na Figura 2

Figura 2. Representação paisagem de baixa altitude incluindo UAM
Fonte: Autores gerado por DALL·E da OpenAI

Em análise aos dados da pesquisa Airbus UTM (2019), apurou-se que 43% dos entrevistados percebem maior segurança se os eVTOL operarem em altas altitudes e 42% se o fizerem em menor frequência durante o dia e dentre os modais estudados, os pedestres, os mais expostos aos fatores externos de deslocamento, são os que mais percebem a operação de UAM como não sendo segura salientam Yedavalli at al (2019).
O sentimento de insegurança fica ainda mais latente quando a violação da privacidade se torna iminente por meio do fácil acesso aos ângulos de visada das propriedades privadas pelo alto, por meio do constante tráfego em baixas altitudes e tecnologias de captura de imagem facilmente embarcadas em drones e eVTOLs. Sendo este um valor social desejado em uma democracia, encontrar formas de mitigar tal condição é medida necessária para a aceitação da UAM ressaltam Bauranov et al. (2021).
Nesse sentido, PytlikZollig at al. (2018) alertam sobre a associação negativa feita pela percepção social das operações aéreas em baixa altitude, com as cada vez mais populares imagens de espionagem e ataques militares autônomos, condição que pode fragilizar o senso de segurança das operações em UAM no sentido de ameaça a proteção da integridade física e patrimonial dos residentes urbanos.
Os estudos consultados indicam que a operação da UAM irá afetar as percepções sociais estudadas e a vida nas cidades por conseguinte, desde o congestionamento junto aos futuros vertportos, que poderão afetar a forma de ocupação urbana de empresas e moradias, gerando desafios novos de planejamento das cidades, condições que devem ser antecipadas por meio de regulamentações propostas pelas autoridades normatizadoras.

3. Método

A exploração da Mobilidade Urbana Aérea (UAM) por meio de veículos elétricos de decolagem e aterrissagem vertical (eVTOL) representa uma inovação disruptiva que exige métodos de pesquisa adequados para tratar de novos produtos, serviços e formas de organização. Segundo Ritala et al. (2020), a análise de documentos é um método eficaz para lidar com descobertas em campos de difícil medição, transformando desafios em oportunidades de pesquisa. Shared (2022) reforça que, em vez de gerar dados primários, problemas de

pesquisa podem ser respondidos eficazmente utilizando fontes já existentes, especialmente documentos produzidos por entidades públicas e acessíveis aos pesquisadores.

Ahmed (2010) argumenta que a pesquisa documental é prática, pois confia na curadoria prévia dos dados, os quais são reduzidos e revisados para codificar um enfoque específico e verificados em conclusões preliminares. Os documentos analisados devem atender aos critérios de veracidade das informações, credibilidade na coleta e registro dos dados, e representatividade, garantindo a autenticidade das informações. A técnica de análise semântica latente (LSA), conforme definido por Ayyagari et al. (2012), neste estudo o método é usado para identificar padrões textuais e palavras-chave relacionadas a regulamentações e impactos sociais na operação dos eVTOL, como segurança, ruído, poluição visual e privacidade, destacados por Yedavalli et al. (2019) e Bauranov et al. (2021).

Os dados para a pesquisa amostral foram fornecidos pela SGM Consulting (2023) através do portal ADVANCED AIR MOBILITY INSIGHTS, que reúne informações públicas sobre eVTOL e construtores de vertportos. A análise do Índice de Infraestrutura AAM deste portal revelou que a maioria das empresas ranqueadas e cidades que planejam construir vertportos estão na Europa, evidenciando a maturidade dessa região em relação à operação iminente da UAM.

A base deste estudo inclui documentos produzidos pela Agência de Segurança da Aviação da União Europeia (EASA), que, em 02.07.2019, começou um processo sistemático de consultas públicas para formular parâmetros técnicos que viabilizem a operação segura dos eVTOLs nos centros urbanos europeus (EASA, 2023). O processo resultou no documento EASA SC-VTOL-01 e no MOC-1 SC-VTOL, que são as normas para a operação segura da UAM na Europa.

Este estudo buscou identificar nos documentos técnicos da EASA o tratamento dado aos impactos sociais urbanos potenciais gerados pela operação do eVTOL na Europa e confrontar essas informações com literatura recente sobre o tema, buscando identificar convergências e divergências nas análises desses fatores. A investigação é essencial para entender como a UAM pode ser integrada de forma eficaz e segura no tecido urbano, considerando tanto a infraestrutura técnica quanto as questões sociais envolvidas.

4. Resultados

As palavras-chaves: security, *noise*, *visual pollution* e *privacy,* foram mineradas textualmente nos documentos emitidos pela EASA exclusivamente quando citadas no contexto de informação ou normatização de tais termos como fatores de impactos sociais da operação da UAM.

Os documentos estudados foram:

a) três edições do MOC SC-VTOL (Meio proposto de conformidade com condição especial para VTOL), que são as normatizações geradas após a coleta das três consultas públicas, precedentes de cada edição, que após receber as contribuições de fabricantes, profissionais, pesquisadores e público, são depuradas e revisadas no sentido de atualizar as especificações técnicas e operacionais dos eVTOLs;

b) PTS-VPT-DSN Especificações Técnicas do Protótipo para o projeto de VFR Vertiports, a primeira norma técnica europeia sistematizada para com as diretrizes para construção dos pontos terrestres de pouso e decolagem dos eVTOLs;

c) EPAS – Plano Europeu para Segurança Aérea 2023/2025, Volume I, Prioridades Estratégicas, que minerou os capítulos pertinentes a operação da UAM.

Após a detida análise de cada um dos documentos citados foi possível apurar os resultados da Tabela 1.

Tabela 1. Frequência de menções textuais normativas dos impactos estudados.
Fonte: Autores

Norma	Data	**Security**	**Noise**	**Visual pollution**	**Privacy**
MOC-1 SC-VTOL	25.05.2020	12	0	0	0
MOC-2 SC-VTOL	23.06.2021	0	1	1	0
MOC-3 SC-VTOL	12.08.2022	0	0	0	0
PTS-VPT-DSN	mar/22	2	4	1	0
EPAS	2023/2025	0	5	0	1

A análise das normativas sobre Mobilidade Urbana Aérea (UAM) revela uma evolução significativa no tratamento dos impactos sociais de veículos elétricos de decolagem e aterrissagem vertical (eVTOL), especialmente em aspectos de segurança, ruído, poluição visual e privacidade. Os principais documentos

estudados incluem as edições do MOC SC-VTOL, a PTS-VPT-DSN, que regula vertports, e o EPAS — Plano Europeu para Segurança Aérea.

A primeira edição do MOC SC-VTOL em 2020 destaca a preocupação com a segurança cibernética para eVTOLs não tripulados, enfocando a necessidade de estabelecer padrões rigorosos para prevenir ataques digitais, refletindo temores de um potencial uso malicioso semelhante aos atentados de 11 de setembro. Nas edições subsequentes, contudo, o foco em segurança migra para melhorias na navegabilidade e operação das aeronaves, divergindo das preocupações sociais iniciais.

Quanto ao ruído, apesar dos esforços antecipados pela NASA em 2018 para estabelecer o UNWG - Grupo de Trabalho de Ruído de Mobilidade Aérea Urbana, a normativa é insuficiente, tratando os testes de ruídos dos eVTOLs de maneira limitada no MOC-2 SC-VTOL e sem abordar a mitigação em cenários urbanos reais. A poluição visual é minimamente considerada, sendo discutida somente na segunda edição do MOC SC-VTOL em relação à intensidade dos sinais luminosos dos eVTOLs.

A proteção da privacidade é notavelmente subestimada nas normativas, com ausência de regulamentos efetivos para garantir a privacidade das populações sobrevoadas, apesar das discussões em estudos como os de Airbus UTM (2019) e os autores Yedavalli et al. (2019) e Bauranov et al. (2021). Esta lacuna destaca-se especialmente no contexto das democracias europeias, onde se esperaria um foco maior na proteção dos direitos individuais.

O documento PTS-VPT-DSN fornece diretrizes para a construção de vertports, enfatizando medidas para reduzir o ruído e a poluição visual durante as operações de eVTOL. Regulações específicas, como a limitação de obstáculos de superfície e a orientação para evitar o sobrevoo de áreas povoadas, mostram um esforço normativo para mitigar os impactos sociais negativos associados à UAM.

O EPAS promove regulamentações para operações seguras em baixas altitudes, introduzindo o "espaço U" e medidas para prevenir colisões e mitigar riscos. Este plano inclui diretrizes para definir rotas de voo que minimizem o impacto sobre áreas residenciais, evidenciando uma estratégia proativa de controle de ruído.

Adicionalmente, o EPAS é o único documento que aborda de forma concreta a preservação da privacidade, através da implementação de regulamentos que foram inicialmente desenvolvidos para drones. Esta abordagem pode fornecer um precedente valioso para a regulamentação dos eVTOLs, como sugerido por Lascara et al. (2018), que destacam como as experiências iniciais com operações de UAS podem ser aproveitadas para melhorar a aceitação pública e a implementação responsável dos eVTOLs.

Em resumo, a análise mostra uma crescente mas ainda insuficiente resposta regulatória aos desafios sociais trazidos pela UAM, com necessidades claras de desenvolvimento contínuo em áreas de ruído, poluição visual e, principalmente, privacidade.

5. Conclusão

O presente estudo evidenciou por meio do cruzamento das normas editadas pela EASA e a literatura especializada de UAM, que em que pese a maturidade organizacional do União Europeia em sediar importantes fabricantes e cidades que já se lançam a iniciar a operação aérea com os eVTOLs, os impactos sociais ainda se mostram pouco regulamentados em comparação com as dimensões técnicas de certificação dos aparelhos e métodos operacionais.

Tal fragilidade é contraditória na medida em que tão importante quanto se viabilizar uma aeronave que seja capaz de operar de forma segura e eficiente em baixa altitude, garantir que sua operação não impacte negativamente o bem estar social é condição clara de apuração da sua viabilidade.

Dentre os impactos sociais estudados, vê-se que o ruído, por ser fruto da emissão do próprio eVTOL, bastante estudado, e presente nas outras operações aéreas, é o impacto que apresenta melhor tratamento normativo, aproveitando o lastro científico já produzido.

Porém, ao se analisar as medidas mitigadoras propostas, capazes de tratar tal impacto social, nota-se a necessidade de complementação regulatória por parte do Poder Público local, que por meio da integração da Mobilidade Urbana Aérea em seus Planos Diretores de Ordenamento Territorial, que terão que definer zoneamentos urbanos considerando as rotas de UAM, preservando as zonas residenciais e identificando corredores compatíveis com a proximidade dos vertportos e dos polos geradores de tráfego que buscarão esse novo meio de deslocamento, ressaltando que conforme se apurou, a fixação das rotas de voo priorizando zonas de baixo impacto de ruído e menos habitadas, por consequência tratam também dos impactos da poluição visual e da violação da privacidade, apotados como negativos pela população entrevistada.

A integração das normas regulatórias da UAM por meio da revisão e atualização das normas de zonemaneto urbano local já existentes, se mostra com uma recente lacuna a ser preenchida com futuros estudos.
Na mesma linha, evidenciada pela quase inocorrência numérica textual apurada, o tratamento das questões de segurança pessoal e patrimonial, potencialmente violados pela fragilidade aérea de formatação dos imóveis, projetados para serem seguros por terra, são lacunas legais que precisam ser rapidamente preenchidas pelas autoridades constituídas limitando inicialmente o uso de determinadas tecnologias embarcadas nos drones e eVTOLs por exemplo de maneira que a garantia da inviolabilidade do lar seja preservada, dimensão social que por sua importância igualmente se mostra como fértil oportunidade de pesquisa.

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Los Angeles Versus its Airports: Exploring Monthly Noise Comment Reports to Understand Trends and Geography of Noise Complaints

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Abstract/Resumo/Resumen

Los Angeles' LAX is one of the world's busiest airports, currently processing 66 million passengers/year. This research deals with trends and geographical distribution of noise complaints from LAX's neighboring communities from 2016 to 2023. LAX has a challenging history with cities like Westchester and Surfridge (which it demolished completely). It keeps a sophisticated, quasi-on-line web track of its flights, allowing individuals to submit noise comments (complaints). This work-in-progress paper analyses both the noise comment trends along time, and their geographical location versus the airport site, exploring 95 monthly reports from 2016 to 2023, computed in Excel spreadsheets and GIS mapping. Individuals submitting complaints are in hundreds monthly, usually with thousands of complaints. There are two interesting findings: first, the number of comments has reached astonishing high figures and then diminished during SARS-Cov-2 Pandemics but has not recovered in recent months as the number of flights has; second, the cities or communities with more frequent individuals submitting comments do not match those geographically close to the airport site nor those aligned with its runways – rather, they are far away from the airport site and may be under distant flightpaths, on which LAX has no jurisdiction. This leads to further challenge the use of noise contours as a tool for managing aircraft noise around airports, as most complaints by far are not from individuals living or working within the noise contour areas. The paper gives food for thought on the use of alternative models for managing community noise from airports.

Los Angeles *Versus* its Airports: Exploring Monthly Noise Comment Reports to Understand Trends and Geography of Noise Complaints

1. Introduction

Airports are the functional link between air travel and land, where cities and regions exist. Air travel allows reduced times to cover long distances, quickly moving from one city or region to another, in a process in which time compresses space [1]. By serving cities and regions airports connect the local to the global scales through air travel, transferring capital beyond the limits of national borders [2] in a growing network of world-cities [3]. According to Fuller and Harley [4], "airports reconfigure geography … [and] are geo-mechanical-digital forms that are changing the contours of land, sea, and sky. To consider the relationship between an airport and its environs is to consider the entwining of movement, money, land, sky, matter, and information". But airports are impacting elements of infrastructure in the communities they serve apart from being strong business drivers [5] and providing economic and social benefits [6], airports demand large sites, segmenting urban areas, relocating water bodies, dwellings, and even entire neighborhoods if necessary [7]. Furthermore, they are the locus where aircraft land and take-off, thereby where their noise is more impacting on people [8].

Aircraft noise is a notable problem since the inception of jet-powered aircrafts in the 1950's and the 1960's but there has been more research for its control than any other source of noise [9]. In a study comparing groups of people living under flight paths and nonflight areas, nearly 70% of the former said that were bothered by aircraft noise, reporting sleep difficulties and a perception of being in poorer health conditions [10]. Aircraft noise tends to be louder and more disturbing when close to airports, as aircraft are either in final approach and landing, or at take-off and initial climb [9], [8]. Although high altitude overflights may be disturbing, the louder, more intense noise levels that occur near airports are far more disturbing. Hence, people living near airports tend to be more severely affected than people living far away from them [8], [9].

Continuous exposure to high levels of noise can damage the hearing system [9], [11], but continuous exposure to lower levels of environmental noise can also be detrimental, as the so-called non-auditory effects can cause arousal or stress responses, like those of fear or anger, such as being irritated with a tap dripping water or a television set too loud in the next-door neighbor's house: they generate noise levels that does not harm the hearing apparatus but annoy and stresses the recipient [12]. Noise is one of the continuous stress factors that affects both human performance (*e.g.*: lack of predictability and controllability over distracting stimulus) and social behavior (arousal, tolerance for frustration) [13]. Noise induces sleep disturbances by causing endocrine reactions, and aircraft flight noise is considered significantly or very much disturbing at relatively lower levels, from 51 dB(A) to 61dBA), when compared to road traffic noise, from 57 dB(A) to 65dB(A), and to rail noise, from 63 dB(A) to 78 dB(A) [14]. The main endocrine effect is the secretion of cortisol – a stress hormone released to keep humans ready to react to threats at sleep. Cortisol is secreted even when someone is submitted to high altitude overhead flights [15]. Jarup *et al.* [16] concluded that long-term exposure to night-time aircraft noise and daily average traffic noise increases the risk of hypertension, leading to higher cardiovascular risk.

Aircraft noise also affects cognitive capacity of children at schooling age, as those from noisy schools have higher blood pressure than those from quieter schools [17]. The effects of noise on children at school age include deficits in reading due to deficits in language acquisition [18]. A series of studies of cohorts of pupils attending schools near Munich's former airport (Riem) and its new airport (Franz-Josef Strauss, which opened in 1991), showed that 9- to 11- year old children exposed to airport noise, before and after the closure of the old airport and the opening of the new one, had worse health conditions and poorer long-term memory when submitted to aircraft noise [19], had a decrease in their cognitive capacity [20], and suffered from motivational aspects associated psychophysiological, cognitive and stress index levels [21].

Anti-noise activism started in the 1970s as awareness of noise being harmful grew, calling for legislation for abating and controlling noise sources, for instance, in the United States [22], where all major airports developed noise abatement procedures and identified noise-contours areas defined on daily, 24-hour average noise levels

for 65 dB and 75 dB [23]. European Directives, however, require major airports to develop noise contours levels of 55 dB and 65 dB [24].

The Conflict between airports and cities became evident after 3 consecutive accidents around Newark Airport in New Jersey claimed 11 lives on the ground between December 1951 and February 1952. This led to a crisis due to the proximity of residential development close to airports [25]. A Presidential Commission was established to state whether major airports in the country were located at places where they jeopardized their surrounding communities. The report, produced in 90 days, emphasized that more people died of bicycle accidents than of aircraft accidents in the United States, but already mentioned that the impending use of jet aircraft in airports surrounded by residential areas would create serious noise conflicts [26]. This called for a new generation of airports, larger, farther away from city centers, with longer runways to deal with jet aircrafts [7]. Los Angeles chose to expand its existing airport instead of building a new one and soon faced controversy due to the evidence of reduction of property values surrounding the site. In general, residential areas exposed to aircraft noise are impacted on their market values, from 0.5% to 2% of loss per additional dB(A) of noise [27], [28], [29].

Los Angeles has historical rivalries within California. During the Gold Rush of mid XIX century, it lagged behind San Francisco, which had a harbor and a port [30]. After both cities were connected to the rest of the country by railways, the discovery of oil at Los Angeles basin in the end of the XIX Century allowed it to focus on developing protagonism in the Pacific coast [31]. It acquired the cities of Whitmore and San Pedro to develop its own port, adjacent to its other rival city, Long Beach, sharing the same harbor, but with its own and independent waterfront [30]. But the water resources of the Los Angeles River could barely sustain 250,000 people. So, in the beginning of the XX century Los Angeles developed a robust (and polemic) water and hydropower generation scheme [32], [33], [34] bringing water from hundreds of kilometers away, from Mono Lake and Owens Valley. The city also developed one of the largest networks of mass-transit systems in the World [35] (which was later dismantled, replaced by the freeways [7]). With such infrastructure, Los Angeles grew its population to its current 18 million people (after developing new water transfers from the Colorado River and from San Joaquim Valley, both also hundreds of kilometers away) [32], [33], [34]. It became host of the movie industry [36], followed by aircraft manufacturing, shipyards and a steel-mill during World War II, then evolved to automobiles, tires, and auto parts manufacturing, and finally to defense industry. The demise of Soviet Union in the 1990's cancelled most defense contracts, leading the decrease of industrial activity [37].

Los Angeles International Airport (LAX) is a melting pot example of an early airport built far from residential development which later attracted communities and then entered in conflict with them. Originally developed in the 1920's, it became the city's official airport in 1928. It became the major hub on the Pacific coast and one of the busiest jetports of the world. The need for extending its 4 runways however found fierce opposition and lawsuits from neighboring communities, reaching astonishing US$ 3 billion, so the airport decided to acquire all the houses in the town of Surfridge (a strip between the airport's limits and the ocean) [38], as well as most of the houses in the south of Westchester. The airport bought and demolished circa 3,500 dwellings [39]. LAX processed a maximum of 85.7 million passengers, 623,514 flights, and 2.3 million tons of cargo in 2019 [40], until its patronage was hit by the SARS-Cov-2 pandemics. Its projected noise-contours following FAA directives, considering Community Noise Equivalent Level (CNEL), affect 48.71km^2, 13,045 dwellings, and 42,959 people [41], as shown in Table 1. Figure 1 show the corresponding 65 dB, 70 dB and 75 dB CNEL curves for 2020 over a land use map of the surrounding area of LAX.

Table 1 - Effects of Noise Exposure on the Neighborhood of Los Angeles International Airport, projected for 2020 Based on 2015 Data Source: LAWA, ESA Airports, 2015 [41].

CNEL level	Area (km^2)	Dwellings	People	Temples	Schools	Hospitals	Monuments
65-70 dB	27.83	10,339	32,507	42	21	3	1
70-75 dB	13.07	2,575	10,068	1	5	0	3
> 75 dB	7.81	71	384	0	0	0	1
Total	48.71	13,045	42,959	43	26	3	5

Although the airport's noise contours are precise and technically correct, as in many other large airports, people affected by noise do not necessarily live within their limits; actually, people living off from the airports' noise contours feel affected by aircraft noise [42].

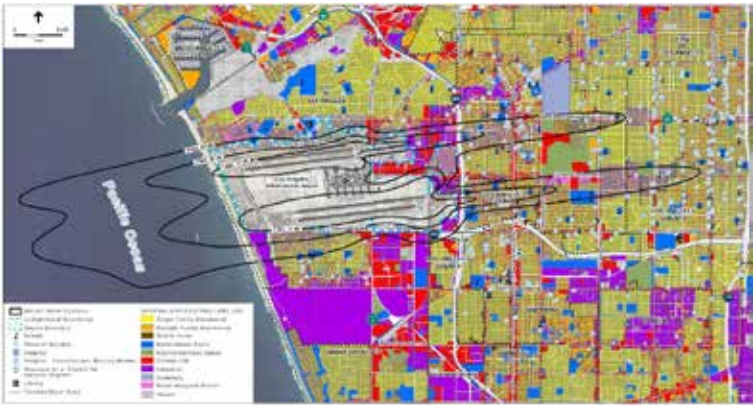

Figure 1 - 65 dB CNEL Curve (Noise Contours) for LAX, Projected for 2020 Based on 2015 Data
Source: LAWA, ESA Airports, 2015 [41].

LAX and all other commercial airports in Greater Los Angeles Area employ a sophisticated, quasi-real-time (20 minutes delay for safety) noise tracking tool named *WebTrak®*, an online noise mapping tool that allows any individual to identify noisy aircrafts overflight events near their location [41]. *WebTrak®* identifies flight number, aircraft model, air carrier, origin, and destination airport, and can be customized to display its momentarily altitude; it also shows the timely records of 24 continuous noise monitoring stations, including noise peak levels when aircrafts fly over them.

2. Objectives

This article analyses the trends and geography of noise complaints on Los Angeles International Airport (LAX), with two hypotheses: (a) the number of noise complaints diminished due to the SARS-Cov-2 pandemic but did not recover to the pre-pandemic level as aircraft movement is recovering; and (b) most of the noise complaints are submitted by individuals not living close to the airport. Noise complaints are dealt with as they evolve along time within the 96-month sample from January 2016 to December 2023. Geographical distribution is analyzed for a 31-month period by grouping individuals and complaints as “near the airport” or “far from the airport”.

3. Methodology

Three different sources of data were employed: (1) a series of 96 monthly noise reports published by Los Angeles World Airports (LAWA) for Los Angeles International Airport (LAX) ranging from January 2016 to December 2023 [43]; (2) monthly movements of passengers (Pax) and flights data published by the United States Bureau of Travel Statistics (BTS) [44]; (3) the noise contours CNEL map for LAX for 2020 [41].

Monthly noise comments reports [43] had their data scrutinized for the overall number of individuals submitting complaints and the number of complaints per month along the 96-months period. For the geographical origin, the name of the city of origin of the record was used to determine the location of the individual and thereby of the complaint, but these are published only on the first 31 months of the reports, limiting the geographical analysis. Geographical distribution was thereby analyzed visually on the maps included on the 96 monthly reports and on grouping and summing individuals and comments on a spreadsheet for the 31 months in categories such as “near the airport” and “far from the airport”, segregating outliers which distort the findings.

Data for Pax and Flights and for origin and destination were selected from BTS statistics database [44] for the period from January 2016 to December 2023, summing domestic and international movements and their grand total on a monthly basis. This accounts for enplaned and deplaned passengers and origin and destination flights; thereby does not include transfer or transit passengers, or aircraft movements such as ferry or training flights.

3.1 Trend Analysis in the Sample Data

To establish a trend analysis, grand total for monthly patronage for Pax and flights were tabled along total overall individuals submitting comments and the number of complaints, for January 2016 to December 2023, totaling 96 months. As these data in absolute numbers have quite different orders of magnitude, the sample was first analyzed in its statistics (minima, average, maxima, and standard deviation of each series) and its trend analysis was standardized with their maxima equaling 100, with all other monthly data expressed as a percentage of the respective maxima. A graph charting standardized Pax, flights, individuals, and complaints *versus* time (96 months) was plotted, allowing visual perception of the trend of each category along the sample period.

3.2 Geographical Analysis of the Sample Data

Los Angeles is a geographically spread metropolis. The 127 locations (places, cities, towns etc.) of the sample where individuals submitted noise complaints cover such a large territory that overlaying the 65 dB CNEL noise contour [41] shows only 6 locations intertwining it. The same applies to an Alignment Runway Model (AMR) used alternatively to analyze land use compatibility in a larger area than noise contours [8]. So, the 127 locations were checked on *GoogleMaps*® to be classified as "near the airport" and "far from the airport". Cities "near the airport" are those that (a) intersect the 65 dB CNEL curve for 2020 ("near LAX") or (b) are under the busiest, more concentrated "flight paths" [41]. All other locations are considered "far away from the airport" (except for Los Angeles city itself). From January to July 2016 there where entries indicated as "unknown" and "anonymous", which do not allow identifying their geographical position but influence the consistency of the analysis. Unincorporated city-like places such as Del Aire and Athens, which belong to Los Angeles County but are not formal cities (in seamless continuity of urbanization with neighbor cities), are not listed in the sample. Many of the "far away" places host or are directly adjacent to one of the other airports in Greater Los Angeles Area: Burbank-Hollywood, Santa Ana-John Wayne, Ontario International, Long Beach International, and Van Nuys (executive and general aviation) but complaints herein dealt with are exclusively those submitted to LAX.

4. Results and Discussion

Results of the analysis are presented in terms of their general statistics, as the trends of evolution of standardized indicators (regarding their maxima) along time, and as per their geographical distribution within LAX catchment area, considering the 127 locations – cities and towns of Los Angeles County and other neighboring Counties.

4.1 General Statistics of the Sample

Table 2 shows the statistical summary of notable data (minimum, average, maximum and standard deviation) in absolute numbers for 2016 to 2023. The patronage data has lower standard deviation as compared to average values for Pax and flights; the noise comments data show larger statistical variation.

Table 2 - Statistical Summary of the Data Analyzed on Patronage and Noise Complaints of Los Angeles Airports, 2016 – 2023
Source: Prepared by the author based on [43] and [44].

Data Origin	Patronage		Noise Comments	
Statistics	Passengers (Pax)	Flights	Individuals	Complaints
Minimum	325,442	11,103	84	904
Average	5,699,117	44,090	213	10,121
Maximum	8,221,126	59,972	523	33,738
Standard Deviation	1,915,361	11,171	109	4,075

4.2 Evolution Trend of Standardized Indicators Along Time

Figure 2 shows the standardized trends of Pax, flights, individuals submitting complaints and complaints data for LAX, from January 2016 to December 2023. In the first 4 years of the sample, Pax and flights vary according to the season, with summer peaks and winter valleys. SARS-Cov-2 Pandemic hit in March and April 2020, collapsing patronage. A more intense recovery can be seen up to the summer of 2021, followed by slower recovery patterns (not yet to pre-pandemic values), again with seasonal variations, throughout December 2023. Individuals submitting comments grow steadily in the first 18 months, vary in high levels close to the maximum until mid-2018 and then slant down to a plateau on the original order of magnitude in the last 3 years of the sample. The number of complaints lags longer on its growth to reach its peak in September 2018, after which it slants back to original levels in the last 3 years of the sample with a mild peak in the summer of 2021.

Figure 2 - Standardized Trends of Pax, Flights, Individuals Submitting Complaints and Complaints for LAX, 2016-2023
Source: developed by the Author based on [43] and [44].

4.3 Geographical Distribution of Noise Complaints Regarding the Airport

Identification of complaints are shown only from January 2016 to July 2018 (31 months), while from August 2018 to December 2023 (65 months), there is no information regarding the location of the complaints, and information regarding individuals submitting complaints are not specified for cases of cities in which there are only one submittal per month. This prevents any geographical analysis on both individuals and complaints from August 2018 onwards.

Figure 3 shows a sample of four maps included on the Monthly Noise Comment Reports published by LAWA for LAX: January 2016 (first month of the sample), July 2018 (last month showing detailed locational data for individuals and complaints), February 2020 (last month before SARS-Cov-2 Pandemic), and December 2023 (last month of the sample).

A significant number of individuals submitting noise complaints are somewhat far away from the airport site in all months depicted (the 4 selected monthly maps are representative of the whole series). There are dots on the maps that are over 80 km away from LAX, and many of them are close to the other 5 airports of Greater Los Angeles Area. Thirty of the 127 locations are "near the airport" (which can barely be seen given the necessary scale of mapping), including "near LAX" and "flight path" locations, including Culver City as an outlier. The maps do not include all 97 locations "far away from the airport" where individuals submitted noise complaints – as some are too far off, demanding a scale in which the details of the map would become unreadable.

This indicates that most of the noise complaint burden is laid on LAX, although some of the flights may not have LAX as their origin or destination – it is unknown if the complaints follow positive identification on *WebTrak*® that the aircraft/flight causing the noise nuisance was indeed flying to or from LAX instead of any of the other airports of Greater Los Angeles Area. Since description of the complaints were included only in the early monthly reports (along 2016), it is not possible to tell if all individuals complained of overflight noise of aircrafts indeed flying to or from LAX instead to or from any of the other commercial airports of Greater Los Angeles Area. Many of the dots in the maps are in the vicinities of these alternative airports.

The percentage of individuals and complaints over the total data for all 127 locations are shown respectively on Figures 4 and 5, highlighting the two outliers: Culver City, for flight paths, and Los Angeles city for general territorial spread. Culver City concentrate many individuals and a much larger number of complaints in an area that is relatively "near the airport" – not adjacent to it, but under a busy flight path on Easterly arrivals landing West-bound on LAX's 4 runways. Los Angeles, on the other hand, is physically so large and spread that it has areas in the runway alignment (*e.g.*: South Los Angeles) as well as parts relatively far from the airport (*e.g.*: Studio City and Hollywood). Unidentified-location data in the beginning of the series affects the number of complaints (circa 21% of the total in January 2016) and the number of individuals (7% of the total in April 2016).

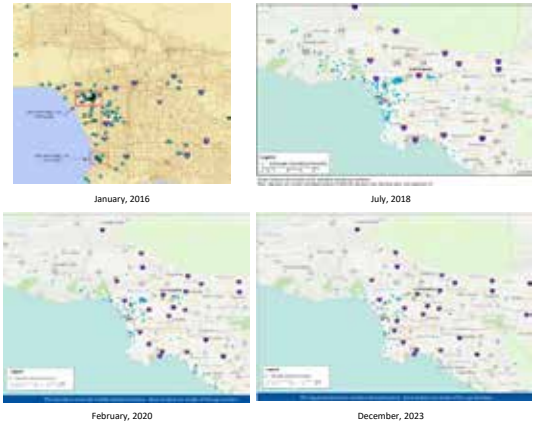

Figure 3 - Example of Maps Showing Location of Submittals in Selected Months
Source: [43].

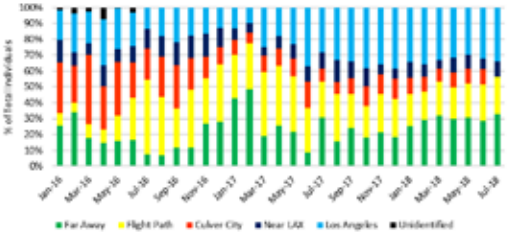

Figure 4 - Monthly Distribution of Location of Individuals Submitting Complaints
Source: developed by the Author based on [43].

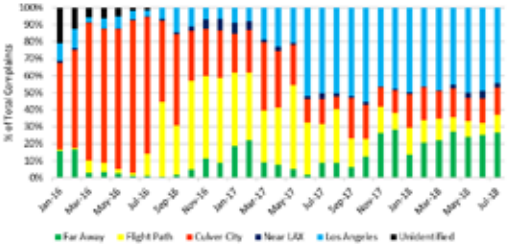

Figure 5 - Monthly Distribution of Location of Complaints Submitted by Individuals
Source: developed by the Author based on [43].

The geographical analysis is severely affected by the availability of locational data only for the first 31 months of the sample. It thereby misses most of the peaks of individuals submitting astonishingly high numbers of complaints (September 2017 to May 2019). At times, the number of individuals from Culver City submitting complaints is larger than all other "flight paths" locations; as per the number of complaints this is a rule in the beginning of the series: individuals from Culver City submitted more complains than all other categories altogether. From mid-2017 to July 2018, when location data began to be omitted on the Monthly Noise

Comments Reports, Los Angeles individuals became dominant on submittals and on complaints, replacing the former lead by Culver City. Levels of individuals "far away from the airport" submitting complaints is relatively high, but the number of complaints is relatively low (although there are exceptions, such as one single individual from Lakewood, close to Long Beach International Airport, who submitted 117 complaints in January 2016). Last but not least, the number of individuals apart from Los Angeles in cities or locations near LAX (Inglewood, Lennox, El Segundo, Playa del Rey, and Westchester) are relatively low, and the number of complaints is surprisingly low as compared to the proportional number of complaints of all other locational categories along these 31 months.

5. Conclusions

None of the 2 hypotheses were fully confirmed with the findings / analysis.

Regarding hypothesis (1), the number of noise complaints indeed diminished along the SARS-Cov-2 pandemic, but this began to happen almost one year before the pandemic hit the Pax and flights movements (see Figure 2). It is correct that the number of individuals submitting complaints and the number of complaints are apparently not increasing back as the Pax and flight movements recover from the effects of the pandemic, but this is probably due to the inflated numbers of individuals submitting complaints and overall complaints respectively along 2017-2018 and from mid-2017 to 2018, as the post-pandemic standardized records for individuals and complaints are in the same order of magnitude of the earlier six months of the sample. A longer sample including data from 2015 and earlier years could clarify if the inflated numbers of complaints and individuals submitting them in the 2017-2018 period were a "bubble" that burst or if there may be other reasonable explanation, as the Pax and most importantly the flights standardized numbers were quite stable in the first 4 years of the sample, with recurrent, similar seasonal summer peaks and winter valleys.

Regarding hypothesis (2), the geographical distribution analysis is severely harmed by the characteristics of such data in the sample. First, there is data only for 31 of the 96 months, not fully coinciding with the peaks (or bubble) of inflated numbers of individuals submitting complaints and overall complaints; second, after July 2018 not only there is no information regarding the location of individuals and complaints but also the information of number of locales with one individual only submitting a complaint is not included – there is only a monthly number of 15-25 locations with solely one individual submitting complaints, without identification of which these locations are. This prevents distributing this data in terms of being "near the airport" or "far away from the airport". The existence of the two outliers – Culver City because of being under "flight paths" rather than "near LAX", and Los Angeles, because of its territorial spread including areas in the direct alignment of LAX runways and other areas quite far from the airport, distorts the analysis even further. However, Figure 3 partially confirm hypothesis (2) as the 4 sample maps do not differ in character from the visual impression of the 96 maps of each Monthly Noise Comments Reports. An exercise selecting only partial data from Figures 4 and 5, excluding both outliers and unidentified locations, show that individuals submitting complaints have the category "far from the airport" responding for more than 50% of the subtotals only in 8 of the 31 months, while the number of overall complaints by individuals located "far away from the airport" respond for more than 50% of the subtotals in only 11 of the 31 months, neither of the cases confirming hegemony as originally hypothesized. On the other hand, evidence show that the number of individuals submitting noise complaints as well as the number of complaints submitted in the "near LAX" category are both very low, which is counter intuitive. This leads to further challenge of the use of airport noise contours as aircraft noise management tool, as most complaints are located under "flight paths" and in outliers such as Culver City and Los Angeles city, where the airport has limited or no governance to enforce corrective noise-control measures. To wrap-up, there may have been an "anti-airport" activism first by residents of Culver City (during the first 9 months of 2016) followed by the rise of a similar behavior from Los Angeles residents from June 2017 to July 2018, which coincide with the beginning of extremely high figures of individuals submitting complaints and of the number of complaints shown in Figure 2 above. This is food for thought on the use of alternative models for managing community noise from airports.

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Unveiling Airport Potential: A Simulation-Based Study of Felipe Angeles Airport's Capacity in Mexico City

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Abstract/Resumo/Resumen

The capacity of the newly inaugurated airport terminal in Mexico City, opened in 2022, has sparked debates regarding its adequacy to accommodate future demand. To address this critical question, our study employs simulation-based analysis to assess the terminal's true potential. By simulating various scenarios, we aim to provide insights into its capacity to handle increasing passenger loads over the coming years and decades. Furthermore, our analysis identifies potential challenges and issues that may arise with the terminal's growth. This research seeks to offer valuable perspectives for stakeholders involved in the airport's planning and management, contributing to informed decision-making in ensuring efficient and sustainable aviation infrastructure.

Unveiling Airport Potential: A Simulation-Based Study of Felipe Angeles Airport's Capacity in Mexico City

1. Introduction

The Felipe Ángeles International Airport (NLU) opened on March 21, 2022, to alleviate congestion at Mexico City's Benito Juárez International Airport (MEX), which has been declared saturated [8] by the local government[. Additionally, the Mexican government aims to develop a comprehensive multi-airport system [6][7], within the metropolitan region of Mexico City. This system includes the new NLU airport, as well as the existing Toluca International Airport (TLC) and Benito Juárez International Airport (MEX).

This paper presents a study that investigates the practical limitations and evaluates the performance indicators of the capacity [10] of the Felipe Ángeles Airport terminal. The facility has been designed for progressive expansion according to demand. Currently, the system appears to be over-dimensioned; however, it is beneficial for all stakeholders to identify potential future problems. Therefore, the authors used simulation models to generate synthetic data and evaluate the turning points when the system reaches its limits. This approach provides timely warnings for airport operators, helping to avoid problems for passengers and stakeholders.

The approach consists of a simulation framework [9] composed of different layers of knowledge that together create a realistic model to assess the current situation and predict future scenarios accurately.

We considered different scenarios, using the 2024 scenario as a baseline to evaluate the current capacity and demand issues. Based on expected growth, we generated new scenarios for each subsequent year until 2028 to identify the turning point of capacity limitations.

2. Current Situation of 2024

NLU features three runways: two runways, each 4,500 meters long, designated for commercial use, and one runway, 3,500 meters long, designated for military use [3] . This runway configuration allows NLU to perform simultaneous operations for commercial traffic. Figure 1 illustrates the airside of the airport.

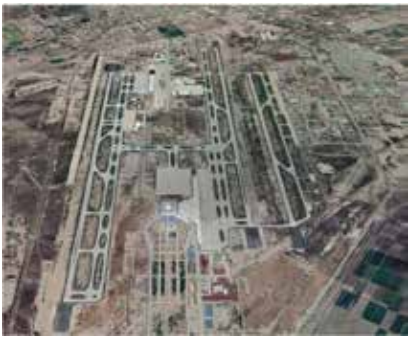

Figure 1 – Aerial view of NLU

Passengers of the commercial operations are directed to the terminal building, as illustrated in Figure 2. This building represents the first of four planned expansion phases outlined in the airport's Master Plan. The terminal is designed to expand in response to increasing demand, ensuring that capacity aligns with passenger needs. Currently, the terminal handles approximately 56 departures per day, accommodating around 5.2 million passengers annually. Future development plans aim for the terminal to support over 100 million passengers per year. Once this capacity is reached, a mirror-image terminal will be constructed on the opposite side of the current one to further increase capacity.

Figure 2 – Aerial view of NLU's Terminal Building

The characteristics of the current terminal are summarized in Table 1.

Table 1-Airport Felipe Angeles Characteristics (May 2024)

	Totals
Total Area	5410 SQM
Passenger entrance	4
CheckIn Islands	12
Check In Desks	330 (estimated)
Security Points (Operational)	14
Operation	Domestic & international
Number Gates	34
Departing Flights (17 May 2024)	56

The data presented in Table 1 is a combination of official information and original research conducted by the authors. These values, specifically considered for May 17, 2024, were used to model the terminal building. It is important to note that passenger flow is segregated between domestic and international travelers. Currently, most passengers are processed in the domestic area, utilizing only 7 out of the 14 available security checkpoints and a portion of the total check-in desks available in the terminal.

3. Methodology

The methodology employed in this study is based on the framework devised by Mujica et al. [4]. This approach integrates various knowledge layers to construct the final model. For the study of NLU, we combined a layer containing information about the distances and locations of the infrastructure. On top of this, we incorporated a logistic model that includes the logic and sequence of processes, as well as the flow of passengers within the terminal. The input for this framework is the demand, or the number of expected passengers, for the year under study. We made certain assumptions based on experience to simulate passenger processing times, walking speeds, and processing times at check-in and security. Figure 3 illustrates the general methodology developed for the current study.

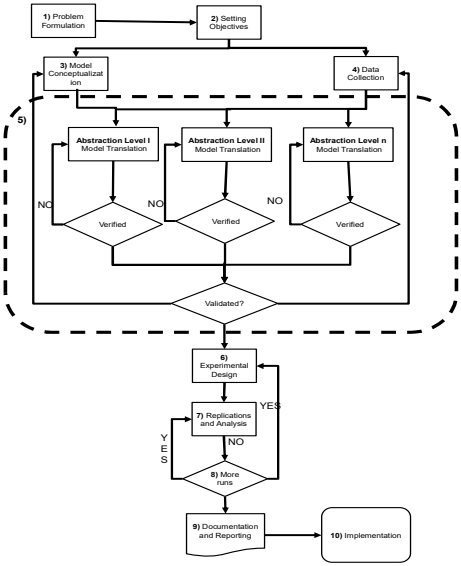

Figure 3 – Aerial view of NLU's Terminal Building

For the model translation we used a propietiary library coded in SIMIO [11]; and flight information was collected from FlightRadar24 [2] and the airports' official webpages to identify what type of equipment was the most used in the operation and which airlines are currently operations . The following section presents the assumptions used for the framework.

3.1. Terminal Building Model

As previously mentioned, the Terminal building model was developed following the aforementioned framework. We utilized terminal charts to ascertain the physical characteristics and locations of various facilities. Atop this layer, we integrated a network model to simulate the sequential processes within the terminal, spanning from the curbside to the gates. Several assumptions were made in this process, detailed in Table 2.

Table 2-Airport Felipe Angeles Model Assumptions

Item	Value used
Passenger entrance	4
CheckIn Islands Active	2
Check In Desks	21
Security Points (Operational)	7
Operation	Domestic
Number Gates	12
Departing Flights (17 May 2024)	56
CheckIn Processing Time (AVG)	45 sec
Sec Screening (AVG)	55 sec
Frequency of Departing Flights	1 hr
Pax Speed	Range (0.6 – 1.1) m/s
Logic	Dom Sequential Process: Entrance-Hall – CheckIn –Dwell Time – Security – Departing Gate
Companions	1
Dwell Time	15 min before goto Gate

Using the provided values, we constructed the model. Figure 4 depicts the resulting model.

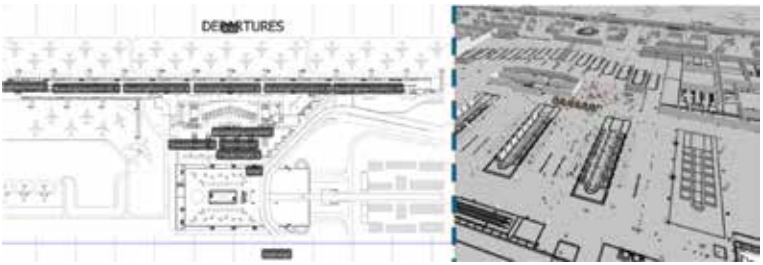

Figure 4 – NLU Simulation Model

4. Experiment Results and Analysis

We conducted an initial experimental design, taking into account an annual growth increment of 50%, which represents the yearly growth of the airport. The primary assumption is that AIFA will grow at a rate of 50% over the next five years. Notably, in January 2024, the growth surged by 82% compared to January 2022 [5]. To maintain a conservative approach, the authors opted for a 50% growth rate estimate for the next five years, and the model was executed based on this value.

As previously stated, a key assumption underlying our study is that the airport operator maintains the current configuration of the terminal, including the number of security lines and the segregation of passengers into domestic and international areas. Figure 5 depicts the evolution of the level of service in the check-in area, identified as one of the potential hotspots within the terminal.

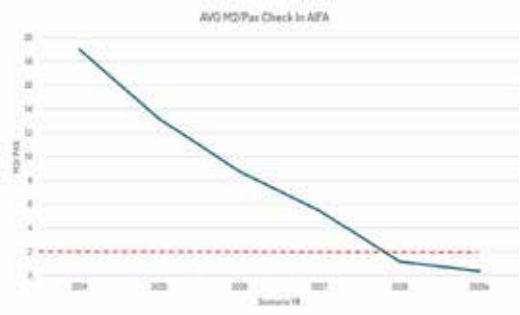

Figure 5 – Evolution of Level of Service at CheckIn

The red line in the graph represents the threshold considered as a good level of service according to IATA standards. It serves as a benchmark to identify the turning point when the system may require expansion or intervention to alleviate congestion. Notably, concerning the check-in area, it has been observed that ample space is available, making it relatively easy to alleviate congestion by opening more check-in counters for processing additional passengers.

However, a more challenging situation may arise in the case of security. Figure 6 illustrates the evolution of the level of service in the security lines. It is pertinent to note that by 2028, the level of service has deteriorated to a critical level.

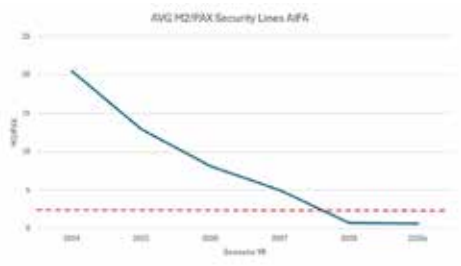

Figure 6 – Evolution of Level of Service at Security

Between 2027 and 2028, congestion issues may arise in the security areas due to insufficient security lines. This observation is significant, as evidenced by the graphs illustrating the results of the analysis. It is important to note that currently, AIFA has ample capacity. However, with the growth rate considered in the study, the years from 2024 to 2027 present no major problems in processing passengers under the current operational assumptions.

Nevertheless, by 2028, significant challenges emerge as the level of service deteriorates markedly. An additional simulation conducted for the second quarter of 2028 reveals that, under existing conditions, operational collapse is a real possibility.

5. Conclusions

This study presents a simulation-based analysis of the terminal building capacity at Felipe Angeles International Airport, located in Mexico City. This airport was established to alleviate congestion at the old Mexico City Airport (AICM). Given that the airport is not currently operating at full capacity, the objective of this study was to stress-test the system to determine when it might encounter operational difficulties under existing conditions, signaling the need for infrastructure expansion to accommodate growing demand and ensure the smooth functioning of the airport for passengers and stakeholders.

The results indicate that the airport has sufficient capacity to accommodate up to 9 million passengers until the year 2027. However, by 2028, when an influx of 13 million passengers is expected, proactive measures will be necessary to advance to the next stage of infrastructure expansion, as per the airport's progressive design, to manage the increased demand effectively and prevent disruptions for passengers and stakeholders

It is important to note that this study assumes static operational conditions, including a fixed number of check-in lines, security procedures, and processing times. While the findings serve as a foundation for identifying potential limitations, the dynamic nature of airports allows for adjustments to be made before problems arise. Future research will involve field studies to calibrate model parameters and incorporate variables such as a higher percentage of passengers using self-check-in, which may impact system performance.

The methodology presented in this study can serve as a valuable tool for establishing baseline criteria for action in the event that the airport system is not managed dynamically. The authors strongly advocate for its use in assessing the impact of new technologies or expansions to anticipate system behavior and performance effectively.

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Transferência Modal de Curta Distância através da Ferrovia, Aplicada aos Aeroportos Portugueses: Uma Análise dos Impactos Sócio Económicos E Ambientais Nos Aeroportos da Rota Lisboa-Porto

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Abstract/Resumo/Resumen

O foco deste estudo é analisar impacto socioeconómico e ambiental do uso do transporte ferroviário substituindo os voos de curta distância. O objetivo é analisar quais as consequências dessa mudança para os aeroportos e fornecer dados aos decisores políticos, partes interessadas e comunidade. Este estudo começa com a revisão da literatura usando uma abordagem de métodos mistos para estabelecer o quadro teórico e os antecedentes contextuais. Em seguida, uma análise quantitativa dos dados é usada para avaliar as implicações socioeconómicas e a pegada ambiental da transferência modal proposta. Além disso, estudos de caso qualitativos são realizados em vários aeroportos e redes ferroviárias para fornecer informações mais detalhadas sobre as aplicações práticas e os resultados. A investigação examina os potenciais benefícios das iniciativas de transferência modal, incluindo a redução das emissões de carbono, a redução do tráfego aeroportuário e o fortalecimento da conetividade regional. Mais ainda, o estudo analisa os efeitos socioeconómicos da opção de transporte ferroviário em viagens de curta distância. Esses efeitos incluem o desenvolvimento da infraestrutura, a dinâmica do turismo e as mudanças nos padrões de emprego. Esta investigação contribui para o domínio do transporte ao fornecer uma análise abrangente dos impactos nos aeroportos da transferência modal do transporte aéreo para o transporte ferroviário. Ao levar em consideração questões socioeconómicas e ambientais, ajuda a criar uma estrutura para a decisão pois levantamos um conjunto de questões-chave que os decisores políticos devem considerar para uma implementação política bem-sucedida de promover sistemas de transporte mais sustentáveis.

TRANSFERÊNCIA MODAL DE CURTA DISTÂNCIA ATRAVÉS DA FERROVIA, APLICADA AOS AEROPORTOS PORTUGUESES: UMA ANÁLISE DOS IMPACTOS ECONÓMICOS E AMBIENTAIS NOS AEROPORTOS DA ROTA LISBOA-PORTO

1. INTRODUÇÃO

1.1. TRANSPORTE AÉREO

Desde a desregulamentação, o transporte aéreo desenvolveu-se de forma económica, permitindo às companhias aéreas a liberdade de definir rotas e preços [1]. A eficiência operacional e a inovação tornaram-se pontos centrais, porém, a sustentabilidade e a visão do futuro ecológico do planeta ganham cada vez mais importância. Diversas metodologias foram analisadas para adaptar o setor a novos desafios, como emissões de CO_2 e alto volume de tráfego. Hoje, a sustentabilidade é uma grande preocupação, pois estudos mostram que mudanças na indústria podem afetar significativamente a competitividade e as operações aeroportuárias [2]

Com a substituição de voos de curta distância por comboios, algumas rotas aéreas podem ser retiradas, impactando o conceito de "*hub*" dos aeroportos e reduzindo o volume de tráfego de passageiros e operações aeroportuárias. O transporte aéreo demonstra um impacto significativo no desenvolvimento económico dos países, direta e indiretamente, criando empregos no setor e gerando receita e empregos em serviços associados, como hotelaria e restauração. Estudos indicam que cidades sem aeroportos têm um desenvolvimento económico mais limitado [3].

A Figura 1 mostra o número de passageiros programados embarcados pela indústria global de companhias aéreas de 2004 a 2022 (em milhões) [4]

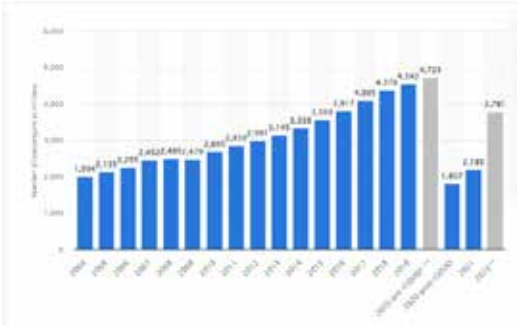

Figura 1 – Nº de passageiros programados embarcados pela indústria global de companhias aéreas de 2004 a 2022 (em milhões)
Fonte: [4]

Com o desenvolvimento do transporte aéreo e a crescente preocupação com as alterações climáticas, uma solução inovadora para os desafios económicos e ambientais enfrentados pela indústria é o uso de aeronaves mais sustentáveis. A pesquisa e desenvolvimento nessa área visam maximizar o desempenho operacional e minimizar os impactos ambientais. O 'design' aerodinâmico é crucial para aumentar a eficiência, reduzindo o arrasto e melhorando o consumo de combustível (John D. Anderson Jr., Fundamentals of Aerodynamics, 5th ed) [5]

O ‘design’ sustentável considera a eficiência do combustível e a redução de emissões, ruído e outros impactos ambientais. Com o avanço do transporte, novas tecnologias e materiais estão a ser adotados, como os materiais leves destacados por estudos, que enfatiza a importância dos materiais como os compósitos de fibra de carbono na redução do consumo de combustível.

Algumas companhias aéreas estão a optar por aeronaves com menor capacidade e alcance para atender à procura local, reduzindo os custos operacionais e aproveitando ao máximo a sua capacidade em voos de curta distância [6]. Essas medidas buscam enfrentar os desafios económicos e ambientais, tornando o transporte aéreo mais sustentável e eficiente.

1.2. VIA-FÉRREA

O cenário atual do transporte ferroviário destaca a importância da inovação e tecnologia para aumentar a sustentabilidade e otimizar as operações. A eficiência operacional é melhorada com a implementação de tecnologia, resultando em redução de atrasos, aumento da capacidade e maior confiabilidade [7]. A Europa possui uma história rica no desenvolvimento ferroviário, desempenhando um papel fundamental na movimentação de pessoas e mercadorias. Ao longo das décadas, testemunhou inovações significativas, incluindo a transição para sistemas de alta velocidade (HSR).

A eletrificação da via-férrea tem sido uma estratégia chave para reduzir as emissões de CO_2 e gases de efeito estufa, e estudos estão em andamento para a implementação de energias renováveis nesse tipo de transporte [8]. Em 2021, a Comissão da União Europeia declarou o "Ano do Comboio", como parte do Pacto Ecológico da UE, propondo uma mudança significativa no transporte ferroviário. A "Estratégia de Mobilidade Inteligente" visa aumentar o transporte ferroviário de mercadorias na UE em 50% até 2030 e em 100% até 2050, sendo que em 2021 o transporte ferroviário já representava 20% do transporte de mercadorias na Europa [8]. Essas iniciativas visam promover um transporte ferroviário mais eficiente e sustentável na Europa.

A eficiência do transporte ferroviário depende diretamente da qualidade da infraestrutura ferroviária. Estudos enfatizam a importância do investimento em tecnologias ferroviárias, como sistemas de controlo de tráfego e manutenção de via permanente, para garantir segurança e eficiência operacional [9]. A implementação de sistemas avançados de controlo de tráfego, como o ERTMS, otimiza a infraestrutura ferroviária e melhora a coordenação dos comboios. A eletrificação das vias-férreas é um avanço crucial para a sustentabilidade, reduzindo as emissões de gases de efeito estufa e a dependência de combustíveis fósseis. Os comboios elétricos também facilitam as viagens de curta distância, promovendo a transferência modal entre cidades. No futuro, os comboios autónomos têm o potencial de revolucionar o transporte ferroviário, aumentando a sua segurança e eficiência [7].

Para garantir que o transporte ferroviário seja uma opção sustentável, é necessário investir em infraestrutura sofisticada e tecnologia inovadora. Isso inclui superar desafios como manutenção eficiente e integração com sistemas urbanos. Em Portugal, a infraestrutura ferroviária desempenha um papel fundamental na conectividade regional, sendo administrada pela Comboios de Portugal (CP) e compreendendo cerca de 2.800 quilómetros de linhas. A eletrificação de áreas como a Linha do Norte reflete o compromisso do país com a sustentabilidade do setor ferroviário.

Portugal e Espanha estão a colaborar em projetos conjuntos de comboios de alta velocidade (HSR), demonstrando um compromisso conjunto com a modernização do transporte ferroviário na Península Ibérica. A expansão do TGV visa reduzir o tempo de viagem entre as capitais, aumentar a conectividade regional e promover a integração económica entre os dois países. O projeto do Comboio de Alta Velocidade em Portugal busca conectar as principais cidades, como Porto e Lisboa, reduzindo os tempos de viagem e melhorando os serviços. O PNI 2030 visa construir um novo sistema ferroviário de alta velocidade entre Porto e Lisboa, com atualizações técnicas e contratações previstas para os próximos

anos. Essas iniciativas visam melhorar a mobilidade nacional e internacional, reduzir as emissões de CO_2 e promover o desenvolvimento sustentável através do transporte ferroviário eficiente.

Figura 2 - Principais Constrangimentos No Sistema Ferroviário Nacional.
Fonte: [10]

A construção de uma linha de alta velocidade dará a Portugal uma grande oportunidade de crescimento econômico e social, pois conectará as principais regiões e cidades do país, melhorando a qualidade de vida dos cidadãos e aumentando sua competitividade na Europa, tal como apresentado na Figura 2. Em Espanha a RENFE (*Red Nacional de los Ferrocarriles Españoles*) opera a rede espanhola de comboios de alta velocidade neste momento operam com o comboio série AVE S-100, o comboio tem capacidade para 314 a 565 passageiros e pode atingir velocidades até 310km/h, dependendo do tipo de configuração.

2. ENQUADRAMENTO

2.1. TRANSIÇÃO MODAL

A transição modal visa otimizar a eficiência do transporte, mudando entre diferentes meios com preocupações ambientais e económicas em mente. Estudos indicam que os modos de transporte estão interligados e interdependentes. Em alguns casos, o Comboio de Alta Velocidade (HSR) pode complementar o transporte aéreo, aumentando a intermodalidade [11] Essa transição modal pode aumentar o risco de competição com companhias aéreas em rotas de média distância, afetando também os aeroportos que servem voos de curta distância. A colaboração entre operadores de HSR, aeroportos e autoridades pode resultar em soluções integradas de transporte, oferecendo aos passageiros opções intermodais eficientes. Estudos recentes destacam um aumento significativo no uso de rotas com serviços sobrepostos de comboio de alta velocidade (HSR). Em França, a Lei do Clima e da Resiliência, promulgada em 2021 após uma Convenção dos Cidadãos para o Clima, cancelou voos domésticos com alternativas ferroviárias de menos de 2h30. Isso afetou rotas como Paris-Orly para Nantes, Lyon e Bordéus [12]; [13]. Atualmente está a ser aprovada uma diretiva comunitária com o intuito desta transição modal. Essa transição modal na França exige uma alternativa ferroviária de alta velocidade com menos de 2h30 e conexões diretas entre estações e aeroportos. Um estudo europeu de 2021 estimou que o transporte ferroviário poderia substituir 27,4% dos destinos na França, economizando toneladas de CO_2 anualmente e liberando capacidade nos voos intra-europeus [14];[15].

O Plano Nacional de Investimentos 2030 (PNI 2030) em Portugal visa construir um novo sistema ferroviário de alta velocidade entre Porto e Lisboa, reduzindo o tempo de viagem entre as duas cidades para 1h15. A conclusão deste projeto não apenas encurtará os tempos de viagem, mas também melhorará a conectividade dentro do país[16].

2.2. IMPACTOS AMBIENTAIS E SUSTENTABILIDADE

Os países desenvolvidos estão a adotar medidas para reduzir as suas pegadas de carbono e preocupações com a poluição em várias áreas ambientais, incluindo água, solo, ruído e atmosfera, sendo a aviação uma

fonte significativa de emissões e poluição atmosférica. Os aeroportos são particularmente responsáveis pela poluição atmosférica, com motores de aeronaves sendo uma das principais fontes de gases de efeito estufa. Além disso, resíduos líquidos e sólidos provenientes das operações aeroportuárias também representam desafios ambientais significativos. Os aeroportos estão a implementar medidas para lidar com esses problemas ambientais, enquanto a União Europeia estabeleceu metas ambiciosas de alcançar zero emissões de gases de efeito estufa até 2050, com o setor de transporte visando reduzir as suas emissões em 90% até 2030. A aviação é responsável por uma parcela significativa das emissões de gases de efeito estufa, com o transporte rodoviário contribuindo com a maioria das emissões, seguido pelo setor marítimo e ferroviário [17]

Nos aeroportos, a sustentabilidade é uma preocupação crescente, enfrentando desafios como emissões de gases de efeito estufa, gestão de resíduos e alto consumo de energia. Programas abrangentes, como reciclagem e uso de energias renováveis, são implementados para mitigar a pegada ecológica[18]. Planos de Ação e Gestão de Energia e Carbono foram estabelecidos para reduzir o consumo energético e alcançar metas ambientais, como "Net Zero" até 2030 [18]. Apesar das iniciativas, a transição modal do aéreo para o ferroviário, especialmente em distâncias entre 500 km e 1000 km, levanta questões sobre sua eficácia ambiental e sustentabilidade. Relatórios indicam dificuldades em determinar os benefícios ambientais dessa mudança, com apenas uma pequena percentagem de voos responsável pela maioria das emissões de CO2 da aviação [17];[19]. Na Figura 4 encontra-se a percentagem de voos versus Emissões CO2 em 2019.

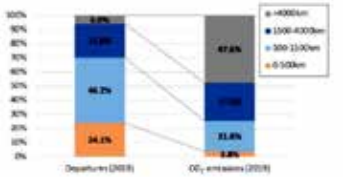

Figura 3 - Percentagem de voos versus Emissões CO_2 em 2019.
Fonte: [20]

2.3. IMPACTES ECONÓMICOS

Os aeroportos desempenham um papel crucial no desenvolvimento económico, gerando empregos diretos e indiretos, especialmente notável após a recuperação em 2022 devido à pandemia [21]. O setor do turismo tem uma importância significativa na economia portuguesa, representando uma parte substancial do PIB e do consumo de turismo (Instituto Nacional de Estatística, 2022). No entanto, a substituição do transporte ferroviário por voos de curta distância pode afetar as receitas dos aeroportos, levando a mudanças na procura por transporte aéreo e impactando as atividades comerciais nos terminais [22]. As políticas governamentais, como o estabelecimento de preços mínimos para bilhetes aéreos, visam mitigar os efeitos negativos do transporte aéreo nas emissões de carbono e na concorrência desleal [13]. A coleta de dados de tráfego é essencial para entender as tendências de passageiros e aeronaves nos aeroportos portugueses, fornecendo informações valiosas para a gestão e planeamento operacional. A transição modal para o transporte ferroviário pode reduzir tanto a receita quanto o número de passageiros nos aeroportos, como exemplificado pela possível diminuição do tráfego na rota Lisboa-Porto devido à disponibilidade de comboios de alta velocidade[23].

3. METODOLOGIA E DADOS

Nesta secção, os efeitos da substituição de voos de curta distância pelo transporte ferroviário nos aeroportos serão examinados, utilizando o método de Análise de Decisão Multicritério (MCDA). A pesquisa incluirá revisão bibliográfica, análise documental, questionários estruturados e estudos de caso para compreender os impactos em diferentes contextos aeroportuários. Os critérios de avaliação incluirão impacto económico, sustentabilidade ambiental e acessibilidade, com a técnica de processo analítico hierárquico (AHP) para atribuição de pesos aos critérios. O objetivo é identificar a melhor opção para os objetivos da pesquisa, considerando as variáveis económicas e ambientais.

Este estudo visa investigar sistematicamente os efeitos da transição modal para a via-férrea nos aeroportos, especialmente os impactos económicos e ambientais da substituição dos voos de curta distância pela via-férrea. Os objetivos específicos incluem avaliar os efeitos na capacidade operacional dos aeroportos, examinar os impactos económicos nas comunidades locais e investigar os efeitos ambientais, como a redução das emissões de gases de efeito estufa. A mudança para o uso de comboios de alta velocidade reflete uma preocupação crescente com a sustentabilidade e os efeitos da poluição global na indústria da aviação. Neste estudo investiga-se o impacto social, ambiental e económico da substituição dos voos de curta distância pela via-férrea nos aeroportos, com hipóteses que buscam avaliar a significância da redução de CO_2 e o impacto na receita dos aeroportos devido à diminuição do tráfego de passageiros.

Por meio da Análise do Processo de Hierarquia Analítica (AHP), a melhor opção de transporte entre aviões e comboios de alta velocidade foi determinada. A estrutura hierárquica incluiu o objetivo de selecionar a melhor opção de transporte/transição modal, com duas alternativas (avião e comboio de alta velocidade) e quatro critérios: emissões totais de CO_2e, emissões de CO_2e por passageiro, consumo de energia por passageiro (KW/h Passageiro) e taxa de serviço aos passageiros. Essa estrutura foi desenvolvida para organizar a avaliação e auxiliar na tomada de decisão com base nos critérios estabelecidos. Os dados foram coletados a partir de relatórios anuais e por entidades envolvidas nas infraestruturas dos meios de transporte aéreo e ferroviário, conforme revisão da literatura.

3.1. TRANSIÇÃO MODAL NOS AEROPORTOS (ITMA)

A revisão da literatura, mostra que a substituição das rotas de curta distância (Origem-Destino) é uma das alternativas para reduzir a pegada ecológica e as emissões de CO_2 atualmente. Contudo, esta substituição pode colocar em causa a receita aeroportuária, a competitividade e outros aspetos.

O ITMA, Figura 5, é um modelo que permite apurar o impacte económico e ambiental da substituição/transição modal da rota Lisboa – Porto (LIS-OPO) via comboio de alta velocidade (HSR).

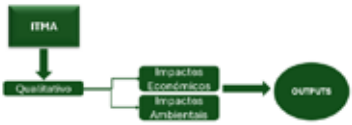

Figura 4 - Esquema do ITMA
Fonte: Elaboração Própria

O Aeroporto Humberto Delgado, também chamado Aeroporto de Lisboa, é o principal aeroporto de Portugal, inaugurado em 1942 pelo general e político português Humberto Delgado. Com códigos IATA e ICAO LIS e LPPT, é o maior do país em termos de passageiros e tráfego, servindo voos domésticos e internacionais. Operado pela ANA Aeroportos de Portugal, tem sido alvo de expansões e renovações ao longo dos anos para lidar com o aumento do tráfego aéreo e melhorar o serviço aos passageiros, sendo também a base da TAP Air Portugal, companhia aérea nacional.

O Aeroporto Francisco Sá Carneiro, também chamado Aeroporto do Porto ou Aeroporto Pedras Rubras, é o segundo maior de Portugal em termos de passageiros. Nomeado em homenagem ao ex-Primeiro-Ministro português Francisco Sá Carneiro, falecido em 1980, foi inicialmente uma base militar em 1945 e depois adaptado para voos comerciais. Operado pela ANA Aeroportos de Portugal, é uma plataforma importante para voos domésticos e internacionais, com códigos IATA e ICAO OPO. Sujeito a várias expansões para lidar com o aumento do tráfego aéreo, tem recebido elogios por sua qualidade de serviços, infraestrutura e operações.

Como suportado na revisão da literatura, existem vários modelos de comboios de alta velocidade. Este estudo utilizará o comboio AVE S-100, capaz de transportar 440 pessoas. Para esta metodologia, esses modelos foram escolhidos devido a uma futura parceria com a Espanha, onde o uso do mesmo modelo de comboio facilitaria a integração. A rota escolhida para o caso de estudo foi selecionada devido á diretiva comunitária estabelecida no regulamento

3.2. IMPACTE ECONÓMICO

A primeira parte do modelo ITMA passa por uma determinação do Impacte Económico. Para apurar este Impacte Económico é necessário completar dois processos. Num primeiro momento é necessário recolher alguns dados, maioritariamente dos Reportes Anuais da ANA Aeroportos, ambos os aeroportos que irão ser impactados e analisados nesta investigação. De seguida, com os dados possuídos segue-se uma fase onde são feitos alguns cálculos, de modo a obter os Outputs pretendidos. Para aplicar a este modelo de investigação é necessário passar por duas fases, uma primeira onde existe uma recolha de dados, e uma segunda onde são feitos alguns cálculos, tais como: Número de Passageiros Total; Número de Movimentos de Aeronaves; Receita de Taxas de Serviços aos Passageiros e Número de Voos Diários Lisboa – Porto. O conceito de "receita" refere-se ao dinheiro gerado por operações comerciais, como vendas, e pode ser categorizado de diferentes maneiras, dependendo do contexto da investigação. No setor aeronáutico, a receita pode ser dividida em aeronáutica e não aeronáutica ao se focar nos aeroportos. As taxas aos passageiros são cobradas para cobrir os custos de assistência prestada pelo aeroporto e pelas companhias aéreas. As taxas de segurança e serviço aos passageiros são as duas partes que devem ser levadas em consideração para calcular a receita total anual das taxas aeroportuárias aos passageiros. Os relatórios financeiros e o guia de taxas da ANA Aeroportos, a empresa responsável pela gestão dos aeroportos portugueses, forneceram os dados utilizados. Conhecer o modelo e a configuração da aeronave utilizada na rota em análise é fundamental para determinar o número de passageiros. O número de passageiros dividido pelo número de voos diários e pelas taxas correspondentes dá o valor diário.

Para determinar o impacto ambiental na segunda parte do modelo ITMA, é necessário completar dois processos distintos. Inicialmente, é essencial coletar dados, principalmente dos relatórios anuais da ANA Aeroportos, referentes aos aeroportos que serão analisados nesta pesquisa. Em seguida, com base nos dados coletados, realiza-se uma fase de cálculos para obter os resultados desejados. Para aplicar esse modelo de investigação, é preciso seguir duas fases: uma de coleta de dados, e outra de cálculos. No caso do impacto ambiental, é necessário obter os dados especificados. De acordo com um contrato de concessão, a ANA Aeroportos tem a responsabilidade de operar todos os aeroportos portugueses e fornecer informações sobre o número de passageiros. A análise, abrange os anos de 2015 a 2022, embora 2020 tenha sido excluído devido à pandemia de COVID-19. Para esta investigação foi decidido não usar os dados desse ano porque havia pouco tráfego aéreo global durante esse período. Em termos de taxas aeroportuárias, neste caso taxa de serviço aos passageiros e taxas de Segurança (*Security*) aplicadas aos passageiros. No aeroporto de Lisboa temos os seguintes resultados da Tabela 1.

Tabela 1 - Receita taxas aeroportuárias Aeroporto de Lisboa
Dados: ANA Aeroportos Fonte: Elaboração Própria

Aeroporto de Lisboa	Época Baixa	Época Alta
taxa de serviço aos passageiros	10,85 €	11,05 €
taxa de Security (Portugal	1,94 €	1,94 €
Total (P. Pax)	12,79 €	12,99 €

Como mencionado anteriormente será aplicado o valor das taxas pagas pelos passageiros, tendo em conta que para determinar o impacte para com o aeroporto em termos de receita. Foram utilizados os valores totais em época alta, demonstrado na Tabela 1. Se calcularmos a receita de um voo LIS-OPO, capacidade total de 174 passageiros, em época alta, no aeroporto de Lisboa (Como Partida) seria uma perda de receita total de 2260 euros em taxas de serviços aos passageiros e taxa de segurança. Com 10 voos diários estimamos uma perda de 22 mil 602 euros em perda para o aeroporto.

Para calcular o valor semanal foi utilizado o resultado do valor diário e multiplicado por 7 dias. Para o mensal foi multiplicado por quatro vezes o valor semanal e por fim, o valor total anula foi obtido através da multiplicação do valor mensal por doze. Na Tabela 2 é possível analisar a perda estimada de receita em taxas, como podemos observar estamos a falar de uma perda 22602€ no aeroporto de Lisboa e 20079€ no aeroporto do Porto respetivamente. Para a ANA Aeroportos seria uma perda total Anual de 14 milhões 341 mil euros aproximadamente com a abolição desta rota apenas em taxas aos passageiros.

Tabela 2 - Receita Total de Taxas Aeroportuárias
Dados: ANA Aeroportos Fonte: Elaboração Própria

Indicadores	Aeroporto Lisboa	Aeroporto do Porto
Passageiros	174	174
Nº de Voos	10	10
Taxas	12,99 €	11,54 €
Total Diário	**22 602,60 €**	**20 079,60 €**
Total Semana	158 218,20 €	140 557,20 €
Total Mês	632 872,80 €	562 228,80 €
Total Ano	7 594 473,60 €	6 746 745,60 €

Os dados anuais da ANA Aeroportos foram utilizados para estimar a perda de receita em taxas de passageiros nos aeroportos de Lisboa e Porto. Para começar, o valor semanal foi multiplicado por sete e, em seguida, multiplicado por quatro para obter o valor mensal. Finalmente, o valor total anual foi calculado multiplicando o valor mensal por doze. Com os dados disponíveis através dos relatórios publicados, vemos a variação percentual na receita total de taxas de passageiros ao longo dos anos. Isso mostra que ambos os aeroportos perderam muito dinheiro em 2021 e 2022. A taxa de variação mostra a perda de mercado, expressa em pontos percentuais, caso a rota entre Lisboa e Porto seja eliminada. A perda estimada de receita em 2022 é de aproximadamente 22.602€ no Aeroporto de Lisboa e 20.079€ no Aeroporto do Porto.

3.3. IMPACTE AMBIENTAL

O segundo objetivo do modelo ITMA é o impacto ambiental. Para calcular esse impacto financeiro, existem duas etapas que devem ser realizadas. Para começar, os dados que serão examinados nesta investigação são coletados principalmente dos Relatórios Anuais dos Aeroportos da ANA. Em seguida, os dados são utilizados para fazer os cálculos necessários para obter os resultados pretendidos. A análise do impacto ambiental depende do volume de tráfego de passageiros. Esses números são obtidos subtraindo o total de passageiros de cada tipo de transporte e multiplicando esse valor pelo número de dias. A variação resulta da diferença no número total de passageiros transportados por avião em comparação com HSR.

De acordo com uma revisão de pesquisas, o setor de transporte é um dos principais responsáveis pelas emissões atmosféricas de gases de efeito estufa e C02. Para atender à procura crescente de passageiros, as nações da UE estão continuamente melhorando a sua infraestrutura. O transporte de carros foi o principal responsável pelas emissões de dióxido de carbono em 2022; a aviação doméstica e internacional contribuiu com cerca de 11% das emissões. A contribuição do transporte ferroviário para as emissões é de apenas 1%.

Tabela 3 - Emissões Meios de Transporte
Dados: TAP Air Portugal, Comboios de Portugal Fonte: Elaboração Própria

Transporte	Passageiros	Rota	Emissões (Kg CO2e)
Avião	**348**	**LIS-OPO OPO-LIS**	**17296,60**
AP	**602**	**LIS-OPO OPO-LIS**	**6675,2**
HSR	**602**	**LIS-OPO OPO-LIS**	**3337,6**

Na Tabela 3, observamos os diversos meios de transporte, a capacidade total (Ida e Volta) e o valor total de emissões de CO_2e[1] para a atmosfera.

Como podemos analisar, o comboio AP polui cerca de cinco vezes menos que o avião e transporta mais duzentos e cinquenta e quatro passageiros.

4. ANÁLISE DE MULTICRITÉRIO: CASO DE ESTUDO

4.1. PESOS DOS CRITÉRIOS SELECIONADOS: CASO DE ESTUDO

Esta secção apresenta uma análise multicritério (MCDA AHP). O foco deste caso de investigação é o uso do HSR em vez de voos de curta distância. O método MCDA avaliará uma série de critérios, incluindo

[1] É uma unidade de medida que é utilizada para comparar as emissões de diferentes gases relativamente ao impacto que possuem no clima, convertendo todas as emissões em dióxido de carbono.

impactos ambientais e económicos, para obter uma compreensão completa dos efeitos da transição modal. Para começar, falaremos sobre os principais objetivos da análise multicritério e os critérios escolhidos para a avaliação. Em seguida, as etapas utilizadas para a metodologia MCDA serão abordadas. A definição dos critérios de peso, Tabela 4, a coleta e organização dos dados necessários e a utilização de técnicas de análise para avaliar as opções estão entre essas etapas. Esta análise destaca os principais resultados e descobertas sobre os efeitos do uso de HSR em vez dos voos de curta distância nos aeroportos de Lisboa e do Porto, no caso da Rota Lisboa-Porto.

Tabela 4 - Peso dos Critérios nos Cenários de Análise
Fonte: Elaboração Própria

Cenário	Peso
Emissões (Kg CO2e)	0,25
Emissões (Kg CO2e) Passageiro	0,25
Consumo KW/h Passageiro	0,25
Taxa de serviço aos passageiros Preço/Passageiro	0,25
	1

Para esta investigação foram apuradas três opções representadas na Tabela 5.

Tabela 5 - Opções de Análise MCDA
Fonte: Elaboração Própria

Opções	
A	HSR
B	Avião
C	Alteração da Rota

4.2. CRITÉRIOS DE ANÁLISE: CASO DE ESTUDO

Tabela 6 - Critérios de Análise Ambiental e Económica
Fonte: Elaboração Própria

Nível	Critério
1	Ambiente
2	Emissões (Kg CO2e)
2	Emissões (Kg CO2e) Passageiro
2	Consumo KW/h Passageiro
1	Economia
2	Taxa de serviço aos passageiros Preço/Passageiro

Os critérios de análise, Tabela 6, estão organizados em dois níveis hierárquicos: Ambiente e Economia. O capítulo está localizado no nível um e o subcapítulo está localizado no nível dois. Os critérios ambientais são classificados em três categorias: emissões (kg C02e), emissões de passageiros (kg C02e) e consumo (KW/H) e a taxa de transporte de passageiros, Tabela 7. Os critérios económicos são representados pelo preço/passageiro.

Tabela 7 - Pesos dos Critérios de Análise Ambiental e Económica Detalhada
Fonte: Elaboração Própria

Critério	Nível 1	Nível 2
Ambiente		0,60
Emissões (Kg CO2e)		
Emissões (Kg CO2e) Passageiro		
Consumo KW/h Passageiro		
Economia		0,40
Taxa de serviço aos passageiros Preço/Passageiro		

4.3. RESULTADOS DA ANÁLISE MCDA

Antes dos resultados é necessário abordar as diversas opções que foram apuradas. A Tabela 8, mostra os resultados da análise de múltiplos critérios (MCDA) para comparar e avaliar as opções de transporte aéreo em comparação com o transporte de alta velocidade ferroviária para a rota Lisboa-Porto. Foram considerados os fatores ambientais e económicos e uma avaliação foi realizada numa escala de 0 a 100, onde 100 indica o melhor cenário possível.

Tabela 8 - Análise MCDA: Caso de Estudo
Fonte: Elaboração Própria

Critério	Opção A	Opção B	Opção C
Ambiente			
Emissions (Kg CO2e)	100	0	50
Emissions (Kg CO2e) Pax	100	30	50
Consumo KW/h Passageiro	100	0	0
Resultado	60	3,6	24
Economia			
Taxa de serviço aos passageiros Preço/Pax	10	100	50
Resultado	4	40	20
Total	**64**	**43,6**	**44**

Critério	Opção A	Opção B	Opção C
Ambiente	60	3,6	24
Economia	4	40	20
Total	**64**	**43,6**	**44**

5. CONCLUSÕES

Com este estudo foi possível investigar sistematicamente os efeitos da transição modal para a via-férrea nos aeroportos, especialmente os impactos económicos e ambientais da substituição dos voos de curta distância pela via-férrea. O modelo ITMA permite apurar o impacte económico e ambiental da substituição/transição modal da rota Lisboa – Porto (LIS-OPO) via comboio de alta velocidade (HSR), quanto à sustentabilidade, e permite a avaliação de 3 alternativas, possibilitando o benchmarking entre o transporte de alta velocidade ferroviária para a rota aérea Lisboa-Porto, o que proporciona que se possam analisar as boas práticas ambientais e económicas para um melhor desempenho de sustentabilidade. Desta forma, as abordagens contribuem para o aperfeiçoamento constante desta importante infraestrutura aérea e ferroviária nacional. Diante do apresentado, o ITMA demonstrou que os cenários avaliados permitem um menor esforço para o decisor, pois é evidente a mitigação da pegada carbónica ao optar pelo cenário HSR. Para trabalhos futuros, sugere-se aperfeiçoar o modelo proposto para cenários com mais rotas de análise

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Spatial Imprint: An Overview of Latin American Airports

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Abstract/Resumo/Resumen

Observing airports as spatial structures with territorial effects is a recent concern. Until approximately 40 years ago, flying was a marginal activity, and there was little reason to consider its effects from the perspective of spatial structure. Today, with the great expansion of airport structures, it is observed that design standards not only lead to territorial impacts (such as noise and urban merger) but also primarily delays and waiting times in airport activities. The physical configuration established by the interplay of elements within an airport, both airside and landside, has significant implications for its operational capacity and efficiency. In this sense, this work presents the spatial patterns implemented in the twenty largest airports in Latin America with the aim of verifying the developmental panorama of these structures. Additionally, this work proposes the classification of these airports according to their physical characteristics, regarding landing and take-off runways (orientation, quantity, length), taxiways (linear extension), passenger terminals (type, quantity), and their landscape (urban context). Spatial and operational data provided by government agencies, along with data derived from aerial photographs and/or satellite images, are utilized, using spatial analysis tools such as geographical information systems (GIS). This results in layout diagrams and corresponding measurement analyses of the studied elements.

Spatial Imprint: an overview of Latin American airports

1. The Physical Configurations of Airports

The evolution of air operations has, over the last 100 years, had significant impacts not only on the spatial organization within airport boundaries but also on their surroundings. Today, we find airports ranging from those constrained by extremely dense urbanization in their vicinity, such as São Paulo Airport (CGH), to airports that have become larger than many cities, such as Dallas-Fort Worth (DFW) and Denver (DEN), which are considerably larger than Manhattan Island [14].

The various physical configurations of airports result from a series of operational, technological, geographical, and physical factors that can be perceived in the size and shape of the airport area, in the design of Airfield with its main internal elements (such as runways, taxiways, taxi lanes and passenger terminals), as well as in the spatial relationships established with its immediate surroundings and the nearest Central Business District (CBD). The combination of these physical elements results in a unique spatial imprint that evolves in response to the increasing size and performance of aircraft and the higher volume of passengers transported.

Recent studies have been able to identify typical spatial patterns for airport-affected regions in European airport areas, describing the general spatial properties of airport regions, such as interrupted urban structure, heterogeneous visual appearance, unplanned mix of uses, recreational landscape, temporary architecture, and distinct movement patterns [1]. Spatial patterns can indicate trends that are not always desirable for the development of places and air operations, such as the unplanned mix of uses attracted by the airport or the excess of urban occupation in the surrounding area that amplifies the intensity of impacts - such as noise - on the population while limiting air operations.

The term "spatial imprint" refers to the physical or tangible impact left by a particular entity, activity, or phenomenon on its surrounding space or environment. It is commonly used in urban planning, geography, and environmental studies to describe the visible and measurable effects of various factors on a geographical area. Building on the premise that behavior in geographic space often reflects patterns of past behavior [9], mapping the spatial imprint of airports would represent the cumulative effect of decisions made over time that guide, constrain, or enhance the potential for the development of operational (or non-physical) activities.

Figure 1 – Busiest Latin American Airports in the World Ranking (2010-2023)
Source: Authors

In this context, this article proposes a survey of the physical characteristics of the 20 busiest airports located in Latin America cities (considering their spatial position, which includes the Caribbean countries and all dependent territories situated in this geographical area), in order to verify how their spatial imprints are configured and the probable impacts. This article proposes to answer questions such as: *Do Latin American airports reproduce the same patterns or follow the same trends seen in the world's largest*

airports? This understanding can anticipate conflicts and assist in better decision-making regarding urban and airport planning.

Over the last 13 years (2010-2023), four airports in Latin America have been among the world's 50 largest airports (Figure 1), which puts greater pressure on strategic decisions that have spatial repercussions. The data on historical passenger movement was extracted from reports from international agencies and aviation industry representations, such as Airports Council International (ACI) and Civil Aviation Administration of China (CAAC).

2. Latin American Airports Scenario

The 20 largest airports in Latin America in 2023 are distributed across 9 of the 22 countries (Figure 2), with 51.4% of the passenger traffic in 2023 handled by the 20 largest airports in Latin America concentrated in 6 airports: MEX (11.9%), GRU (10.1%), BOG (9.8%), CUN (8.3%), SCL (5.7%), and LIM (5.6%). Data on passenger movement for 2023 was extracted from the release made by the National Civil Aviation Agencies of each country.

Figure 2 – 2023 Ranking and Location of the Busiest Latin American Airports (per country on the left), the Map of Airport Locations (in the center), Passenger Traffic (on the right)
Source: Authors

While in Europe, the first daily international scheduled air service, between Hounslow, London, and Le Bourget, Paris, began in August 1919 [11], the beginning of commercial operations in Latin America occurred between Wars. 11 of the 20 airports began their regular commercial operation concentrated in the two decades after World War II, from 1947 to 1966 (Figure 3). Data on the start of commercial operations were extracted through research on airport websites, with the exception of Brazilian airports, which resulted from historical research carried out in the digital newspaper library.

This period - from 1945 onwards - is considered a special moment in the relationship between airports and cities due to the introduction of jet airliners and the deregulation of the airline industry [7], which prompted the need for the reformulation of airport infrastructure, characterizing the second generation of airports (a period that extends until 1960) [1] [2]. Similarly to the rest of the world, in the preceding period, many airports began commercial operations originally established as military airfields [1] [2] [7], which can be seen in the cases of Mexico City Airport (MEX) and Rio de Janeiro Airport (SDU).

Figure 3 – Beginning of commercial operations in the Busiest Latin American Airports
Source: Authors

2.1 Airport Urban Surroundings

One way to evaluate the airport region is by observing the influence of the use of surrounding space [3]. How much airports can expand their facilities - and increase their footprint on the territory - depends largely on their location and their relationship with the surrounding urbanized area.

The Latin American scenario shows that 35% of the largest airports (SDU, CGH, TIJ, SJU, LIM, REC and GRU) have urbanized surroundings at levels that hinder the expansion of their area (Figure 4 on the left). The definition of the occupancy percentage was done through satellite image analysis or georeferenced data (when available), generating figure-background maps (that shows buildings in black and open areas – such as streets, gardens, and other non-built spaces – in white), defining a 5km offset from the limit of the airport area (Figure 4 on the right).

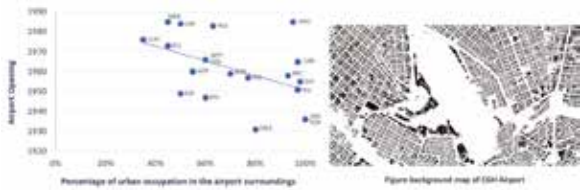

Figure 4 – Urban Occupation in the Surroundings (on the left) and a figure-background map of CGH Airport (on the right)
Source: Authors

The percentage of urban occupation in the surroundings of an airport can vary significantly depending on factors such as the size of the airport, its location within the city, and the level of urban development in the area. In Figure 5, the areas of the respective airports are presented, indicating hierarchy by size and comparing them with the areas of some of the busiest airports in the world. The territorial limits of airports in Latin America were extracted from noise plans, from master plans, from satellite images through the physical delimitation of area protection, and from bibliographic references such as Stewart [14].

Figure 5 – Largest areas of the busiest airport sites in the world and in the Latin America
Source: Authors

About the airport location within the city, the graph below (Figure 6) illustrates the relationship between Central Business District (CBD) distance and the airport age (defined by the beginning of commercial

operations) for the 20 busiest airports in Latin America. Additionally, it includes data updated for 2024 on the largest airports globally, as presented by Rodrigue [8] for 2023.

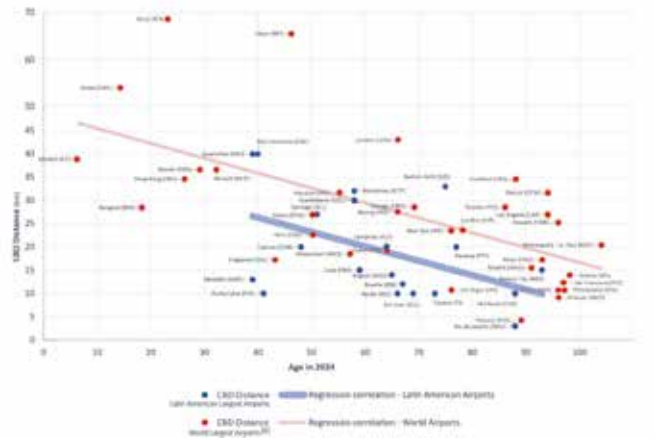

Figure 6 – Distance from CBD and Age of the Busiest Latin American Airports and World Largest Airports
Source: Authors (for Latin American Airports data) and [8] (for world airports data)

This preliminary assessment of the CBD serves as one of the theoretical foundations for analyzing the urban configuration of Latin American airports in this article. In a paper presented before (at the American Sociological Society in Washington in 1922), Professor Burgess outlined the processes involved in the growth of cities, emphasizing the influential role of the transport system configuration [4]. Subsequently, in 1925, Burgess proposed a descriptive urban land-use model that divided cities into concentric circles expanding from downtown to the suburbs [13].

The downtown area, also known as the central business district (CBD), is the most recognizable subarea of a city. It is characterized by its concentration of commercial buildings, offices, retail stores, and cultural activities. CBDs typically exhibit several characteristics: (a) higher land values and tax assessments compared to other parts of the city; (b) central accessibility and transportation networks; (c) concentration of office buildings; (d) heavy vehicular and pedestrian traffic; and (e) ability to attract businesses and people from diverse backgrounds [12]. It's important to note that the CBD's position within a city may not be static, as land use evolves over time. The CBD serves as a hub for urban attraction and travel, with significant economic importance that can lead to conflicts regarding airport locations. The proximity to the CBD can impose restrictions on airport operations due to limitations such as lack of space for expansion or noise regulations. Many older urban airports have been replaced by suburban facilities, exemplified by the replacement of Stapleton Airport, located 8km from downtown Denver, with the new Denver International Airport (DEN), situated 37km away [5].

It is possible to observe the trend of greater distance (highlighted by the regression lines) of newer airports in relation to the CBD. The decision to move the Airport away from the CBD may be the result of a political-strategic action, as is the case of Guarulhos Airport (GRU), established in 1985 40km from the CBD of the city of São Paulo as an alternative to the operation of the CGH - which it was limited by the urban occupation around it; or the case of Monterrey Airport (MTY), which had its location defined from the perspective of future expansion of facilities and airport operations. The remoteness of the CBD may also be the result of a lack of space in areas closer to the city – such as Narita (NRT) and Incheon (ICN) airports [5].

The comparison between the regression lines shows that Latin American airports, despite following the trend of moving away from the CBD, the distances are, on average, 40% smaller than those found in the

largest airports in the world. In general, this difference may suggest that there are characteristics of urban occupation in Latin American cities that are different from those found in cities in other locations, countries or continents.

3. Airside Configurations

In this section, the physical configurations of the main elements that compose the air side of the airports are presented: runways, rapid exit taxiways, taxiways, and taxi-lanes, with the passenger terminal gates serving as an element that allows interface with the land side. The composition of these elements is called the airside layout, and particular concern is focused upon the movement of aircraft.

3.1 Runways and Rapid Exit Taxiways (RETs)

The analysis of the runways at Latin American airports has focused on identifying four basic characteristics: the runway elevation, the number of runways, the Takeoff Distance Available (TODA) for each runway, and the number of Rapid Exit Taxiways (RETs).

a) Runway elevation: Among the various variables that influence runway length, airfield elevation holds considerable importance in determining the length of runways at airports. As the pressure altitude increases, the attainable takeoff weight decreases [10], meaning that, to ensure operational safety at high-altitude airports, their runways will require greater length to perform the same operation compared to an airport situated at sea level. The runway altitude is one of the factors that impact hourly capacity [5], as aircraft operations at airports with higher elevation require more runway occupancy time to perform landing or takeoff than at airports with lower altitudes, directly influencing the number of operations conducted, according to the aircraft mix. Figure 7 shows the variation in altitudes of the main airports in Latin America, highlighting the six busiest airports in the network (responsible for 51% of the air traffic).

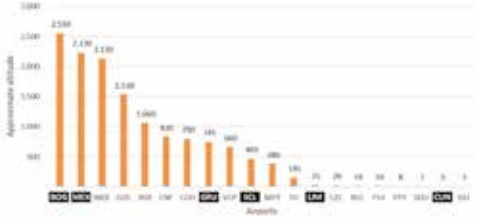

Figure 7 – Elevation at the Latin American airports
Source: Authors

b) Number of runways and their Takeoff Distance Available (TODA): The fundamental capacity constraint of any airport lies in the runway system, since the runway capacity puts a natural limit on the expansion capability of any airport [5]. Among the runway characteristics that affect the definition of the reliable maximum aircraft received by the airport, this article presents the survey of the number of runways at each of the 20 main airports in Latin America and their lengths, considering the Takeoff Distance Available (TODA). Figure 8 identifies the Takeoff Distance Available (TODA) in different scenarios used for the survey presented in this article.

Figure 8 – The declared distances measured for each runway.
Source: [5]

c) Rapid Exit Taxiways (RETs): RETs are constructed to minimize aircraft runway occupancy time in order to increase runway capacity [5]. As this article proposes a general analysis of the configurations of

the elements, characteristics such as width, separation, location, and geometry of the RETs are not analyzed. The objective of this topic is to identify the generic physical flow capacity characteristics. Thus, Figure 9 presents the quantity of rapid exits on each runway and airport analyzed. Airports with higher altitude from the set of airports are highlighted.

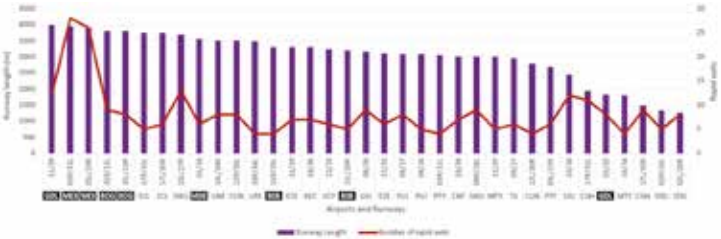

Figure 9 – Rapid Exit Taxiways (RETs) corresponding to each runway length, with emphasis on the airports with higher altitude
Source: Authors

3.2 Taxiway Systems

Taxiways provide a defined path between one part of the airport to another (e.g., between gates/aprons and the runway system) [5]. In this section, ranked data of Latin American airports are presented based on the extent of their taxiways and taxi-lanes, indicating the presence of one or two runways (Figure 10). The graph below shows that, as expected, the largest taxi networks are deployed in airports with two runways. However, there is a greater irregularity in the samples of airports with smaller taxi networks.

Figure 10 – Taxiways extensions and number of runways at Latin American Airports
Source: Authors

The figure below (Figure 11) illustrates the layout of taxiways and taxi-lanes in relation to the position and orientation of the runways, with airports organized from the largest taxi network (upper line on the left) to the smallest (bottom line on the right).

Figure 11 – Airside configurations: runways (in red), taxiways and taxi-lanes (comparison at same scale).
Source: Authors

The taxiway system connects five types of runway configurations: 05 airports have the simplest configuration with a single runway, similar to the majority of airports worldwide [1] (VCP, REC, TIJ, MDE, CNF); 05 airports have systems of parallel runways with close parallels (MEX, GRU, PTY, SDU, CGH); 05 airports have dual-lane runways with independent parallels (SCL, BOG, LIM, CUN, BSB); 02 airports have a two-runway angled configuration in an open/close-V shape (SJU, PUJ); and 03 airports have intersecting runways (GDL, EZE, MTY).

3.3 Passenger Terminal Concept and Bridges Connections

In the analyzed airports, there is not an immediate correlation between the number of terminals and the annual passenger movement at first glance (Figure 13 – on the left), as the airports with the highest number of passenger terminals are not necessarily the busiest in the network. This could suggest greater peak variation at certain airports, under the premise that demand for peak-hour schedules affects the required infrastructure at the airport, potentially implying the number of terminals needed to handle concentrated passenger processing in a short period. Airport traffic exhibits peak characteristics by the month, day, and hour, depending on the nature of the airport traffic and the hinterland served.

The graph presented in the Figure 13 (on the right) compares the monthly flow variations in 2023 among the 5 airports with the highest number of terminals: GRU (3), CUN (4), EZE (3), PUJ (4), and SJU (4), aiming to verify if monthly peaks could indicate seasonal flow concentration. It can be observed that, for the three airports with a tourist profile (CUN, SJU, and PUJ), the greatest variation occurs in September, with an average flow decrease of 63% compared to the peak month. Hence, understanding flow distribution on a smaller scale (within the peak month and on the peak day) proves essential to determine how the correlation between infrastructure and operation functions in these specific airports (this analysis goes beyond the proposed scope for this article).

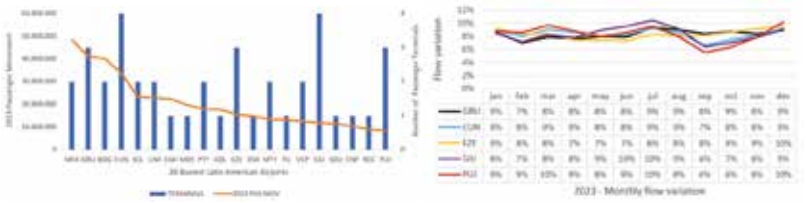

Figure 13 – Number of Passenger Terminals (on the left) and monthly flow variation during 2023
Source: Authors

Regarding the configuration of passenger terminals, there are generally three main terminal configurations recognized globally: Linear, Pier/Finger, and Satellite. The classification of design concepts used in Latin American airport terminals follows the definition proposed by the Airport Development Reference Manual developed by IATA [5]:

- Linear Terminals: These terminals consist of a centralized passenger processing area and an associated airside concourse, often integrated and adjacent to the processor. The geometry typically involves aircraft parking positions oriented along one side of the concourse, which may wrap around each end of the concourse.
- Pier Terminals: These terminals consist of a centralized, or several semi-centralized, passenger terminal for processing passengers, linked to piers (airside concourses) in single or multiple pier configurations. The geometry can accommodate aircraft parking positions on one or both sides of the concourse.
- Satellite Terminals: These terminals consist of a central processing building for passenger and baggage processing, with remote concourses around which aircraft are parked.

The 20 busiest Latin American airports together have 38 terminals, where 15 have the hybrid Linear-Pier (L-P) configuration, 12 have the pure Pier concept configuration, 9 terminals have a Linear configuration, and 1 terminal is Satellite. Regarding the number of passengers boarding bridges per terminal configuration, an important aspect to reduce passenger disembark/embarkation time, the data shown in Figure 14 (on the left) indicate that the hybrid linear-pier model, besides being the most used, is also the one with the highest number of bridges connections. In the same Figure 14 (on the right), the total number of connecting bridges per airport is presented, highlighting Mexico City Airport (MEX), the busiest airport analyzed, as the one most equipped with this infrastructure.

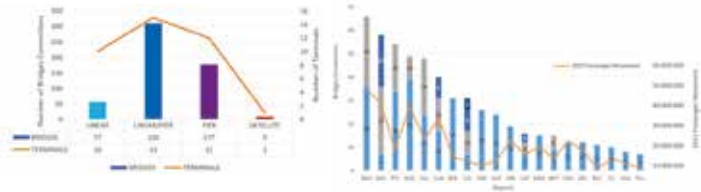

Figure 14 – Most adopted passenger terminal configurations (on the left) and distribution of passengers boarding bridges per terminal and airport (on the right)
Source: Authors

The figure 15 shows the distribution of the 38 terminals according to the number of passenger boarding bridges and presents the layout of the largest terminals of each configuration.

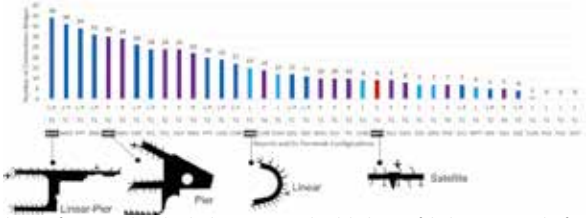

Figure 15 – Distribution of passenger boarding bridges per terminal and the layout of the largest terminals of each configuration
Source: Authors

In many airports, the adoption of the hybrid concept (the main model installed in Latin American airports) largely resulted from renovation and/or expansion projects of existing terminals, as is the case with terminal (T1) at BOG, which does not occur in pure concept terminals. The airports' passenger terminals highlighted in Figure 15 are those with the highest capacity in each adopted concept.

4. Final considerations: spatial imprint patterns and airport development in Latin America

The physical characteristics can present specific patterns that, in isolation and without considering the operational aspects of air transport in each location, represent the maximum spatial conditions found at each airport. The final question that this article aims to answer is: *Which airports gather the best spatial imprint patterns?* The central idea is that such standards would indicate the best conditions for the aerial operation at the Airport's facilities, therefore indicating which airports have the greatest spatial potential. Thus, the characteristics presented throughout this article have been individually systematized as indicators based on the best spatial condition found (Figure 16).

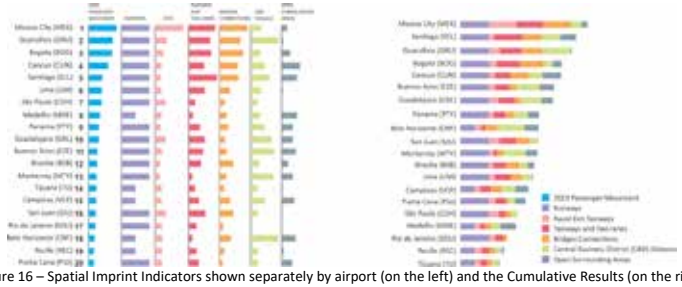

Figure 16 – Spatial Imprint Indicators shown separately by airport (on the left) and the Cumulative Results (on the right)
Source: Authors

The cumulative results show the sum of the spatial conditions of each airport (considering exclusively the best scenario found among the airports analyzed in Latin America). The graph highlights the Mexico City Airport (MEX) as the one that, in 2023, gathered the largest accumulated set of measured physical attributes, despite not all aspects analyzed having been measured under the best spatial conditions (especially regarding the urbanized surrounding configurations). The MEX Airport has the following characteristics: 02 runways, an average of 27 RETs, 24km of taxiway system, 63 bridge connections, 15km distance from the CBD, 80% urbanized area in its vicinity. The graph also emphasizes that the five busiest airports in Latin America possess the best sets of measured physical attributes (with their positions varying across rankings). The results of this study reinforce the importance of physical infrastructure – spatial imprint – for achieving higher capacity performance in airport operations.

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Heuristic Optimization in Runway Orientation Selection Applying Computer Vision

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Abstract/Resumo/Resumen

The following work consists of the HORO algorithm, an implementation of Heuristic Optimization in Runway Orientation developed in Python using the OpenCV library for creating a computer vision simulation environment. HORO has been designed to optimize the orientation of runways at airports, taking into account factors such as wind variation, magnitude, and direction. The execution of the algorithm took approximately two minutes for a single analysis of an airport using an Intel(R) Core(TM) i7-13th Generation processor. The HORO algorithm was applied to seven Brazilian international airports with analysis periods ranging from five to twenty years, demonstrating that the factor of operation (FO) stabilizes on the modeled runway between 15 and 20 years. A positive percentage variation was also observed in relation to the current runway for the modeled runway in all analyzed scenarios, indicating an effective use of runway orientation. The analysis also highlighted a significant reduction in crosswinds, with reductions of up to 97%. All analyses were performed automatically by HORO using pre-processed data. The source code is available for access and contributions on GitHub, allowing its use and improvement by the scientific and professional community. In conclusion, HORO shows promising results in improving the performance of runways at aerodromes, emerging as a valuable tool for increasing the efficiency and safety of air operations.

Heuristic Optimization in Runway Orientation Selection Applying Computer Vision

1. Introduction

One of the most important definitions of an airport is: "An airport is a complex system of facilities and is usually the most important business in the region, as it is a major economic generator and a catalyst for attracting investment in its area of operation" [1]. However, the presence of a runway of sufficient size and compatibility with the planned aircraft is what ensures that this infrastructure generates economic power for the region where it is located [2].

Runway orientation is one of the key aspects of runway design for airport infrastructure designers. Probably the oldest, most basic and fundamental characteristic of an airport is its geometric configuration and runway orientation [3]. Orientation is the angle that the centerline makes with the azimuth. This has been an issue in aerodrome design since the early days of aviation, when aircraft landed on dirt and grass runways (known as the infancy of aviation) and pilots were guided by the direction of the wind through the windsock, an instrument that shows the direction and speed of the wind and guides pilots, air traffic controllers, and other aerodrome professionals [2].

The adverse effects of crosswinds are minimized by always landing and taking off in the opposite direction to the wind. Thus, runway orientation depends on the wind speed component, frequency and direction [4]. Nowadays, with technological advances and the search for tasks that require as little time as possible, especially when it comes to studying and analyzing projects, the time factor has a considerable weight in decision-making. However, in addition to the time factor, one of the fundamental points to consider when analyzing the orientation of the runway is the behavior and variation of the Earth's magnetic declination.

The variation in magnetic declination over time changes the difference between true north and magnetic north, and consequently changes the number of airfield headlands [5]. For example, consider a hypothetical point 08 where the annual magnetic variation is assumed to be 6' (six minutes) and the difference between true north and magnetic north is 84º4' (eighty-four degrees and four minutes). Assuming that in a later year the difference becomes 85º (eighty-five degrees), then the hypothetical headland that was 08 would become 09.

One of the main motivations for this study revolves around guaranteeing runway operability and the safety of landing and take-off operations at aerodromes. An airport infrastructure project must consider the study of winds as an essential part. It is worth noting that winds account for around 40% of aviation accidents in landing and take-off procedures [5].

Therefore, the wind direction and speed at the airport site are unique variables for the development of runway guidance. In addition, projects must meet in the [16] Annex XIV recommendation of at least 95% operability to remain effective. This, properly defined, makes the airport operational and commercially attractive [7].

Faced with this problem, this article aims to present a methodological proposal to ensure the effectiveness of operations in new airport developments. The aim of this work is to enable aerodrome designers to determine the optimal runway position (PPD) in the shortest possible time and in real time, using data containing the magnitude and direction of the winds.

The magnetic declination of the study area and the historical series can be obtained to estimate how often there will be changes in the orientation of the headlands, since they are affected by the annual variation in magnetic declination. To validate the study, existing Brazilian airports with a high crosswind index will be evaluated to present the non-conformities in the existing runway orientations. To achieve this validation, two scenarios will be considered: the current orientation of the existing runway and the simulated orientation developed by a model generated by this study [8].

2. Geometric design of an aerodrome

The runway is a fundamental component of the geometric design of an aerodrome. It encompasses the most critical information pertinent to an airport project, which serves as the foundation for the preparation of all subsequent infrastructure projects. In accordance with current regulations, the runway must incorporate the essential elements. As the most crucial element of an airport, every project must initially consider the fundamental runway length (CBL), which is primarily designed to guarantee the requisite runway length for landing and takeoff for a specific aircraft [4].

The size of a runway is determined by a few factors related to infrastructure. These include the altitude of the airfield, the reference temperature of the site, the effective slope of the runway, and the wind data for the region of the airport site (anemogram). Aircraft-related parameters that influence this sizing include the maximum takeoff weight of the critical aircraft, aerodynamic characteristics, and engine configuration [4].

An anemogram is a graphical representation of the frequency of wind incidence in each of the specific wind direction sectors and wind speed modules for a given location and specified period. It can be used to analyze the runway based on data available on the INMET website, which is the National Institute of Meteorology website. The data is from weather stations in the region of the construction site. An anemogram represents the frequency of wind incidence in each of the specific wind direction sectors and wind speed modules for a given location and specified period.

Magnetic declination is defined to be the angle formed between the true meridian and the magnetic meridian; or it can also be identified as the deviation between the true azimuth or bearing and the corresponding magnetic ones. Azimuth is the horizontal angle formed between the North/South direction and the alignment in question (in this study, it would be the PPD axis). It is measured from North, clockwise (to the right), and can vary from 0º to 360º [9].

It can vary with time and geographic position, and can be westerly (δW), negative when the magnetic pole is west (W) of the geographic pole, and easterly (δE) otherwise. Graphically shows the transformation of elements (bearings and azimuths) with orientation by True North (NV) or Magnetic North (NM) is a simple process, in which case it is enough to algebraically add the magnetic declination [9].

Once the azimuths of the alignments have been determined, the corresponding bearings can be readily identified through the application of straightforward geometric principles. This is achieved by noting that, when viewed from the north, the bearings rotate in a clockwise direction towards east and in a counterclockwise direction towards west.

Conversely, from the south, bearings grow in the opposite direction, counterclockwise to east and clockwise to west. It is customary to count bearings from the north or south point, with values ranging

from 0° to 90°. Consequently, bearing has no negative value. However, it is imperative to designate the quadrant to which the azimuth angle belongs in the polar system, as shown in Figure 1.

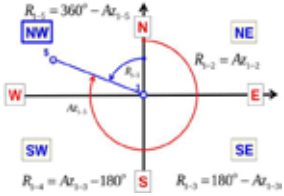

Figure 1 – Directions and azimuths in each quadrant. Source: [10]

Equation 1 shows how the magnetic heading ("MH") of a runway is calculated from the true heading ("TH") of the wind. The TH is determined from the statistical study of wind direction data obtained for that region over time, through an anemogram, a graph that is constructed in the polar system, representing directional phenomena [10].

$$RM = RV - [\delta ø + V \times (T - Tø)] \quad (1)$$

Where:
TH: true heading (degrees); δø: magnetic declination of the initial year; V: annual variation in magnetic declination; T: year in question (current); and Tø: year with known data.

3. Methodology

The methodology proposed in this work includes the steps necessary to achieve the results by means of a heuristic optimization analysis to obtain lane guidance [11]. The main steps are:

- Definition of the airports to be analyzed - seven international airports in Brazil were selected.
- Obtaining and analyzing the database - data collection stations with a collection history of up to 20 years were considered, and
- The development of two sequential scripts. The first classifies winds based on magnitude and frequency, while the second creates 180 runway positions to check crosswinds along with their utilization coefficient. The combination of the two scripts allows the PPD orientation to be obtained, including magnetic declination.

3.1. Choosing Airports

Initially, ten international airports in Brazil were selected for analysis based on reports of crosswinds during landing and take-off operations on their runways. However, upon examination of the database, discrepancies were identified at certain collection stations, including inconsistencies in wind direction, a history of less than 20 years, and others. Therefore, the following airports were excluded from the analysis: Macapá International Airport (ICAO code: SBMQ), Porto Alegre International Airport (ICAO code: SBPA), and Recife International Airport (ICAO code: SBRF). This resulted in seven airports being included in the analysis. Figure 2 illustrates the location map of the selected airports.

Figure 2 – Situation map of the proposed airports. Source: [12] adapted by the authors.

Table 1 describes the main information on the study airports and the open data on all operational information for Brazilian public civil airports [13].

Table 1 - Data on the selected airports. Source: [13]

Name	city / UF	ICAO	Current orientation runway 1	Length	Name	city / UF
Pres. Juscelino Kubitschek	Brasília - Distrito Federal	SBBR	11L – 29R	3200 m 10499 ft	11R – 29L	3300 m 10827 ft
Afonso Pena	Curitiba - Paraná	SBCT	15 – 33	2218 m 7277 ft	11 – 29	1798 m 5899 ft
Hercílio Luz	Florianópolis - Santa Catarina	SBFL	14 – 32	2400 m 7874 ft	03 – 21	1320 m 4331 ft
Pinto Martins	Fortaleza - Ceará	SBFZ	13 – 31	2755 m 9039 ft	-	-
Gov. André Franco Montoro	Guarulhos - São Paulo	SBGR	10L – 28R	3700 m 12139 ft	10R – 28L	3000 m 9483 ft
Pres. Castro Pinto	João Pessoa - Paraíba	SBJP	16 – 34	2515 m 8251 ft	-	-
Zumbi dos Palmares	Maceió - Alagoas	SBMO	12 – 30	2602 m 8537 ft	-	-

3.2. Data Collection

The data used in this study was obtained from the website through the BDMEP platform. It was collected in March 2024 and comprises a vast series of records from national weather stations, available by city and by type of weather station (automatic and/or conventional). The user can select approximately 25 types of variables, including variables related to winds, such as direction, maximum gust, and hourly speed [14].

To improve the accuracy and quality of the analysis, the raw official database was processed as described, so that typing errors and incongruous values that could impact and distort the analysis could be removed. After processing the data, 986,281 lines of data were obtained. Table 2 describes the data processed for each airport.

Table 2 - Description of post-treatment data by the authors.

Study airports			Time horizon		Number of lines analyzed	
Pres. Juscelino Kubitschek	Brasília - DF	SBBR	2000/05/07	2024/04/09	209.760	203.882
Afonso Pena	Curitiba - PR	SBCT	2007/02/07	2024/04/09	185.856	112.805
Hercílio Luz	Florianópolis - SC	SBFL	2003/03/17	2024/04/09	186.000	173.230
Pinto Martins	Fortaleza - CE	SBFZ	2007/02/07	2024/04/09	185.352	125.487
Gov. André Franco Montoro	Guarulhos - SP	SBGR	1975/01/01	31/07/2023	95.949	91.478
Pres. Castro Pinto	João Pessoa - PB	SBJP	2007/07/07	2024/04/09	146.616	120.498
Zumbi dos Palmares	Maceió - AL	SBMO	2003/02/25	2024/04/18	185.400	158.901
					1.194.933	**986.281**

The data were analyzed and preprocessed in a computer environment. This library was responsible for creating the anemograms, which were derived from the direction and speed of the winds [11]. These winds were treated in a data frame to standardize them, as they had different titles and data types. Finally, the wind speeds were converted from meters per second to knots(kn) [15].

It should be noted that the data was not processed directly with the Pandas library, as it was in unknown "unicode" and different from the UTF-8 (8-bit Unicode Transformation Format) standard. The solution was therefore to create a specific function to read this information, called *ReadDatasets* [14]. This function employs native tools to work directly with files that have unicode limitations, thus allowing pre-processing and subsequent analysis to be carried out and the data to be read correctly. This adjustment meant that the data was read by the Pandas library [11].

The most difficult part of the analysis was rounding up the algorithm and processing the data, as there were duplicates and nulls in some of the data downloaded [14]. In a database with 1,259,754 lines of raw data, we removed around 208,652 lines with inconsistent values, dates and times outside the Brazilian standard, with different notations and negative 4th order values. Due to the large amount of data, it took time to adjust and process the entire database. However, eliminating this problem ensured that robust results could be generated. The Table 3 describes the selected variables.

Table 3 - Variables of the weather stations and highlights of the selected variables. Source: [14]

1. Date of measurement	1. Air temperature - wet bulb, hourly (âºC)
2. Time of measurement	2. Dew point temperature (âºC)
3. Ch (high clouds) (code)	3. Max temperature -the hour before (aut) (âºC)
4. Cl (médium clouds) (code)	4. Min temperature in the previous hour (aut) (âºC)
5. CM (low clouds) (code)	5. Max. relative humidity previous hour (%)
6. Hourly cloudness (tenths)	6. Min. relative humidity previous hour (%)
7. Total precipitation, hourly (mm)	7. Hourly relative humidity (%)
8. Atmospheric pressure at station level, hourly (mb)	***8. ** Wind, hourly direction (º (degrees))***
9. Atmospheric pressure at sea level, hourly (mb)	*9. Wind, maximum gust (kn)*
10. Max. atm pressure the hour before (aut) (mb)	10. Wind, hourly speed (m/s)
11. Min. atm pressure the hour before (aut) (mb)	***11. Wind, hourly speed (m/s) (kn)***
12. Global radiation (kj/m²)	12. Visibilidade, horária (código)
13. Air temperature – dry bulb, hourly (âºC)	

3.3. Algorithm Structure

The algorithm was developed in a 64-bit Windows environment and has not been tested in other environments. For consultation, the file has been made available by the authors at doi.org/10.5281/zenodo.11114344. It is crucial to acknowledge that the *ReadDatasets* function, situated within *Modulos\Dados\Engine.py*, is likely to necessitate modification, as it was designed with the specific purpose of reading and processing data. The occurrence of reading errors may be attributed to the presence of data in disparate formats [14].

The structure of the algorithm is relatively simple, consisting of a project with three folders and three *.py* files, plus an. ipynb file. The *input* folder should contain the data from the weather stations in *.csv* format. The modules folder includes a browser module for collecting magnetic declination, as well as the data module for reading the data entered in the *input* folder. The last folder, movies, will store the videos resulting from the simulation at the end of each run.

The three *.py* files are *Default.py*, *Functions.py* and *Script1.py*, where *Default.py* contains all the basic settings for running the simulation, such as image size, wind limits and so on, which can be changed as required. The *Functions.py* file contains all the auxiliary functions for the simulation. Finally, the *Script1.py* file generates the wind percentage table, as explained in the next chapter. Finally, the *Run_HORO.ipynb* file in *Jupyter* (jupyter.org), which contains all the simulation routines. Figure 3 shows the interface of the algorithm structure.

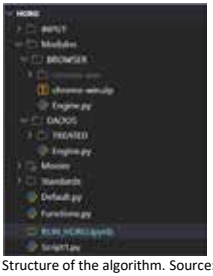

Figure 3 - Structure of the algorithm. Source: Authors.

3.4. Script 1 – Wind percentage table

This script is found in the root of the algorithm project, called *Script1.py*. It is responsible for creating the wind proportion table for each direction of the wind rose. To do this, the following *input* parameters must be defined: *Direction, Magnitude, Sector Names and Boundaries*, where *Direction* indicates all the wind directions starting clockwise from north, *Magnitude* represents the winds already converted from (m/s) to (kn), so both variables must contain the same sizes.Considering the *sector names*, which must be transmitted for each sector of the wind roses, these may be pre-configured in 4, 8, or 16 sectors. To

modify the sector names, it is sufficient to alter the RoseWind variable in the *Default.py* file, which contains all the fundamental settings for running the application.

Regarding the final parameter, *Limits*, it is first necessary to ascertain the type of runway being analyzed, since according to CBP it is recommended that the landing or take-off of aircraft is impossible under normal conditions when: (i) The CBP is equal to or greater than 1500 m, and the crosswind component does not exceed 20 kn. (ii) The CBP is equal to or greater than 1200 m, and less than 1500 m. (i) The CBP is greater than or equal to 1500 m and the crosswind component does not exceed 13 kn; (ii) the CBP is greater than or equal to 1200 m and the crosswind component does not exceed 10 kn; and (iii) the CBP is less than 1200 m and the crosswind component does not exceed 10 kn.

Once the wind speed ranges have been predefined for the Anemogram according to the recommendations, these values are updated in the *Limits* variable within the *Default.py* file, in this work: 0-3, 3-13, **13-20**, 13-25, 25-40 and > 40, in this case, the winds from **13** to **20** kn were inserted, which limit crosswinds for runways with a CBP greater than or equal to 1500 m [16]. All the airports analyzed meet this requirement.

You will then need to update the *WindRunwayLimit* value within *Default.py* depending on the airport you are analyzing. For this study, they all have a CBP greater than 1500 m. This variable is used in the algorithm to consider the winds present within the runway limits and outside the runway limits, these being the crosswinds. Once this has been defined, the routine for executing this script 1 can be run as defined by the authors of the research:

1. *Receive the wind direction data, its magnitude, the names of the sectors and the magnitude limits for each sector.*
2. *Create the sectors of equal size directed on the wind rose.*
3. *For each sector, count the number of winds that fall within the specified magnitude limits.*
4. *Calculate the percentage of winds for each sector in relation to the total.*
5. *Return the table of wind percentages by sector.*

Subsequently, the directional sectors were calculated. A directional sector is defined as half a sector on each side of a specific direction of the wind rose. To illustrate this, Figure 4 depicts the wind rose for the 16 sectors, while Figure 5 illustrates the algorithm's scanning system in a sector facing north (N) for 8 sectors. The cardinal and collateral points are 45° apart, thus a half sector corresponds to the sub-collateral points that cover 22.5° degrees to the right and 22.5° degrees to the left of the cardinal point, North (N). This process is repeated for all the other sectors during the execution of the algorithm.

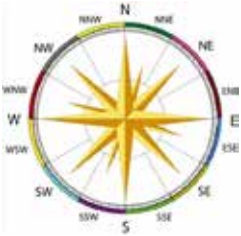

Figure 4 - Compass rose
Source: [17]

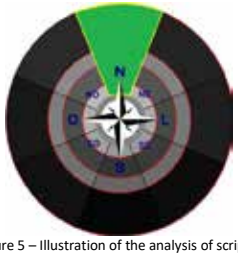

Figure 5 – Illustration of the analysis of script 1
Source: [18] Edited by the authors

3.5. Script 2 – Runway Guidance

Script 2 is where the actual simulation of the runway's orientation takes place. Its entire execution is based on computer vision, and for its execution, it is also necessary to make some settings left in the *Default.py* file, such as: the size of the image for the simulation, the desired font to write next to the compass rose, the font size, among others.

Before executing Script 2, a routine was created in selenium (www.selenium.dev) to access the website and extract the magnetic declination of the location under analysis [8]. After, you need to enter the location in Table 4, this routine uses the chromium browser (www.chromium.org) which is zipped within

the project in *Moduls\Browser\chrome-win.zip*, where it will be necessary to extract it, as this unzipped file exceeds the 100 mb allowed in [19].

Table 4 of the *dataset* should contain three columns: *date* in *datetime*, *direction*, and *magnitude* in *float*. Based on these assumptions, the second script, Script 2, is executed. Script 2 is based on the result of Script 1, as its execution requires the wind table. Therefore, when Script 2 is executed, it will call Script 1 and pass on the wind data frame, as it has been configured to receive more than one airport for analysis. Finally, the execution routine requires that the data for analysis be hierarchized as follows in a JSON file:

Table 4 - Input format for Script 2 execution. Source: Authors

Input para script 2
{
"AIRPORT NAME": {
"Dataset": "DataFrame",
"Local": [Longitude, Latitude]
}
}

The execution routine for this Script 2 follows the pattern below:

1. Create an image of the wind rose and its boundaries as shown in Figure 5.
2. Assign each sector its respective value in the wind table in Script 1.
3. Plot the track in the center of the anemogram and rotate it 180 degrees.
4. For each degree of the 180, check the runway's operating factor.
    a. Calculate the utilization factor as follows:
    a. count the area inside the track by the total area of the sector in pixels.
    b. multiply the previous fraction by the sector's wind.
    c. add up all the fractions within the runway to obtain the final wind %, which gives the operating factor.
    d. calculate the crosswinds, where 100% is the operating factor.
5. for each degree save the operating factor and crosswind.
6. It is necessary to ascertain the extent to which the operating factor is optimized. Once this has been determined, the process can be concluded.

4. Results and Discussions

The proposed open-source HORO algorithm, in its initial iteration, employs a *heuristic optimization in runway orientation* (HORO), a computer vision-based simulation utilizing the OpenCV library (www.opencv.org) within a computer environment [11]. The analysis of each airport in Table 5 required approximately seven minutes, with the entire process taking approximately 50 minutes on a 2.60 GHz *Intel(R) Core (TM) i7-13650HX* processor. To check the algorithm's performance in different scenarios, it was applied to seven Brazilian international airports, varying the period of analysis every five years until reaching a historical base of 20 years, as shown in Table 5. This approach revealed, in general, that in all the cases analyzed, the operating factor (OF) stabilizes on the modeled runway between 15 and 20 years.

It was observed that the difference between the analyses with historical data and winds of less than 15 years increased, but that this had less impact when comparing periods of more than 15 years. In all the cases analyzed, there was a percentage variation in relation to runway 1 and the modeled runway. The variation of the FO was high in all the scenarios, thus optimizing the orientation. This highlights the effectiveness of using HORO to determine the ideal runway orientation.

Furthermore, the crosswinds exhibited a consistent pattern, with the smallest reduction registering at 3% and the largest reaching 97%. Finally, we can see the orientation column on all the runways, from the modeled one to the current one, which already has the magnetic declination obtained up to the 3rd of May 2024 on the website, in which all the analyses in Table 5 were obtained with HORO fully automatically, if the data is already as shown in Table 4 [8].

Table 5. Comparison of the current track with the track modeled by HORO. Source: Authors

VARIABLES		CURRENT RUNWAY 1				CURRENT RUNWAY 2				MODELED RUNWAY 1				PERCENTAGE VARIATION		
AIRPORT	YEAR	FO	HEADING	ORIENTATION	CROSS WIND	FO	HEADING	ORIENTATION	CROSS WIND	FO	HEADING	ORIENTATION	CROSSWIND	FO	HEADING	CROSS WIND
BRASÍLIA	5	89%	85º	11 - 29	11,38%	PARALLEL RUNWAY				97%	25º	05 -23	3,23%	9,19%	-71	-72%
	10	87%	85º	11 - 29	13,00%					97%	10º	03 - 21	3,34%	10,59%	-88%	-74%
	15	87%	85º	11 - 29	13,09%					97%	18º	04 - 22	3,41%	11,14%	-79%	-74%
	20	86%	85º	11 - 29	13,56%					97%	18º	04 - 22	3,25%	11,93%	-79%	-76%
CURITIBA	5	93%	135º	15 - 34	6,75%	86%	93	11 - 29	14,17%	98%	6º	03 - 21	1,52%	5,61%	-96%	-77%
	10	93%	135º	16 - 34	6,78%	86%	93	11 - 29	13,88%	98%	6º	03 - 21	1,73%	5,42%	-96%	-74%
	15	93%	135º	16 - 34	6,96%	86%	93	11 - 29	14,06%	98%	6º	03 - 21	1,82%	5,56%	-96%	-74%
	20	93%	135º	16 - 34	7,18%	86%	93	11 - 29	14,34%	98%	6º	03 - 21	1,82%	5,76%	-96%	-75%
FLORIANÓPOLIS	5	93%	122º	14 - 32	7,25%	87%	193	03 - 21	12,62%	99%	76º	10 - 28	1,36%	6,35%	-38%	-81%
	10	93%	122º	14 - 32	7,01%	86%	193	03 - 21	14,29%	99%	76º	10 - 28	1,28%	6,16%	-38%	-81%
	15	93%	122º	14 - 32	6,85%	85%	193	03 - 21	15,42%	99%	74º	09 - 27	1,23%	6,03%	-40%	-82%
	20	94%	122º	14 - 32	6,37%	84%	193	03 - 21	15,66%	99%	76º	10 - 28	1,30%	5,41%	-38%	-80%
FORTALEZA	5	70%	105º	13 - 31	29,61%	-	-	-	-	99%	30º	05- 23	0,78%	40,94%	-71%	-97%
	10	68%	105º	13 - 31	31,67%	-	-	-	-	99%	30º	05- 23	0,72%	45,28%	-71%	-97%
	15	69%	105º	13 - 31	31,36%	-	-	-	-	99%	27º	05- 23	1,07%	44,13%	-74%	-97%
	20	69%	105º	13 - 31	31,37%	-	-	-	-	99%	25º	05- 23	0,99%	44,25%	-76%	-97%
GUARULHOS	5	97%	73º	10 - 28	3,34%	PARALLEL RUNWAY				97%	67º	09 - 27	3,24%	0,10%	-8%	-3%
	10	96%	73º	10 - 28	4,39%					96%	61º	08 - 26	3,62%	0,79%	-16%	-17%
	15	95%	73º	10 - 28	5,03%					96%	61º	09 - 27	3,53%	1,48%	-16%	-30%
	20	95%	73º	10 - 28	4,88%					97%	49º	07 - 25	3,33%	1,64%	-33%	-32%
JOÃO PESSOA	5	90%	135º	16 - 34	9,68%	-	-	-	-	99%	49º	07 - 25	0,70%	9,94%	-64%	-93%
	10	78%	135º	16 - 34	22,26%	-	-	-	-	99%	40º	06 - 24	1,08%	26,73%	-70%	-95%
	15	77%	135º	16 - 34	23,27%	-	-	-	-	99%	30º	05 - 23	1,32%	28,61%	-78%	-94%
	20	76%	135º	16 - 34	23,78%	-	-	-	-	99%	34º	06 - 24	1,38%	29,41%	-75%	-94%
MACEIÓ	5	81%	100º	12 - 30	19,34%	-	-	-	-	97%	06º	03 - 21	2,89%	20,39%	-94%	-85%
	10	79%	100º	12 - 30	20,83%	-	-	-	-	97%	06º	03 - 21	2,61%	23,04%	-94%	-87%
	15	79%	100º	12 - 30	20,55%	-	-	-	-	97%	06º	03 - 21	2,70%	22,48%	-94%	-87%
	20	79%	100º	12 - 30	20,86%	-	-	-	-	97%	06º	03 - 21	2,65%	23,01%	-94%	-87%

5. Conclusion

The initial implementation of the HORO algorithm, using computer vision in a computer environment, showed promising results. The data obtained highlighted its effectiveness in defining the most suitable orientation for runways [11]. In all the cases analyzed, the operating factors (OF) were optimized, indicating that, at some airports, the presence of two runways may not be necessary, since they all reached values higher than 95%, with the worst result reaching 96%.

A review of data collected over periods of five to twenty years revealed that, in all cases, the operating factor (OF) stabilized on the modeled runway between 15 and 20 years. This indicates that the most suitable period for analysis is 15 years, which underscores the importance of long-term analysis in optimizing runway orientation. The modeled runway exhibited a positive percentage variation in relation to runway 1 in all scenarios, indicating the efficacy of the optimization carried out by the HORO algorithm. Furthermore, there was a notable reduction in crosswinds, reaching up to 97% in the optimal case.

It is crucial to highlight that all the analyses were conducted automatically by HORO, provided that the pre-processed and typed data were already arranged according to Table 4 in the *input* folder. This was necessary for the analysis of this work, as it required the creation of a specific function to read the data [14]. The results presented in this article show the algorithm's potential as an effective tool for optimizing the orientation of runways at aerodromes, which in turn contributes significantly to the safety and efficiency of air operations, since the higher the aerodrome operation factor, the lower the downtime. Furthermore, the optimization of runway orientation results in a reduction in aborted take-offs, "crab landings," and touch-and-goes, due to the reduction in crosswinds. This reduction, in turn, contributes to an increase in the airport's operational safety.

Acknowledgments

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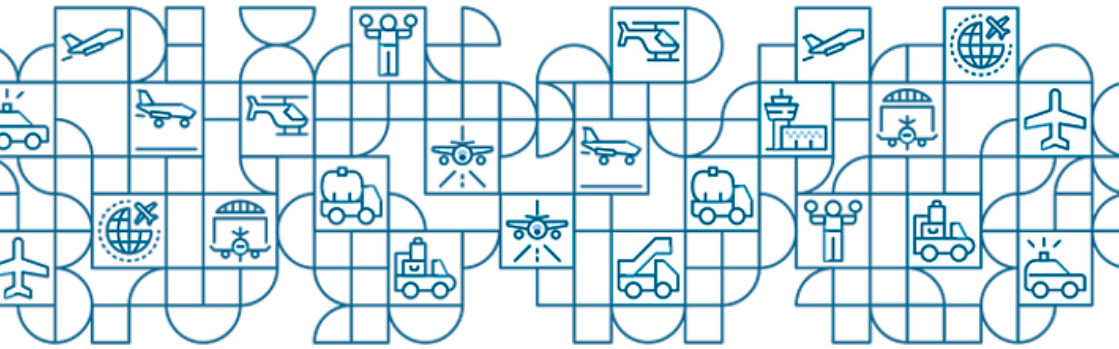
6. Airports and Sustainbility



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Aircraft Pollutants Emissions from LTO Ground Operations

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Abstract/Resumo/Resumen

Pollutant emissions at an airport arise from various activities, with the most significant in terms of volume of emissions being those associated with aircraft operations, known as LTO (Landing and Takeoff) operations. The focus of the present work is the analysis of pollutant emissions generated by aircraft traffic in LTO activities, including arrival and departure taxiing, takeoff, and landing, to determine the most critical locations on the ground in terms of emission concentration. To calculate emissions (for 1 hour of operation at Guarulhos Airport), the methodology proposed by ICAO AEED was used. The Geographic Information System (GIS) allowed the mapping of emissions, helping to interpret the results and serving as visual support for measuring georeferenced data. The study showed that: a) CO2 is the pollutant emitted to a greater extent in all LTO stages, totaling between 98-99% of total emissions; b) the takeoff stage is the most polluting in terms of emissions per second; c) the takeoff stage is the most polluting in terms of total emissions; d) the taxiing stage is the most concentrated polluting of all operations on the ground during the study hour. The mapping carried out shows that reducing taxiing times and improving operations are crucial to reducing the main focus of emissions on the ground. The results underscore the importance of optimizing ground operations—especially taxiing—to reduce concentrations of pollutant emissions and stimulate discussions on the development of technologies linked to fuel efficiency.

Aircraft Pollutant Emissions from LTO Ground Operations

1. The Pollutant Emissions at Airports

The growth of the aviation sector is driven by the increase in the number of passengers, which requires a greater number of aircraft operating and, consequently, increases the impacts of air transport. Among the negative impacts generated by air transport, the atmospheric impact is of particular concern, given that aircraft emissions can have serious effects on air quality, depending on the concentration of air traffic.

The Intergovernmental Panel on Climate Change [12] states that the aviation sector is responsible for 2% of carbon emissions from human activity. Pollutants are mainly released during aircraft flight operations, but there are other emissions from the movement of operational vehicles at airports, operations with Auxiliary Power Units (APUs), or engine maintenance. As a direct consequence, impacts are produced on air quality, affecting fauna, flora, and the population. The impacts of pollutant emissions are more critical the higher the concentration in the air and the longer the exposure, meaning that, at ground level, neighborhoods near airports and airport ground workers, as well as frequent passengers, experience greater risks.

The negative impacts have prompted the sector to take mitigation measures; however, it is one of the most challenging industries to decarbonize. The complexity of operations and weight limitations are factors that hinder the transition to green aviation. On one hand, electric batteries are too heavy, making long-distance and high-capacity flights unfeasible. On the other hand, hydrogen propulsion faces challenges related to storage, as it occupies a volume up to three times larger than current fuel, requiring a redesign of aircraft fuel tanks. Finally, aviation biofuels, Sustainable Aviation Fuels (SAF), are still expensive due to limited supply [5].

ICAO contributes by establishing rigorous CO2 emissions measures and aircraft certification contained in Volume III of Annex 16 of the Chicago Convention 'Environmental Protection,' with the CO2 emissions standard for aircraft being the world's first standard for CO2 emissions from any sector. The standard will apply to new designs from 2020, and those aircraft not meeting the standard from 2028 cannot be manufactured unless their designs are appropriately modified [4].

New technologies enhance fuel efficiency, contributing to mitigating aviation's impact on air quality. For the sector, the most viable alternative is Sustainable Aviation Fuel (SAF). The European Union's ReFuelEU Aviation regulation will require the use of 2% sustainable fuel by 2025 and increase every five years, requiring the use of SAF blends of 6% in 2030, 20% in 2035, 34% in 2040, 42% in 2045, and 70% in 2050 [7]. To achieve the zero-emission goal for the sector, there is no single solution; a combination of different technologies and collaboration from all stakeholders is necessary, and for each scenario, there will be an optimal sustainable solution [3].

Pollutant emissions at an airport stem from various activities, with the most significant in terms of emission volume being those associated with aircraft operations, known as Landing and Takeoff Operations (LTO). The LTO cycle consists of four operating modes, which involve a thrust setting and a time-in mode: taxiing for arrival and departure, takeoff, climb (up to 915 meters), approach (below 915 meters), and landing [9].

Among the LTO operations, this article focuses on studying those performed by aircraft on the ground of the airport, specifically landing, takeoff, and taxiing. For this study, the busiest airport in Brazil, Guarulhos Airport (GRU), was selected.

1.1. LTO Operations and Aircraft Engines

Emissions on the ground resulting from airport operations have an immediate impact on the local air, consequently affecting people and the environment. As the aircraft ascends, moves on the ground, or descends, pollutants are released at various altitudes of the troposphere [13].

In this process, engines play an essential role in pollutant emissions, given the need for combustion of fossil fuels to generate the thrust energy of the aircraft. Engines are classified according to their emission factor, which is a representative value that relates the quantity of pollutants (in kilograms) emitted into the atmosphere to an activity associated with their release per LTO cycle per engine. Total emissions and fuel consumption are calculated based on the time the aircraft operates in modes and thrust levels standardized by ICAO [9].

At each stage of flight, the proportion of emitted pollutants can vary. The main gases emitted at all stages are CO2, followed by H2O. In smaller proportions, other pollutants (HC, NOx, SO2, and MP) are found, the quantity of which varies depending on the LTO stage.

The LTO phases stand out as the most critical phases of the flight in terms of the amount of pollutants emitted per second. These phases follow the standards established by ICAO, providing greater availability of information on consumption and emissions, which gives greater reliability to the data. Variations in the amount of emissions at each stage are influenced by the engine thrust configuration and the weight of the aircraft, as illustrated in Figure 1 [10].

The phases of the LTO cycle (Figure 1) require different power applied by the engines and the average time of each operation. During takeoff, the aircraft employs 100% of the available power to lift the maximum load of the flight. Subsequently, upon initiating the pitch, the engines are configured with 85% of the maximum thrust, marking the ascent phase.

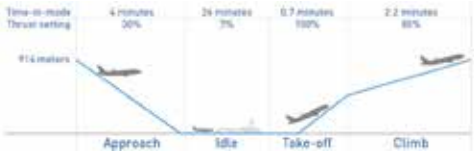

Figure 1 - ICAO engine emission certification LTO cycle
Source: [10]

When the aircraft is approaching the airport and is at 914 meters altitude, the approach phase begins, during which the engines operate with reduced power of 30%. The contribution of this stage to the total emissions of the LTO cycle totals approximately 24% [1]. Subsequently, it enters the landing stage upon touching the ground, and the thrust is reversed to slow down the aircraft. The stage referred to as "idle" in Figure 1 refers to engine ignition operations and ground activities encompassing all aspects of aircraft handling at the airport, known as taxiing in-out. During this phase, the engines operate with 7% of the maximum thrust [10].

During the takeoff phase, the aircraft uses 100% of the maximum thrust that will be employed during the flight, resulting in the highest emissions per second among all stages of a flight. In the climb phase, the aircraft adjusts a climbing angle, and the necessary thrust is 85%. The takeoff and climb stages combined contribute 51% of the total emissions during LTO cycles [1].

In the taxiing stages, the engines are configured with a thrust corresponding to 7% of the maximum value. Since the taxiing phase is the longest of the LTO cycle, emissions end up being slightly higher than those of the approach, landing, and takeoff considered individually, totaling approximately 26% of the total emissions of the LTO cycle [1].

The cruising stage is the longest of the flight; consequently, it emits the most pollutants into the troposphere. However, LTO stages (Takeoff, Climb, Approach, and Landing) are highly polluting and have the highest rate of pollutants emitted per second.

2. Methodological Structure for Pollutant Calculations

The methodology adopted for measuring aircraft emissions during LTO (landing and take-off) activities on the ground at Guarulhos Airport is based on the tool recommended by the Air Pollutant Emission Inventory book of 2013, developed by the European Environment Agency (EEA), EUROCONTROL, ICAO, and EASA [6]. The Guidebook is structured to provide the user with general information on the basic principles of constructing an emissions inventory and the specific estimation methods and emission factors to compile one, guiding the user through the stages, methods, and limitations associated with key category analysis and methodological choice; data collection (including measurement methodologies); time series consistency; uncertainties; inventory management, improvement, and quality assurance/quality control (QA/QC); spatial emissions inventories; and projections.

The AEED (Aircraft Engine Emission Databank) [10] was used to determine the emission factors since the models of aircraft operating at GRU airport are known, as well as the number of LTO operations each model performs. The AEED database is extensive, however, it does not include all engine models available in the market, so in these cases, another methodology recommended by the Guide is applied. In these situations, Methodology Level 2 was used, which consists of a table that relates each aircraft with simplified emission factors.

Rigor in applying methods to reduce the degree of uncertainties is a key point in the development of pollutant emission calculations. For this reason, a comparison was made between three methodologies to determine the most suitable one for the study, namely the AEED, Level 2 methodologies (both proposed by the EEA Guide [6]), and the one used by ANAC [1]. The Figure 2 illustrates emissions by pollutant for LTO cycles using data from Guarulhos Airport applying the three different methodologies.

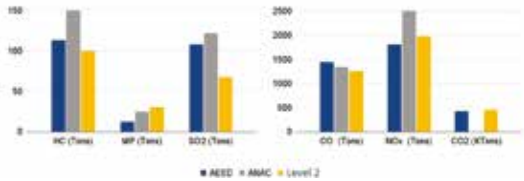

Figure 2 – Comparing methodologies for annual emissions of different pollutants
Source: Authors

It is observed that the results obtained with the three methodologies differ slightly, but are used to estimate quantities (since there are no air quality meters in Guarulhos). For this study, the methodology chosen is that indicated by AEED, which determines the emission factors for each aircraft (according to engine models). It is important to highlight that the methodology suggests the use of the Level 2 method for aircraft that are not included in the AEED database. The calculation sequence indicated by AEED and applied to this study is presented in Figure 3.

Figure 3 – Calculation methodology proposed by AEED and applied in this study
Source: Authors

Regarding the emission factors from the ICAO AEED database; the WRF (Weather Research and Forecasting) and AERMOD (American Meteorological Society/Environmental Protection Agency Regulatory Model) models were used to analyze air pollutant concentrations and simulate their dispersion. The conversion of meteorological data format was performed using the MMIF program (Mesoscale Model Interface Program). For data spatialization (mapping), the open-source QGIS tool was used.

The years 2019 and 2020 were selected as the study scenario to compare a year before the pandemic with the pandemic year since air operations during 2021 and 2022 did not reach the levels of 2019, and this study was conducted before the release of operations data for the year 2023.

Regarding the pollutants analyzed, it is important to note that the emissions of CO2, SO2, and H2O are not included in the ICAO database. Following the EEA guide, the emissions of these pollutants depend on the mass of fuel burned. The guide offers several alternatives to estimate the emissions of these pollutants. In the present study, a method proposed by the guide was used, which consists of multiplying the mass of fuel used in the LTO stages by a factor of 3.149 for CO2, 0.0008 for SO2, and 1.6 for H2O.

3. GRU Airport Data: Aircraft and Operations on the Ground

The chosen location for this study is the busiest airport in Brazil, GRU Airport, where gas emissions are significantly relevant in terms of air operations concentration in the country [1].

GRU Airport has two runways with lengths exceeding 2,100 meters (Figure 4), capable of accommodating all commercial aircraft, including large ones such as the 747-800 and A380 [2]:

- Runway 1: With a length of 3,700 meters, it is the longest runway at the airport, certified for landings and takeoffs of the largest commercial aircraft (A380, B747-800, and Antonov).
- Runway 2: With a length of 3,000 meters, it is used for landings and takeoffs of aircraft of various sizes, except for large aircraft.

Figure 4 – Airside of GRU Airport, Runway 1 (09L/27R) and Runway 2 (09R/27L)
Source: Authors

During the year 2019, 180 different aircraft models were identified in operation, and 140 during the year 2020, with the A320 being the most used aircraft (over 81,000 operations), followed by the B738 (with about 65,000 operations). The 10 aircraft illustrated in Figure 5 (for 2019 on the left and 2020 in the center) encompass 86.33% of the total operations in the year 2019 and 86.37% of the air operations during 2020. The remaining (13.67% in 2019 and 13.63% in 2020) is distributed among operations of 170 different aircraft for 2019 and 131 aircraft in 2020.

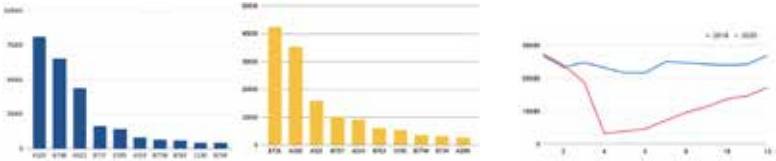

Figure 5 – The 10 Most Used Aircraft During the Years 2019 (on the Left, in Blue) and 2020 (in the Center, in Yellow), and Number of Operations per Month During the Two Years (on the Right)

The yellow columns represent the aircraft with the highest number of operations and highlight the most used aircraft models. Aircraft types B738, A320, A321, B737, A319, E195, B763, B77W, and B734 coincide in both analyzed periods.

Figure 5 also shows the comparison of movement between the periods (2019 and 2020), highlighting the exceptional reduction in the number of operations by 47% (representing 155,910 flights in 2019, approximately half the volume of flights compared to the previous year of 2018).

Based on the survey of aircraft models used in the analyzed periods (180 models from 2019 and 140 from 2020), compatibility of engines was verified to assess pollutant emissions. In some cases, the same aircraft model is compatible with more than one type of engine, such as the A320, which can use both the V2500-A5 and CFM56-5B models. The identification of the emission factor for each engine model is indicated in the AEED database, and in cases where the same aircraft is compatible with more than one engine model, the average emissions of all compatible models are calculated.

Based on emission factors, it is possible to identify the aircraft that stand out as the most polluting in terms of emissions per passenger. These specific models can be considered as priority targets when taking mitigating measures. Figure 6 provides a representation of the results related to the 30 most used aircraft, displaying their CO2 emissions during LTO cycles and comparing them with CO2 emissions per passenger.

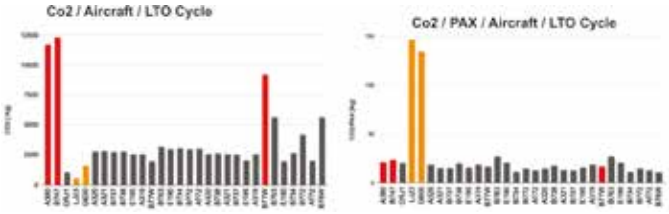

Figure 6 - Comparison of CO2 total emissions per Aircraft (on the left) and emissions per passenger (on the right)
Source: Authors

The graphs reveal that total emissions during LTO cycles are higher in aircraft with greater capacity, such as the A380, B747, and B777 (highlighted in red). However, when evaluating emissions per number of passengers, an inversion in the results is observed, demonstrating that flights operated by smaller aircraft, such as the LJ23 and G600 jets, highlighted in orange, may emit a higher quantity of pollutants per passenger when compared to larger aircraft. These data can be interpreted as relevant elements in the formulation of strategies to limit certain types of aircraft or in the implementation of a pollution tax per passenger, representing potential mitigation measures.

3.1. Mapping the Distribution of Airport Pollutants

This section presents thematic maps with the spatialization of pollutant emission points produced during LTO (landing, takeoff, and taxi) operations, allowing observation of locations with higher concentration on the airside of the airport.

The spatial representation of emissions should consider a probable time for pollutants to remain in the air, which restricts the analysis to data related to a short period. The data from operations carried out throughout the year (presented in the previous section) can illustrate the general profile of GRU Airport operations, but mapping the concentration of pollutant emissions will require greater precision in scenario evaluation. In this regard, this article presents the spatialization of emissions accumulated during

a 1-hour interval of operation resulting from real-time monitoring conducted on November 24, 2023, between 1 PM and 2 PM, using the Flight Radar tool.

During the analyzed period, 7 distinct aircraft were identified, which performed 14 takeoffs and 19 landings, totaling 33 operations (Figure 7, on the left). The ground routes of each aircraft were mapped, as well as the time between taxiing operations, engine-on waiting, takeoff, and landing. Figure 7 shows the routes taken for landings (in red) and takeoffs (in blue).

Figure 7 - Aircraft Identified in 1 Hour of Operation (Left), Landing Routes (Red in the Center), and Takeoff Routes (Blue on the Right)
Source: Authors

The Flight Radar tool combines data from various sources, including ADS-B, MLAT, and radar data, providing information about the identity and model of aircraft, position, routes, flight status, travel times, etc., allowing for more detailed tracking and characterization of linked operations.

Based on surveys, emission calculations of the aircraft that operated during this period were conducted using software (provided by the Air Pollutant Emission Guidebook) that provides emission factors per unit of time, identifying the following aspects:

- Average speeds used by each aircraft on takeoff, landing, and taxiing runways.
- Distances and times of each route for each aircraft.
- Emissions per time required to travel each route for each aircraft.
- Total emissions emitted by each aircraft when passing through each route (to obtain the total emissions of each route).
- Mapping of emissions by route in QGIS.

Figure 8 presents the results of the calculated emissions associated with the seven aircraft models that were in operation during the analyzed period, considering the segments and routes of the operations, as well as the engine powers in each phase of the LTO operations.

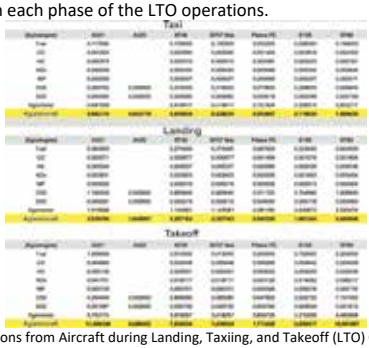

Figure 8 – Emissions from Aircraft during Landing, Taxiing, and Takeoff (LTO) Ground Activities
Source: Authors

Once the route information and corresponding emissions have been integrated into QGIS, it becomes possible to obtain a map of pollutant concentration potential for the defined scenario of 1 hour of operation. The Figure 9 (on the left) indicate the most critical routes in terms of total pollutant quantity,

with the takeoff runway being the most critical, emitting 4,722 kg of pollutants, followed by the main taxiway, emitting 1,837 kg.

Emission per route refers to the total amount of pollutants released by aircraft on that route. This data is useful for identifying routes that accumulate the most emissions in total. However, it does not necessarily mean that they are the locations with the worst air quality and highest concentration of harmful substances. To determine these, it is necessary to conduct an approach based on emissions per unit of distance and determine their dispersion (Figure 9, on the right).

Critical emission points per distance traveled are highlighted in yellow as locations that concentrate a higher amount of pollutants per kilometer, which coincide with the waiting points on the taxiways. Although these points do not stand out for total emissions in Figure 9, they represent areas of pollutant concentration.

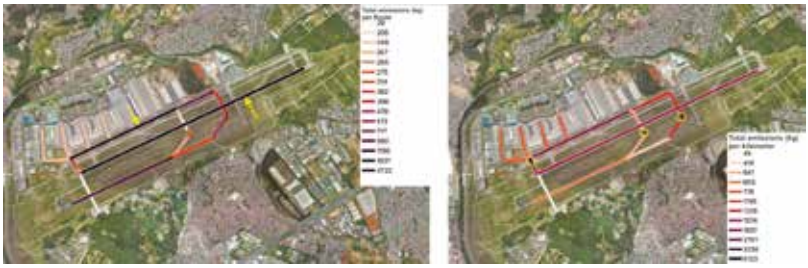

Figure 9 – Total emissions per route (on the left) and Total emissions per kilometer (on the right)
Source: Authors

Based on the results obtained, it is possible to conclude that during 1 hour of operation on November 24, 2023, at Guarulhos Airport, the following volumes of pollutants (CO2, SO2, NOx, PM, HC, and CO) were emitted:

- Taxiways accumulated a total of 7,618 kg of emissions.
- Emissions on the takeoff runway (runway 1) totaled 4,722 kg.
- Landing runways each summed up to 1,240 kg.

Therefore, measures aimed at reducing taxiing times will be directed at the main source of emissions on the airport ground.

4. Analysis of the Results

The analyses proposed in this article identified CO2 as the pollutant emitted to the greatest extent in all LTO (landing, takeoff, and taxi) stages, totaling between 98-99% of the total emissions.

For each analyzed operation, the following highlights are noted:

a) Takeoff stage is the most polluting in terms of emissions/s at Guarulhos Airport during the study hour. In this stage, engines operate at 100% of maximum thrust and have a duration of 0.7 minutes following ICAO standards.
b) Climb stage is the most polluting in terms of total emissions in the study scenario. Although engines operate at 85% of maximum thrust, being longer in time, 2.2 minutes, ends up accumulating a greater total amount of pollutants.
c) Taxiing stage is the most polluting among all ground operations at GRU Airport during the study hour, an unexpected result given that engines operate at only 7% of maximum thrust. This result is a consequence of the fact that the taxiing stage is the longest in the LTO cycle. This result

indicates that reducing taxiing times has great potential for a positive impact on emissions reduction on the ground.

d) Guarulhos Airport's takeoff runway has the potential to accumulate the highest amount of pollutants, although the climb stage is the most polluting in terms of total emissions. In the study scenario, it was determined that the sum of emissions on all taxiways is greater than the sum of emissions on the takeoff runway. This means that, for the study in question, pollutants released on the taxiways contribute more than emissions from the takeoff runway.

e) Although not the locations with the highest total emissions, waiting points on taxiways accumulate the highest amount of pollutants per unit of distance. Therefore, it is expected that these are points where air quality is worse.

Calculating aircraft emissions through emission factors proves to be an efficient way to quantify and size them. This method is very useful in locations that do not have on-site measurement equipment, as is the case with Guarulhos Airport.

Sulfur dioxide (SO2) emissions are linked to fuel consumption. The AEED methodology shows greater agreement with ANAC results, estimating 111 tons of SO2 annually, while methodology level 2 suggests a 40% reduction.

Particulate matter (PM) emissions are closely related to the aircraft model and type of engine used, with uncertainties also high due to lack of data in many models. Methodology level 2 and ANAC present similar estimates, ranging from 30 to 25 tons, respectively, while using the AEED method, it is estimated at 13 tons, differing by almost 50%.

For CO2, emission factors are well determined and depend on fuel consumption, with a small uncertainty of 5% between methodology 2 and AEED, estimated at 439 kilotons annually.

5. Conclusions

The classification of aircraft based on their emissions provides useful information for the development of future regulations to be applied to aircraft emitting the most harmful substances into the atmosphere. Investment in new aircraft, traffic control systems, and SAF (Sustainable Aviation Fuel), along with subsidies and government involvement, will enable the decarbonization of the airport.

To quantify the impact of the pandemic on total emissions, the greenhouse gas emissions (CO2, H2O) and major air pollutants (HC, CO, NOx, SO2) and suspended particles (MP) from LTO activities at Guarulhos Airport during 2019 and 2020 are estimated.

The COVID-19 pandemic represented an unprecedented phenomenon in the airport's history, exerting an exceptional impact on Guarulhos' air traffic. The most affected month was April 2020, during which operations experienced an 86% decrease, resulting in a 47% reduction in the total number of flights throughout 2020.

Total emissions during the pandemic followed the trend of operations, with greenhouse gases, CO2 and H2O, being the most emitted, both with a 46% reduction. Specifically, CO2 emissions decreased from 428 Kton in 2019 to 233 Kton in 2020. HC, CO, NOx, and SO2 emissions decreased by 40%, 44%, 46%, and 45%, respectively, during that year. Suspended particles (MP) are highly harmful when inhaled, and their emissions decreased by 53% in 2020, from 12.7 tons in 2019 to 5.9 tons in 2020.

The 2019 results are compared with emission estimates released by ANAC, along with the application of methodology level 2, aiming to quantify the inherent discrepancies in each method. It can be concluded that CO emissions are adequately estimated, differing by only 8%, totaling approximately 1350 tons of CO per year. However, NOx and HC emissions, using methodology 2 and the emission factors of AEED, are similar, but both differ from ANAC estimates by 25% and 30%, respectively. Both pollutants are dependent

on flight conditions and technology used; the lack of knowledge of these parameters in the present work contributes to uncertainties. Emissions of 1809 tons of NOx and 125 tons of HC are estimated.

The future of clean aviation is possible but requires the collaboration and coordination of all stakeholders in the aviation sector and major investors to enable projects. The advancements achieved in terms of emission reduction with new technologies are significant when comparing emissions from old fleet aircraft with current ones; however, they are not sufficient to achieve the goal of zero total emissions by 2050.

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The Evolution of Airport Sustainability Research: A Bibliometric Analysis

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Abstract/Resumo/Resumen

This study aims to review and analyze airport sustainability research using bibliometric analysis in order to investigate major trends, theme evolution, and significant findings that have influenced this area of study. Also, the study intends to understand prior research focus and offer potential research topics for the future. The study utilizes Python programming language for both data collection and data analysis. To achieve the purpose of the study, research papers on airport sustainability published in English, sourced from Scopus and Web of Science (WoS) databases were collected. The results of analysis helped to examine how the main topics and themes in this field have evolved. The authors with the highest publication rates, the most used keywords, and common research methods were also identified. Findings of the study include the identification of core themes within airport sustainability research. It was indicated that a prevailing focus on the environmental aspects of sustainability, while there are limited number of studies concentrating on the social and economic dimensions. It was also observed that there is a noticeable rise in the importance of these limited research areas. The study contributes to the existing literature by providing a detailed bibliometric overview of airport sustainability research. The study highlights research gaps and emerging trends to make recommendations for future studies. Moreover, by using advanced data analysis techniques with Python, it offers a novel methodological approach. The contributions of this study are not limited to theory, but provide a broad scope for airport sustainability for practitioners

The Evolution of Airport Sustainability Research: A Bibliometric Analysis

1. Introduction

Sustainability has become crucial in different industries, including aviation [1]. As an essential part of the air transportation system, airports are pivotal in addressing sustainability challenges and mitigating their operations' environmental, social, and economic impacts. With the industry's continuous growth, the imperative for sustainable airport practices has grown significantly and attracted researchers' and practitioners' attention [2].

Airport sustainability is having and implementing strategies and practices to reduce airport operations' environmental, social, and economic impacts [3]. To ensure airports' long-term viability and resilience, airport sustainability requires a comprehensive approach containing all areas like carbon emission, land use, air, noise, and water pollution, waste generation, economic growth, robust workforce, and community engagement related to these three dimensions. To address airport sustainability practically, these sub-categories necessitate individual attention and effort. Understanding each helps airports identify the specific areas within airport operations that require improvement and more attention. By recognizing the distinct dimensions of sustainability, airports identify opportunities for enhancement and can develop tailored solutions for each dimension [4].

Although previous studies have examined airport sustainability and its dimensions, there still needs to be a comprehensive understanding of airport sustainability. Therefore, this study aims to expand the existing body of literature by providing a bibliometric analysis of airport sustainability research. The study reveals research trends, thematic changes, and significant findings shaping this field.

The study makes significant contributions to both academia and practice. Firstly, by leveraging airport sustainability research, findings provide insights into the areas of focus, emerging themes, potential gaps that require further exploration, and future research avenues to be explored. Additionally, the study employs a novel methodological approach for data collection and analysis by preferring Python as the programming language, demonstrating the potential use of advanced computational techniques in such analyses. The study's contributions are not limited to theoretical contributions; it also provides potential sustainable solutions and practices regarding airports' environmental, social, and economic dimensions.

2. Background of the study

Sustainability, which is recently popular discussion topic, is to meeting the needs without depleting resources or compromising future viability [5]. Nowadays, companies have given more attention to sustainability, as well as there is increase in the number of academic publications. Different researchers have often examined the definition of the concept, the areas it affects, and sector-oriented reviews. However, 'sustainability' continues to be a concept open to many interpretations and context-specific understandings [6].

Airports, which are nodes in the transportation network, play a strategic role as the gateway for economic activities, the hub for the interconnection of modes of transportation, and the activity center aimed at meeting the demand for transportation improvement, achieving development equity, growth, economic stability, and national development harmony [7]. Therefore, ensuring long-term viability has become more important for maintaining their operational effectiveness and reducing the environmental and societal consequences of their extensive operations [2]. This can be achieved by clear understanding

of sustainability and exploring its vast implications. For this reason, thanks to increase in academic studies, practitioners have become more knowledgable on airport sustainability in recent years.

The three-pillar concept is one of the most commonly used frameworks in sustainability research, including economic, environmental, and social aspects of sustainability [4]. First, the environmental pillar represents reduce in the environmental impact of airport operations [8]. Since airports are critical sources of air, water, and noise pollution and waste production, it is important to implement sustainable practices to protect the ecosystem. Airports can decrease their harmful impact by having energy-efficient technologies and environmentally friendly infrastructure, using renewable energy sources, having waste management systems, and optimizing operational processes [2].

Secondly, the economic pillar represents sustainable economic growth and development over the long run by using available resources responsibly [8]. Airports have significant revenue streams that contribute to regional economic growth. They enable trade, tourism, and business activities and provide employment opportunities [9]. Therefore, sustainability efforts should take into consideration an economic dimension. Airports can contribute to financial sustainability by creating different income sources, reducing expenses, adopting technological advancements to their processes, and planning to use all their resources efficiently [10].

Lastly, the social pillar is related to people. Core value of this pillar is to create positive relationships with local communities, to have equitable labor practices, and to promote diversity and inclusion [8]. Airports can contribute to social sustainability by providing fair, equitable labor practices, giving opportunities for local employment and offering education programs, collaborating with non-governmental organizations, and giving importance to diversity and inclusion [1].

Taking everything into account, while all pillars are important, environmental aspects have typically been the primary focus, particularly in studies conducted within the airport context. Although recent studies have started to shift this focus, the research volume in this area still needs to grow. Therefore, this study aims to address this gap, assess the current state of research in the field, and propose potential avenues for future investigation.

3. **Methodology**

As a quantitative method, bibliographic analysis was preferred in this study to analyze bibliometric data, including authors, abstracts, keywords, etc. [11]. Bibliometric analysis has become essential for processing vast scientific outputs and providing significant insights [12]. Although other traditional methods, such as meta-analysis and systematic literature reviews, exist and are used for similar purposes, this analysis method was selected for this study for several compelling reasons. While meta-analysis helps to extract information from selected quantitative studies by potentially limiting the diversity of research examined, systematic literature reviews cover diverse studies and methods, enabling more profound analysis and understanding of contextual issues with a lack of a quantitative element in literature reviews [13]. On the other hand, bibliometric analysis, which is time-intensive, effective, and reliable for managing large datasets, provides robust visualization capabilities and enables the identification of research groups, emerging trends, and the scholarly framework of the field. By eliminating researcher subjectivity, this analysis offers enhanced analytical rigor and reliability of the findings [14].

As interest in bibliometric studies grows, the variety of tools used for analysis is also expanding, and Gephi, VOSviewer, CiteSpace, BibExcel, and Bibliometrix are just some of these [15]. In this study, the Python programming language and its associated packages like ‘metajknowledge' were chosen because of their ease of use and diverse output range.

To align with the study's objectives, 'airport sustainability' was selected as the keyword. All journal papers in the WoS and Scopus databases featuring this keyword in their titles, abstracts, or keywords

were compiled. These two databases were selected for their comprehensive coverage and the quality and credibility of their content [16]. At this stage, 1254 publications from 1995 to 2023 were accessed at the end of December 2023. After exclusion and inclusion criteria were implemented, 691 studies were identified as the primary focus of this study. The most critical criterion involved sorting publications that appear in both databases. Also, the study included only journal papers written in English.

4. **Results and Discussion**

All studies in English published between 1995 and 2023 were considered for this study to reach aim of the study. There has been a continuous increase in several publications, which has been remarkable in the last few years. These studies were published in 78 different international journals. Most studies published in the Sustainability journal are followed by the Journal of Air Transport Management, Journal of Airport Management, Journal of Cleaner Production, and Transportation Research Record, respectively, and their contribution to the literature. Although 22 journals were preferred multiple times, 57 journals have each published only a single study, indicating a diverse range of publications.

Table 1 presents the top 10 journals with the highest number of publications.

Table 1-Top 10 Journals with the highest number of publications
Source: Authors

Journal Name	Total
Sustainability	61
Journal of Air Transport Management	24
Journal of Airport Management	21
Journal of Cleaner Production	14
Transportation Research Record	13
Sustainable Development	7
Sustainable Cities and Society	7
International Journal of Sustainable Aviation	7
Journal of Transport Geography	5
Transport Policy	6

There is diversity among authors in this field, with some contributing more publications than others. The top 10 most published authors are presented in Figure 1.

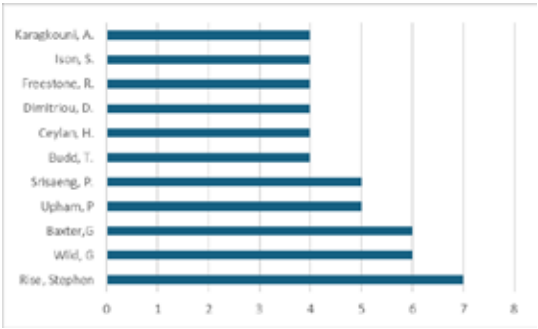

Figure 1 – Authors vs Number of publications
Source: Authors

Data collection and analysis were also examined, and it was observed that traditional approaches continue dominating the field. Surveys are the most commonly utilized data collection method in airport sustainability research. However, various research methodologies have been reviewed, and it shows that case study analysis, data envelope analysis (DEA), and reviews, including bibliometric or systematic

and structural equation modeling (SEM), are among the preferred techniques for comprehensive analysis. For instance, case study analysis was selected to investigate the sustainable operations of airports within the United States [17] and Italy [10]. As another example, data envelopment analysis (dea) was conducted to assess airport performance [18] and to provide a comparative analysis between airports [19]. It's essential to note that as the significance of this topic grows, the approaches to understanding it also evolve and diversify. An example of this evolution is the diversification in analysis techniques observed in recent years. While traditional analyses like reviews and related analyses remain predominant [11], [13], more sophisticated methods have started to emerge in contemporary research, as demonstrated in this study. For instance, review studies increasingly leverage advanced tools like R (programming language) for more detailed and efficient analysis, moving away from traditional manual research methods [20].

When the citation trends over various years are reviewed, they are shared in Figure 2. The analysis revealed a prominent peak in 2019, which showed a significant surge in scholarly engagement and the publication of highly influential research during that year. Other peak observed in 2003 similarly suggests periods of heightened academic interest or the introduction of new research topics. Moreover, there is a decline in 2020, and the reason behind this can be possible shifts in research focus, delays in publication processes, or external influences such as global events that may have impacted research productivity and citation practices.

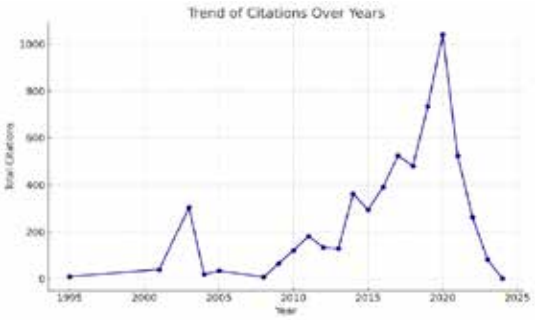

Figure 2 – Total Citations vs. Year
Source: Authors

Several of the United Nations' Sustainable Development Goals (SDGs) are connected to topics in the studies. The most associations with these goals are respectively Sustainable Cities And Communities (SDG 11), Climate Action (SDG 13), Industry Innovation and Infrastructure (SDG 09), Responsible Consumption and Production (SDG 12), and Life on Land (SDG 15). This indicates a specific commitment to creating sustainable cities, reducing the effects of climate change, building resilient, creative infrastructure, and responsible use of natural resources, specifically land ecosystems [1],[21]. This shows that most of the attention was paid to the environmental aspects of sustainability.

Furthermore, after examining the keywords of all studies, it was observed that consistent themes were emerging, with the terms 'airport,' 'sustainability,' 'transportation,' 'analysis,' and 'management' frequently appearing. Each author selects these keywords. However, to find critical concepts in airport sustainability research, a word cloud was created from the top terms across all studies and abstracts included in the analysis. Word cloud is a graphical representation of word occurrences in textual content [22]. The creation process of the word cloud involved standardizing data through tokenization, conversion to lowercase, and removing stopwords [15]. After preprocessing was completed, the word cloud in Figure 3 was prepared.

Figure 3 – Word Cloud
Source: Authors

The word cloud indicates the key concepts that emerge from the analysis, with "Sustainable Development," "Management," and "Environmental" prominently featured, highlighting the multifaceted nature of sustainability. A comprehensive plan that fosters a commitment to sustainability and appropriate resource management across the airport's functional domains can be attained by harmonizing these interconnected parts. Additionally, it's evident that while environmental factors are heavily emphasized, there's a dynamic interplay with social and economic elements.

Reviewing all the studies provides insights into potential future trends in airport sustainability, including shifts in focus areas and the growing prevalence of specific terms. To begin with, as the focus shifts away from studies solely centered on environmental sustainability, there is an increasing emphasis on exploring economic and social sustainability [2]. Recent research increasingly highlights the significance of all these fundamental pillars. For example, there is an increasing trend in research focusing on diversity, equity, and inclusion practices at airports, which addresses the social aspects of sustainability [23]. Also, studies focus more on the financial performances of airports [10]. On the other hand, topics like community engagement stakeholders relationships, assessment of social sustainability and interaction between pillars are needed to be explore in more detail.

Another finding of this research is that the growth in these studies can be attributed to the influence of the United Nations' Sustainable Development Goals (SDGs) and initiatives by authorities like ICAO. Firstly, it is clear that the connections to specific Sustainable Development Goals (SDGs) in the journals once the publications are shared. Additionally, within the text, authors frequently relate their findings to these goals [2], [24]. Also, authorities' policies encourage sustainability practices and research [25]. These demonstrate that such goals and policies promote sustainability efforts - at least, they create awareness. Consequently, common goals, standards, and regulations are critical in identifying the research area and encouraging a more robust dedication to sustainability practices within the airport industry.

5. **Conclusion**

This study aims to contribute to the current airport sustainability literature by conducting a bibliometric analysis. For this purpose, the study implements an innovative methodological approach by utilizing Python for data collection and analysis, which sets an example of the application of advanced

computational methods in this study. All journal articles indexed in English on WOS and Scopus from 1995 to 2023 were included for analysis.

The study indicates trends in journal selection and prominent authors in airport sustainability highlight dynamics and critical contributions within the academic community. Awareness of these trends and recognizing influential researchers and their work can offer potential direction for future studies. In addition, it reveals thematic shifts and critical terms that are effective in the field, offering a more comprehensive view of airport sustainability. Overall, a key observation is the increasing diversification of research in the field over the years regarding the variety of journals, authors, keywords, and main topics explored. Lastly, understanding the studies conducted in the context of airport sustainability and identifying the critical focus terms and concepts will offer valuable guidance for airports.

The study has certain limitations. First, inclusion and exclusion criteria can be included among them. Necessary studies published in other languages or databases may be missed if the literature evaluation is limited to English-language publications indexed in WOS and Scopus. Second, from an analytical perspective, it relies on bibliographic analysis to identify trends and patterns in specific topics. This must be revised to reflect the depth of understanding accurately and might restrict how broadly the findings can be used. Several techniques, such as topic modeling, can be utilized for discovering themes and patterns. These constraints allow new avenues for future research by suggesting an investigation and more inclusive study designs that examine the concepts using various data sources, languages, and methodological techniques. Furthermore, future research must consider sustainability as whole including every aspects of it. There are some topics that still require detailed explanation, which will serve as valuable resources for practitioners.

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Proposal of Means of Compliance for Flight Termination System - Medium Risk

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Abstract/Resumo/Resumen

The purpose of this research is to contribute to the evolution of legislation for unmanned aerial vehicles, by proposing Means of Compliance (MoC) for Flight Termination System up to SAIL IV operations.The research begins with a literature review of UAS legislation, with a particular focus on documentation and industry standards essential for developing the proposed MoC with Light-UAS.2511 requirement for SAIL IV operations. The development of the proposed MoC integrates insights from the existing MoC for operations up to SAIL II, already issued by EASA, but adapted to address operations with a higher level of risk.Findings suggest that MoC for SAIL II operations can be useful for demonstrating compliance with Light-UAS.2511 up to SAIL IV operations. However, the main difference lies in the necessity of conducting compliance demonstration activities, supported by evidence through safety assessments and design and installation appraisals. The number of tests needed to demonstrate the FTS performance increases, due to the increase of operation risk level to SAIL IV.Regarding the contribution of this paper, it is mainly the development of proposed means of compliance, offering a pathway for demonstrating compliance with the requirement Light-UAS.2511 for Containment up to SAIL IV operations. It allows the UAS operator to demonstrate that systems comply with industry standards, adhering to safe and sustainable practices.

Proposal of Means of Compliance for Flight Termination System – Medium Risk

1. Introduction

Unmanned Aircraft Vehicles (UAVs), also known as drones, are aerial vehicles designed to operate remotely without an onboard human pilot. UAVs can be controlled remotely by a human operator or can be programmed to fly autonomously. UAVs are used in a range of applications, including aerial photography and videography, surveying and mapping, agriculture and forestry, infrastructure inspection and maintenance, search and rescue operations, disaster management and humanitarian aid, military and security operations, and environmental monitoring [1].

However, the use of UAVs has also raised concerns about privacy, safety, and security. Consequently, the European Union Aviation Safety Agency (EASA) has implemented regulations and guidelines for Unmanned Aircraft Systems (UAS) operation and usage among its Member States in the European Union (EU). To successfully operate UAV services, it is essential to comply with all the regulations established by EASA. One of the requirements set forth by EASA is the implementation of efficient safety and emergency systems. Among these systems, the Flight Termination System (FTS) emerges as a pivotal component in preventing accidents and mitigating risks.

A FTS is a safety mechanism installed on UAVs designed to terminate flight operations in case of emergencies and ensure containment of the aircraft. The FTS provides means for ground operators to quickly and safely stop a UAV flight in the event of an uncontrollable or unsafe situation, such as loss of control or navigation, system malfunction, or unauthorised flight that leads to operation outside the operational volume [2].

According to the Specific Operations Risk Assessment (SORA) methodology developed by the Agency, which evaluates the risks and determines the acceptability of a proposed operation [3], the operations can be defined with a Specific Assurance and Integrity Level (SAIL). The SAIL level represents the level of confidence that the UAS operation will remain under control [3].

Given that Means of Compliance (MoC) with containment for operations up to SAIL II are already issued by EASA, there is a pressing need to develop and propose means of compliance with containment for SAIL IV operations, which represent medium-risk scenarios.

2. Literature Review

2.1. UAS Regulations

Since the UAS have rapidly become popular in many applications, ensuring the safe operation of UAS is paramount to mitigate potential risks associated with this technology. The importance of UAS regulations is demonstrated by their function in preserving public safety and minimising potential harm. While allowing for the continuous advancement and application of UAS technology, these laws seek to establish standards and limitations that promote responsible UAS operation.

2.1.1. Global UAS Regulations

When dealing with UAS regulations at a global scale, the International Civil Aviation Organisation (ICAO) takes center stage as the specialized agency of the United Nations. To ensure uniformity and safety across nations, ICAO is responsible for establishing global rules and guidelines for UAS operations.

Another crucial organisation in global regulations is the Joint Authorities for Rulemaking on Unmanned Systems (JARUS). One of the most important and influential documents published by JARUS is the Certification Specifications for Unmanned Aircraft Systems (CS-UAS) issued in 2019. This document provides recommendations for Member States to use in developing their own national legislation concerning certification specifications for UAS [4].

2.1.2. EU UAS Regulations

Concerning European Union regulations, the EASA plays a leading role in developing and implementing rules. Established in 2002, EASA has become a dynamic and central organisation dedicated to aviation safety and environmental protection in Europe [5].

EASA has published two specific regulations for UAS: Commission Delegated Regulation (EU) 2019/945 of 12 March 2019 and Commission Implementing Regulation (EU) 2019/947 of 24 May 2019. The first regulation focuses on UAS and third-country operators of UAS [6], while the second regulation addresses the rules and procedures for the operation of unmanned aircraft [7]. To provide further guidance, EASA has also developed Acceptable Means of Compliance (AMC) and Guidance Material (GM) for the Regulation (EU) 2019/947.

2.2. UAS Operations in the Specific Category

All EU Member States are governed by Regulation (EU) 2019/947. That document establishes three categories of operations: open, specific, and certified.

The specific category of UAS operations applies to drone operations that exceed the operational limitations set for the open category. Examples of UAS operations within the specific category include [8]:

- Operating a UAS in Beyond Visual Line of Sight (BVLOS);
- Operating drones with Maximum Take-Off Mass (MTOM) greater than 25 kg;
- Flying at altitudes exceeding 120 meters above ground level;
- Using a drone to release or drop material during flight;
- Operating drones in urban environments with an MTOM greater than 4kg or without a class identification label.

To operate in specific category of operations the UAS operator needs to obtain an operational authorisation from the competent authority. To obtain an operational authorisation, operators must apply to the competent authority by conducting a risk assessment and proposing adequate mitigating measures [9]. This risk assessment is known as SORA methodology.

2.3. Specific Operations Risk Assessment (SORA)

SORA, published by EASA as an AMC to Article 11 to Regulation (EU) 2019/947 [3], serves as both a methodology and guidance for UAS risk analysis and assessment to ensure an equivalent level of safety as in manned aviation.

The SORA methodology follows a systematic approach to analyse the proposed Concept of Operations (ConOps) and establish a sufficient level of confidence in the operation's ability to be conducted with an acceptable level of risk. SORA is supported by ten steps, as illustrated in Figure 1. This methodology comprehensively addresses the risks associated with both ground and air components of UAS operations and provides applicable mitigations to reduce these risks. It defines OSOs that must be achieved with a designated level of robustness based on specific levels of risk for both ground and air. The outcome of the SORA process is the determination that the proposed ConOps can be executed with an acceptable level of risk [3].

From this risk analysis results the SAIL level. The SAIL is an index ranging from one to six that indicates the level of assurance and integrity of the mitigation measures to be implemented, representing their robustness. A low SAIL value corresponds to operations with low risk, indicating a lower level of robustness required for the mitigation measures. Conversely, a higher SAIL value indicates a higher level of robustness needed, as the associated operation carries a higher level of risk [10].

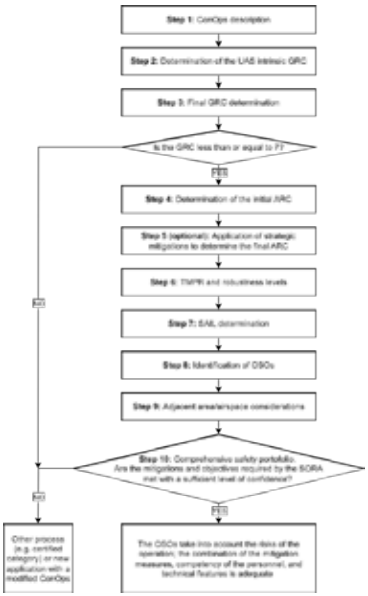

Figure 1 – The SORA process
Source: [3]

2.4. Relevant Documents issued by EASA

2.4.1. Special Conditions for Light-UAS Medium Risk

Special Conditions (SC) provide general requirements that serve as a basis for more specific standardization efforts incorporating quantitative requirements, parameters, and testing methods. From this document, the requirements for containment (Light-UAS.2511) are [11]:

a) No probable failure of the UAS or any external system supporting the operation must lead to operation outside the operational volume.
b) When the risk associated with the adjacent areas on ground or adjacent airspace is significantly higher than the risk associated with the operational volume including the ground buffer:
    1. the probability of leaving the operational volume must be demonstrated to be acceptable with respect to the risk posed by a loss of containment;
    2. no single failure of the UAS or of any external system supporting the operation must lead to its operation outside the ground risk buffer; and
    3. software and airborne electronic hardware whose development error(s) could directly lead to operations outside the ground risk buffer must be developed to a standard or methodology accepted by the Agency.

2.4.2. Means of Compliance with Light-UAS.2511

The means of compliance with Light-UAS.2511 Containment, issued by EASA in May 2022, is a significant document that pertains to operations up to SAIL II. It serves as a formal declaration to the relevant regulatory authority responsible for granting operational authorisation. This document primarily focuses on containment, specifically addressing the FTS within UAS. It offers a streamlined approach for UAS operators to demonstrate FTS performance compliance through a simplified design checklist and a series of tests [2].

It is important to notice that this MoC does not address the design of the specific UAS concerning their probability of leaving the operational volume. However, it provides a logic according to which a maximum probability can be determined based on SAIL. This MoC's foundation on a specific FTS design facilitates a straightforward calculation of the maximum probability of leaving the ground buffer [2].

3. Proposal of Means of Compliance with Light-UAS.2511

3.1. Scope and General Approach

To demonstrate compliance with the specified requirements for the FTS, it will be essential to calculate the probability of failure per flight hour of the installed FTS ($P_{FTS(fails)}$) by considering both the probability per flight hour of the UAS exiting the operational volume ($P_{UAexitOV}$) and the probability per flight hour that the UAS may leave the ground risk buffer and exit in adjacent areas/volumes ($P_{UAexitGB}$). Based on the existing MoC for containment up to SAIL II operations, the general equation that correlates the probability that the UAS would exit the ground risk buffer and enter adjacent areas is [2]:

$$P_{UAexitGB} = P_{UAexitOV} \times P_{FTS(fails)}$$

By restructuring the previous equation concerning the probability of failure per flight hour of the installed FTS, then:

$$P_{FTS(fails)} = \frac{P_{UAexitGB}}{P_{UAexitOV}}$$

3.1.1. Probability of the UAS leaving the operational volume per flight hour

The probability of the UAS leaving the operational volume is calculated by the probability of loss of control. In the context of SORA 2.5, a collaborative initiative among aviation experts has culminated in the establishment of a relationship between the SAIL objective levels of robustness and the expected maximum probability of loss of control. Subsequently, the probability of loss of control per flight hour is determined by the SAIL of the operation. Table 1 is a representation of the correlation between SAIL and the maximum expected rate (λ_{LOC}) of a loss of control event [12].

Table 1-Mapping between SAIL and maximum acceptable Operation Failure Rate
Source: [12]

SAIL Level	1	2	3	4	5	6
Probability of loss of control per FH	10^{-1}	10^{-2}	10^{-3}	10^{-4}	10^{-5}	10^{-6}

For SAIL IV operations, the aircraft must meet a probability of loss of control lower than 10^{-4}/FH.

However, it is considered that a loss of control may result in either a crash within the operational volume or an attempt to exit the operational volume. Without specific analysis of the UAS design, it can be assumed that the probability of a loss of control leading to an exit from the operational volume is at least 10 times smaller than the probability of it resulting in a crash within the operational volume [2]. Therefore for a SAIL IV operation, $P_{UAexitOV} < 10^{-5}$/FH.

3.1.2. Probability of the UAS exit the ground risk buffer and enter adjacent areas per flight hour

To quantitatively assess the safety of unmanned operations, it is necessary to establish an acceptable level of safety. Following SORA 2.5, this is expressed as a Target Level of Safety (TLOS) [12].

$$\mathrm{TLOS} = \lambda_{\mathrm{LOC}} \times \mathrm{N}_{\mathrm{fatality}}$$

Where TLOS is measured in expected third party ground fatalities per flight hour; λ_{LOC} is the loss of control rate of the operation, and $N_{fatality}$ is the total number of fatalities resulting in the event of a loss of control [12].

In accordance with the requirements identified for containment, if the risk associated with the adjacent areas on the ground or adjacent airspace is significantly higher than the risk associated with the operational volume including the ground buffer, then the probability of leaving the operational volume must be demonstrated to be acceptable with respect to the risk posed by a loss of control [11].

To satisfy this requirement, the risk associated with adjacent ground areas or adjacent airspace must be equal to or lower than the risk linked to the operational volume. Only under these conditions is it considered that the risk of the UAS exiting the operational volume is acceptable.

The TLOS is the safety target for the operation and must be met in normal operation conditions and in cases of fly away in the adjacent area. Then, can be deduced that the TLOS in adjacent areas ($TLOS_{AA}$) should be less than the TLOS in operational volume ($TLOS_{OV}$). This consistency ensures that the UAS leaving the operational volume is deemed acceptable.

The TLOS in operational volume is:

$$TLOS_{OV} = \lambda_{\mathrm{LOC}} \times \mathrm{N}_{\mathrm{fatality|OV}}$$

Regarding adjacent areas, a loss of control event in adjacent areas corresponds to an instance where the operation exits the ground risk buffer, as the aircraft would otherwise remain within it. Therefore, it is assumed that the loss of control rate for the operation can be substituted with the probability of the UAS leaving the ground buffer and entering adjacent areas.

$$TLOS_{AA} = \mathrm{P}_{\mathrm{UAexitGB}} \times \mathrm{N}_{\mathrm{fatality|AA}}$$

It can be deduced:

$$P_{UAexitGB} \times N_{fatality|AA} < \lambda_{\mathrm{LOC}} \times \mathrm{N}_{\mathrm{fatality|OV}}$$

Rearranging the previous equation concerning the parameter sought:

$$P_{UAexitGB} < \lambda_{\mathrm{LOC}} \times \frac{\mathrm{N}_{\mathrm{fatality|OV}}}{N_{fatality|AA}}$$

The correlation between the number of fatalities in the operational volume and adjacent areas is directly affected by population density. As the population density in the operational volume rises, the expected number of fatalities within the operational volume also increases, driven by a higher number of individuals exposed to the associated risk. It is assumed that the system is designed to ensure safety in operations where the population density in adjacent areas is up to three orders of magnitude higher than the operational volume, the ratio of population density between the operational volume and adjacent areas is less than 10^{-3}. Then, substituting the values in the previous equation, results:

$$\mathrm{P}_{\mathrm{UAexitGB}} =< 10^{-4} \times < 10^{-3} =< 10^{-7}/\mathrm{FH}$$

3.1.3. Probability of failure of the installed FTS per flight hour

The value of the maximum acceptable probability of failure per flight hour of the installed FTS is:

$$\mathrm{P}_{\mathrm{FTS(fails)}} = \frac{< 10^{-7}}{< 10^{-5}} =< 10^{-2}/\mathrm{FH}$$

In conclusion, the scope of the present MoC is intended for FTS systems installed in aircraft with the capability to operate at SAIL IV, with a population density in the adjacent area up to 1000 times greater that the operational volume, and also encompasses systems with a probability of failure below 1 per 100 flight hours.

3.2. Design Checklist General Requirements

Since that the probability of the installed FTS remains constant for SAIL II and SAIL IV operations, $P_{FTS(fails)}<10^{-2}$/FH, then the MoC with Light-UAS.2511 Containment up to SAIL II [2] can be used to give insights on the necessary design checklist.

The FTS should be segregated from the UAS flight control system architecture. This separation must be easily verifiable and align with Sections 3.2.1, 3.2.2, and 3.2.3. The activation of the FTS can be achieved manually or automatically. In instances of manual activation, the system comprises ground and air segments [2].

A design checklist document must include, at least [2] [13]:

- A high-level description of the FTS architecture, including functions, systems, and implementation;
- Details concerning the installation of the FTS on the UAS;
- An understanding of the physical and mechanism operation of the FTS;
- An assessment addressing the segregation of the air segment and ground segments, frequency considerations, and frequency diversity. Each aspect of this assessment should be supported by concrete evidence of compliance;
- Compliance evidence activities as per Section 3.3: perform and document safety assessment containing a description of functional and operational principles of the UAS and its architecture, perform an Functional Hazard Assessment (FHA), and perform a design and installation appraisal;
- Additional evidences as needed for substantiating compliance with the TMPRs.

3.2.1. Segregation of the air segment

The air segment of the FTS, encompassing the FTS elements installed onboard the UAS, must be segregated from the UAS flight control system architecture and from any other element within the UAS architecture whose failure could potentially result in a loss of control unless such failures are limited to causing a crash within the operational volume or the ground risk buffer [2].

In the event of ground activation of the FTS, the onboard receiver responsible for receiving the FTS signal must operate independently of the receiver employed for command and control functions [2].

In cases where the FTS is automatically activated, the triggering mechanism for its activation should be distinct from systems used for the UAS operation control within the operational volume. For instance, positioning information employed to initiate the FTS activation should originate from systems that are different (not necessarily implying distinct technology) compared to those used during the typical operation of the UAS [2].

3.2.2. Segregation of the ground segment (where applicable)

The unit or units employed to initiate the FTS activation must be segregated from the Command Unit (CU) responsible for UAS control during normal operations. This segregation should be designed, so that, even in the case of a loss or erroneous CU operation, the proper functioning of the FTS remains unaffected [2].

3.2.3. Frequency and frequency diversity

When using radio frequencies to initiate a flight termination, it is imperative to ensure that the frequency band used by the FTS is distinct from the frequency band used for UAS control. If cellular technology is used for both Command and Control (C2) and FTS functions, thus is recommended to use different service providers [2].

In situations where the designated operational volume includes high-power radio frequency emitters, the frequencies used by the FTS should not overlap or be superimposed with these existing frequencies [2]. This preventive measure is essential to prevent interference and maintain the integrity of the flight termination process.

3.3. Compliance Evidence

As stated before, it is now necessary to perform compliance demonstration activities with adequate confirmation of the compliance [13], to complement the design checklist. These activities allow the applicant to demonstrate compliance with the claimed high level of assurance. This fact underscores the primary rationale behind the restriction of the MoC Light.2511 issued by EASA, designed to demonstrate containment compliance exclusively up to SAIL II operations.

To adhere to the indications in Annex E of SORA 2.5, it is essential to consider the means of compliance with Light-UAS.2510 Equipment, Systems, and Installation for SAIL IV operations. Given that MoC Light-UAS.2510 is used to verify that the system does not activate when is not desired (ensuring the system does not activate erroneously), it can be understood as a guarantee that the system functions correctly, aligning with the intended purpose. Therefore, the process outlined in MoC Light-UAS.2510 can be followed to demonstrate compliance that the system operates as the applicant intends.

Then, the realization of the processes outlined in MoC with Light-UAS.2510 (conducted to prove the system's compliance) and their respective results serve as evidence of the system's compliance. This evidence will be also used to demonstrate compliance with the Light-UAS.2511 requirement, alongside the results of the test campaign.

To confirm compliance with Light-UAS.2510, the applicant is required to undertake a set of compliance demonstration activities with adequate confirmation of the compliance to the competent authority [13]:

1. Perform and document a safety assessment as per ED-280 containing:
    a. Detailed description of functional and operational principles of the UAS and its architecture;
    b. UAS level FHA;
    c. Failure Modes and Effects Analysis (FMEA) analysis;
2. Perform a Design and Installation Appraisal as outlined in ASTM F3309-21;
3. Provide additional evidence as necessary to support compliance with the TMPRs.

3.4. Test Campaign

The tests outlined in this section are already presented in the existing MoC Light-UAS.2511 up to SAIL II operations, as the maximum acceptable probability of failure of the FTS installed in the UAS identified before remains consistent for SAIL II and SAIL IV operations. However, it is suggested to add a new test, named the Power Cut-Off Test.

The test campaign consists of [2]:

1. Bench tests on FTS;
2. Ground integration tests after installation of the FTS on the UAS;
3. Flight tests;

4. End-to-end activation tests;
5. Power Cut-Off Test.

Guidance on bench tests, ground integration tests, flight tests, and end-to-end tests can be found in the existing MoC Light-UAS.2511 up to SAIL II operations.

Regarding the new test, the Power Cut-Off Test aims to simulate a load similar to the UAS power load, with high voltage and current. The objective is to evaluate the system's capability of withstanding and cutting off real power loads. The test approach involves connecting the battery to the FTS system, applying a load (that can simulate the real load), and leaving the system running for 30 minutes (approx. the time of flight). After this period, send a trigger and check if the load shuts down. This test simulates a real flight scenario and assesses the system's ability to execute a power cut-off. A minimum of 100 activation tests is mandated. Successful Power Cut-Off tests are complete when the entire set of tests is consecutively passed.

A minimum of 100 activation tests is mandated for bench tests, ground integration tests after installation of the FTS on the UAS, flight tests, and power cut-off tests. This value is determined using the statistical rule of three. EASA already uses this rule in the proposed version of SORA 2.5.

Regarding end-to-end tests, the number of activations should be equal to the number of expected activations of the FTS for its entire life [2].

3.5. Flight Manual, Maintenance Instructions, and Prescriptions for Ground Risk Buffer Definition

The proposed MoC includes additional sections: Flight Manual, Maintenance Instructions, and Prescriptions for Ground Risk Buffer Definition. However, these sections are the same as those outlined in the existing MoC for operations up to SAIL II, as their content does not depend on the SAIL of the operation.

Thus, for the completion of these three sections, the MoC already issued by EASA up to SAIL II operations should be consulted.

4. Conclusions

In conclusion, the proposed MoC for demonstrating containment compliance in operations up to SAIL IV has been successfully acquired. Nonetheless, it is insightful to underscore the main distinctions between the existing MoC applied to operations up to SAIL II and the new MoC suggested for operations up to SAIL IV.

A notable disparity between the mentioned MoCs pertains to the probability of the UAS leaving the operational volume and to the probability of exiting the ground risk buffer to enter adjacent areas per flight hour. In the existing MoC for operations up to SAIL II, the probability of the UAS leaving the operational volume per flight hour stands at 10^{-3}, while the proposed MoC lowers this probability to 10^{-5}. Regarding the probability of the UAS exiting the ground risk buffer and entering adjacent areas per flight hour, it is 10^{-5} in the MoC for operations up to SAIL II and 10^{-7} in the proposed MoC for operations up to SAIL IV.

Although the probability of failure of the installed FTS per flight hour remains consistent for SAIL II and SAIL IV operations, the number of activations differs due to the increase in the level of assurance.

An additional noteworthy modification in the new proposed MoC for SAIL IV operations is the introduction of a new test, termed the Power Cut-Off Test. This test is designed to augment the set of tests previously accepted by the agency in the existing MoC for operations up to SAIL II.

However, the primary distinction and contribution of the proposed MoC lies in the inclusion of the compliance demonstration activities. Consequently, a safety assessment becomes necessary to showcase the high level of assurance for SAIL IV operations. In contrast to operations up to SAIL II, where the level of assurance is low, it is now imperative for cases with higher assurance levels to demonstrate compliance with this declarative level.

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NLP techniques for event-based identification for Air Traffic Control workload

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Abstract/Resumo/Resumen

The aim of this work is to analyse the feasibility of automate the classification of Air Traffic Controllers (ATCOs) communications into Air Traffic Control (ATC) events as input for calculation of ATC workload based on Natural Language Processing (NLP) techniques. NLP is a branch of Artificial Intelligence that extracts information from oral or written sources. The approach focusses on the identification of events from the ATC's oral transcript and determines whether it is feasible to use ATC communications as a data source for ATC workload models. This is a two-step approach: 1) Automatic Speech Recognition (ASR) models automatically transcript oral communications and 2) NLP techniques focussing on classification techniques allow to identify ATC events. The methodology was applied in a Spanish airport tower focusing on local air traffic controller role. The results shows that Word Error Rate is around 66% although Event Error Rate decreases up to 30%. The main restriction of this study was the limited number of events available.ENAIRE (Spanish Air Navigation Service Provider) has developed the SCOPE model to quantify ATC workload from the analysis of controller actions, triggered by situations or events that require the controller's intervention. However, this correlation between communications and associated ATC events is performed manually by engineers who perform an analysis of ATC communications based on continuous oral listening. The main contribution of this research is to automate this process without need of human intervention.

NLP techniques for event-based identification for Air Traffic Control workload

1. Introduction

The current and expected constant growth in air traffic forces the seams of the current Air Traffic Management (ATM) system. One of the main bottlenecks for demand is capacity, that is, the maximum number of aircrafts that can be handled by Air Traffic Control (ATC). Hitherto, capacity is determined based on ATC workload. The process to calculate the ATC workload due to air traffic management is highly based on the methodology developed by Air Navigation Service Providers (ANSPs). Eurocontrol developed the Capacity Analysis (CAPAN) methodology which takes into account the controller task list and the controller working method simulation capabilities [1]. ENAIRE, as Spanish ANSP, has developed, validated and implemented the SCOPE model to determine the ATC workload [2] [3] for different dependencies on the route, TMA, and TWR. The SCOPE model is based on the analysis of controller actions, triggered by events that require the controller's response.

The main limitation for ATC workload measurement is that it has to be done manually during simulated or real exercises. The identification of events or tasks is carried out based on ATC communications and radar analysis. However, the correlation between communications and associated tasks or events is established manually by engineers who perform an analysis of ATC communications through continuous oral listening. Typically, an hour of ATC transcription requires eight to ten hours of human work [4] [5]. Consequently, event identification, which involves attentive listening, speech comprehension, and annotation of the corresponding events, exceeds the duration of actual ATC communications by relying heavily on manual labour.

Natural Language Processing (NLP) is a branch of Artificial Intelligence (AI) that enables computers to understand, interpret, and generate human language [5]. Work in this field can be conducted to develop Machine Learning (ML) models that can extract information from oral or written sources. Automatic Speech Recognition (ASR) models employ neural networks to perform the same process that a human brain performs to identify which words have been spoken [17]. The use of ASR models in the aeronautical domain has evolved since it was first introduced in ATC training in the late 1980s [6]. Nowadays ASR models have developed further away from their use to enhance simulation infrastructure. ASR models have been applied in different areas such as to detect incursions on closed runways [7], Air Traffic Control Operator (ATCO) workload assessment [8], flight callsign identification [9] and pilot read-back errors [9].

To increase the capacity of airspace, one of the research areas is focused on reducing the workload of ATC based on automatization of tasks. The aim is to automate tasks currently handled by the ATCO, with the goal of reducing the number of tasks or their complexity, so that the extra available time can be used to increase the number of aircraft managed. This task automation reduces the workload of ATC by providing tools that can think or act alongside them. In the last decade, the development of ASR models has been geared towards using the transcription of pilot-controller voice communications to extract valuable information and update the system without the controller having to be responsible for manually updating and entering data. One solution that has been a major focus of research is the use of a speech recognition system embedded in a controller assistance system, known as Assistant-Based Speech Recognition (ABSR). [10] [11] developed models for the active listening assistant and AcListant Strips. The MALORCA project builds a machine learning tool for controller assistance based on ASR models. Similar to MALORCA HAAWAII [4], build AI-based automated ATC workstations to integrate ATC communications. [13] applies ASR models to evaluate safety in ATC communications.

Hence, the implementation of Speech-to-Text in the aeronautical domain has proved that it has the capability to improve the ATC environment by reducing the ATCO workload and further developing the automatization of ATC communications. To achieve a suitable speech recogniser for the ATC domain, specific domain datasets are used to train the model. The results in [10] [4] confirm this assertion and

support the need to build a public database. The main problem is that this process is time consuming and requires a lot of resources, so there are few public ATC datasets, such as ATCOSIM [15]. Moreover, main projects focus on en-route environments and few data or applications focus on TWR dependencies.

Therefore, the goal of this work is to analyse the feasibility of automated ATC-event identification based on NLP techniques applied to TWR dependency. The approach focusses on the identification of events from the ATC's oral transcript and leverages the accuracy rate of ATC communications as a data source for further ATC workload models. The rest of the work is structured as follows. Section 2 presents the methodology based on a three-step approach. Section 3 presents the case study and the ATC communications used for the experiment. Section 4 presents the results of the application on the case study and Section 5 summarises the main outcomes and findings.

2. Methodology

As previously described, the aim of this work is to determine whether it is feasible to use ATC communications as a data source for ATC workload models. ATC communications encompass the exchange of aeronautical information and clearances necessary for the safe operation of aircraft in airspace. These communications can be conducted orally or digitally, although due to the source of information available, only oral communications will be considered. This automatization problem is solved on the basis of a three-step approach: the transcription of oral communications, the speaker classification and the classification of events.

1. Speech-to-text: ASR allows automated transcription of oral ATC communications. The primary benefit of implementing an ASR system is the elimination of manual transcription processes, allowing ATC communications to be used directly as raw data for the ATC workload model. An ASR model provides additional features beyond transcriptions, such as duration and start/end times. Given the variety of available ASR models, a benchmarking analysis is performed to identify the model that best fits the characteristics of ATC communications.
2. Agent role: The second step is the automated process to correctly classify the communications between pilots and ATCOs. It should be noted that there are similarities between pilots and ATCOs communications, as there is a need for readback of commands for air traffic control services. Therefore, a first classifier must be considered to correctly identify ATCO communications.
3. Text-to-event: The third step in the automation process involves identifying ATC tasks and events from ASR transcriptions. Traditionally, this identification relied on predefined keywords to determine the various types of tasks or events that ATCOs manage. NLP, an AI-based technology, allows the automatic classification of text, sentences or words based on various features, such as keywords, n-grammes, or sentence structures. Unlike the traditional keyword-based approach, NLP algorithms learn patterns from the data, eliminating the need to manually identify specific keywords or command structures.

2.1. Performance of an ASR

As in every ML or data-driven technique, ASR and classification problems are evaluated based on the accuracy between the real and the predicted data.

- The Word Error Rate (WER) is a metric used to evaluate the accuracy of ASR models [6]. It measures the percentage of incorrectly recognized words in the system output when compared to the reference transcription of the same spoken words. A lower WER indicates a better performance of the speech recognition system.

$$W = \frac{s + d + i}{n} \qquad \textbf{Equation (1)}$$

Where s is the number of substitutions, d is the number of deletions (words missed by ASR), i is the number of insertions (words never spoken), and n is the number of words in the reference.

- Command Recognition Error rate (ErR) is a metric for leveraging commands more than all words said [19]. In this approach, each ATCO instruction in a speech utterance is considered a single entity, and substitutions, deletions, and insertions are tailored and compared to the total number of utterances or commands.

$$ErR = \frac{S + D + I}{N} \quad \text{Equation (2)}$$

Where S is the number of command substitutions, D is the number of deletions (commands missed by ASR), I is the number of insertions (commands never spoken), and N is the number of commands in the reference.

Future work should consider the introduction of an acceptable performance threshold as a limit for its validation.

3. Case-study: TWR dependency

In general, ASR models can be developed ad hoc or to take advantage of already developed ones. The decision to use the open-source ASR model and not to develop a new one is driven by the project's limitations and the absence of manual transcriptions. The selection of an existing model ensures a readily available solution and serves to analyse the potential use of voice recognition systems without direct training in the ATC field. After a benchmarking of different open-source ASR models was performed, the Whisper speech reconstruction model was identified as the most suitable [20]. However, without explicit training in ATC communications, the ASR model provides lower performance in the ATC domain that should be improved in further research.

This study has selected the Local (LCL) position of TWR dependency as the ATCO role to be evaluated due to the reduction of different types of commands. Besides, there are two main air traffic flows managed by the LCL TWR controller: departures and arrivals. In this work, we focus on arrival flights. The LCL arrival controller is responsible for managing air traffic during the landing and taxi-in phases of a flight. This includes ensuring safe entry into airspace, providing clearance for landing, issuing taxi instructions upon landing, and coordinating with other parties such as maintenance vehicles, wildlife control teams, and coordination [18]. Given the scope of the project, Table 1 shows the six main categories of events related to the LCL arrival role.

Table 1 - Events for the classification process.
Source: Authors.

Event	Description
APTEntry	Entry into the area of responsibility
APTClearLanding	Clearance for runway alignment
APTTransferTWRToGMC	Transfer traffic to the adjacent responsibility area
APTInfoLCLarr	Information exchanged between CTA and aircraft
APTCoorCTA	Coordination between CTAs
APTCoorVehiculo	Coordination with a vehicle

Thus, the only costly aspect is the creation of a database (DB) containing automatic transcriptions of the Whisper model and the events tagged. To train the ASR and ML model, it is necessary to build a DB that defines the train and test sets. The audio file used to evaluate Whisper performance and, subsequently, the ML model is described in Table 2.

Table 2 – ATC communication features. Source: Authors.

	ATC role	Date	Time	No words	Voice data (h)	Manual transcription (h)
Audio	LCL ARR	28-03-2022	9:00 - 11:00 UTC	3092	1.96	20

The DB is split into 90% of the database (197 utterances) for training and testing the classifiers, and 10% (21 utterances) to evaluate the sequential use of both classifiers, as will be explained in Section 4. The main limitation is the reduced number of utterances considered due to the novelty of the work and the high cost of manual transcription. Figure 1 shows an example of the DB targeting speaker and event labels.

Figure 1 – Example of the DB with labels.
Source: Authors.

4. Results

After selecting the ASR model and designing the procedure for detecting events based on automatic transcriptions, this section shows the results of the performance assessment of the entire methodology. This step relies on the open-source Whisper model as the chosen ASR tool. Although Whisper has shown remarkable WERs [20], it is important to test its performance specifically in the context of TWR communications. First, an evaluation of Whisper performance on the TWR dependency is carried out. Subsequently, the identification of events or commands is developed and tested based on ASR transcriptions and NLP techniques.

4.1. ASR performance analysis (Speech-to-Text)

The first step of the methodology is to transcript ATC communications using the Speech-to-Text block. For the analysis, a random sample of 30 minutes was selected from the available ATC communications. 2 shows a section of the transcript and its corresponding manual transcription. Substitutions (red), insertions (green) and deletions (blue) are highlighted.

Figure 2 - Word-by-word analysis based on Whisper transcription.
Source: authors.

The duration of the recorded ATC communications for this case study is rough one and a half hours. Hence, the WER is not considered a representative metric to estimate the quality of the model given the size of the sample analysed. However, analysis of each of the WER elements can help identify and understand the problems encountered during this stage. It is important to note that Whisper occasionally translates certain Spanish communications into English while transcribing. As long as the transcription remains

accurate, these instances have not been considered errors in the calculation. The WER obtained is $WER = \frac{56 + 81 + 140}{423} = 65.48\%$ which is not an accurate result.

Therefore, in ATC communications, WER is less significant than ErR. The crucial aspect lies in identifying the keywords associated with commands; for instance, the transcription of "torre" as "corre" does not impact ErR. The result for ErR is $ErR = \frac{1 + 5 + 4}{34} = 29.41\%$. The ErR result is lower than the WER (accuracy is higher) and can be considered as a basis for measuring the quality of transcription. It may be feasible to enhance results by processing the data before using them as input for the Text-to-Event block in further research.

text	text events	manual transcription	manual transcription events
Corre de Barcelona, muy buenas, el B2LV estableciendo en el VLS de la pista 24 derecha		Torre de Barcelona, muy buenas, el VLG2LV estableciendo en el ILS de la pista 24 derecha	
B2LV buenas, continue approach runway 24R, wind 360 degrees 4 knots	APTEntry	VLG2LV buenas, continue approach runway 24R, wind 360 degrees 4 knots	APTEntry
Approach runway 24R, B2LV		Approach runway 24R, VLG2LV	
Lufthansa 62SX, runway 121.655, goodbye	APTTransferTWRToGMC	Lufthansa 62X, 121.655, goodbye	APTTransferTWRToGMC
Runway 121.655, Lufthansa 62SX, goodbye		121.655, Lufthansa 62X, goodbye	
Corre de Barcelona, muy buenas, el B2LV estableciendo en el VLS de la pista 24 derecha	APTEntry	RYR1SR runway 24R, cleared to land, wind 350 degrees 3 knots / Cleared to land, runway 24R, RYR1SR	APTClearLanding
Tower, good day, B101B		Tower, good day, VLG101P	
B101B, buenas, continue approach runway 24R, wind 350 degrees 3 knots	APTEntry	B101P, buenas, continue approach runway 24R, wind 350 degrees 3 knots	APTEntry
Continue, B101B		Continue, B101P	
Runway 121.655, goodbye	APTTransferTWRToGMC	RYR1SR 121.705, goodbye	APTTransferTWRToGMC
Runway 121.655, B101B, B101B		121.705, hasta luego gracias, RYR1SR	
B2LV, 24R, cleared to land, wind 340 degrees 4 knots	APTClearLanding	VLG2LV, 24R, cleared to land, wind 340 degrees 4 knots	APTClearLanding
Tower, B101B, cleared to land, wind 350 degrees 4 knots	APTClearLanding	Autorizado a aterrizar pista 24R, 2LV	
Tower, B101B, good day, B764U, established 9 miles out		Torre de Barcelona, B764U, established 9 miles out	
B764U, good day, continue approach runway 24R, wind 350 degrees 3 knots	APTEntry	B764U, good day, continue approach runway 24R, wind 350 degrees 3 knots	APTEntry
Continue approach runway 24R, B764U		Continue approach, B764U	

Figure 3 - Whisper transcription events vs manual transcription events.
Source: Authors.

Figure 3 shows the Whisper text and the corresponding transcription, along with the events identified in each. One of them is omitted by Whisper (in blue) and two events utterances are inserted although they do not actually occur (in green).

4.2. ML model for event classification based on NLP techniques

As described in the methodology, Steps 2 and 3 consist of the subsequent classification of the communications into speakers (ATC or pilot) and event. Two independent ML models have been developed using the NLTK library in Python® [21]. Performance metrics for classification, such as accuracy, precision, recall, f1 score and confusion matrix, have been employed to analyse and identify areas where errors are concentrated. Besides, the ML process has analysed the results based on three ML models: Naïve Bayes, Decision Trees and Maximum Entropy model. First, the results are shown only for the Naïve Bayes model and to get insights for each classifier as shown in Table 1, secondly the final results of both classifiers are presented. The main features of each DB are:

- The Speaker classifier has a specific goal: to differentiate between pilot and ATCO communications. It could be achieved in the case where available communications were provided by different channels, but it was not the case. To accomplish this, the speaker DB contains 197 utterances where the data set was divided into training and test sets with a 20/80 ratio. Consequently, 158 utterances were utilised to train the speaker classifier and 39 to test it.
- The Event classifier has the specific goal of categorising each utterance corresponding to ATC according to the real event. To accomplish this, the Event DB contains 108 utterances (89 utterances are dropped because they belonged to pilot speaker) where the data set was divided into training ant test sets with a 20/80 ratio. Consequently, 87 utterances were used to train the event classifier and 21 to test it.

Table 1 - Speaker and event classifier metrics for the test set. Source: Authors.

Classifier	Accuracy	Precision	Recall	F1
Speaker	0.69	0.69	0.69	0.69
Event	0.86	0.67	0.75	0.70

In the initial exploration of the Speaker classifier, the average performance across all metrics hovers around 70%. This result aligns with the primary objective of the model: identifying the words within an

utterance to distinguish between pilots and ATCOs. Although there are different phraseologies and variations in language usage between ATCOs and pilots, the need for pilots to read the ATCO instructions leads to a significant overlap in vocabulary. Consequently, the model faces challenges in pinpointing specific keywords for differentiation. Examining the confusion matrix (as shown in Figure 4), we observe that the model errors are relatively balanced. However, it tends to mistakenly classify ATC as pilots more frequently than the reverse.

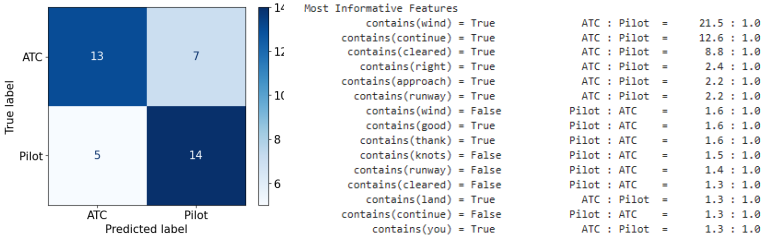

Figure 4 – Left: Confusion matrix for the test set (Speaker classifier) and right: Most Informative Features of the Speaker classifier. Source: Authors.

Furthermore, the NLTK tool provides insights on the development of the ML model based on specific features (keywords). This probability analysis informs about the likelihood of an utterance containing a particular word (True) or not (False). Among the notable words, 'wind' stands out with a strong relationship of 21.5 to 1 for ATC. This classification is accurate because 'wind' is predominantly used by ATC in their communications. Another important term is 'continue' (with a ratio of 12.6 to 1), frequently used by ATCs to instruct pilots to maintain their approach when landing clearance cannot be granted immediately. Although words like 'cleared', 'runway', and 'approach' also carry ATC connotations, they can be used by both agents. The presence or absence of the remaining words slightly influences the classification, as they are more generic and are used almost equally by both pilots and ATCOs. Context and usage play a crucial role in distinguishing between pilot and ATC speech, and these insights help the ML model make informed decisions based on specific language patterns.

Regarding the Event classifier, it increases accuracy value around 90% although the rest of the metrics round 70% similar to Speaker classifier. Figure 1 shows the confusion matrix and the most informative features of the Event classifier where it can be noticed that the primary error is related to the event "APTInfoLCLarr". This misclassification error is related to the lack of standard phraseology for this command, due to the model's emphasis on the words present in each utterance. Moreover, the main issue is the reduction of number of utterances in the test DB for event classification: 6 utterances for each command type and 3 for the one that is mismatched. On the other hand, all remaining events are accurately classified.

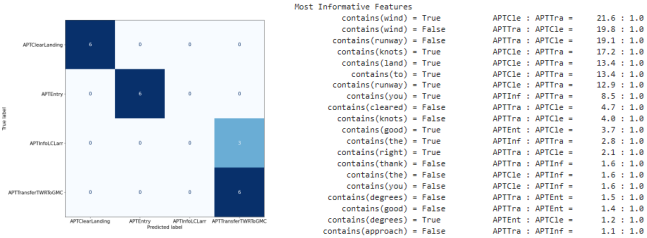

Figure 1 – Left: Confusion matrix for the test set (Event classifier) and right: Most Informative Features for the Event classifier. Source: Authors.

For the 'APTClearLanding' event, key characteristics include the presence of words such as 'wind', 'knots', 'land', and 'runway'. These align with the standard phraseology for this type of event. On the contrary, in

the ‘APTTransferTWRToGMC’ event, the absence of 'wind' and 'runway' is of significance. This highlights that the model not only learns crucial words but also recognises the importance of their absence in each event. Moving on to the ‘APTEntry’ event, the model focusses on features such as the presence of words such as 'good' or 'degrees'. Lastly, for the ‘APTInfoLCLarr’ event, the model emphasises more generic terms like 'the' or 'you', which explains its challenges in categorisation and the errors obtained.

These results detail insights about the individual performance of the Speaker and Event classifiers. However, both classifiers normally do not work isolated but into a sequential process: first, the Speaker classifier identifies the ATCOs utterances and second, the Event classifier identifies the utterances according to the command types. Table 4 shows the performance of the sequential set in which three ML models are analysed. The results of the sequential set improve the performance of the isolated classifiers. Decision Trees and Maximum Entropy provide better results than Naïve Bayes, particularly, the Event classifier corrects the errors of the Naïve Bayes model. The main limitation of this sequential process is the loss of ATC communications from the Speaker classifier that should be analysed in further research.

Table 4 - Sequential classifier performance.
Source: Authors.

Model	Classifier	Accuracy	Precision	Recall	F1
Naïve Bayes	Speaker	0.76	0.79	0.75	0.75
	Event	0.86	0.58	0.67	0.62
Decision Trees	Speaker	0.81	0.87	0.80	0.80
	Event	1.00	1.00	1.00	1.00
Maximum Entropy	Speaker	0.81	0.87	0.80	0.80
	Event	1.00	1.00	1.00	1.00

5. Conclusions

This work has proven that speech recognition is a useful tool for dealing with ATC communications. In this paper, the authors explored whether automated event identification could replace the labour-intensive human annotation process, which involves hours of listening to and annotating oral ATC communications. The methodology proposed translates ATC communications from TWR dependency based on the ASR model, classifies it according to the speaker (pilot or ATCO) and for ATCO communications classifies it according to command types based on NLP techniques. The whole process showed potential for automation.

About ASR model, Whisper was identified as a suitable candidate due to its pre-training process in general scenarios. However, when applied to ATC communications without specific training in this domain, its performance falls short. The overall results indicate that the performance of the ASR model in the ATC domain is not acceptable, significantly deviating from an ideal result. To improve this, a pre-processing step on the raw transcriptions could enhance performance. Interestingly, focussing solely on transcribing the essential words for event identification shows promise.

About classifiers, two classifiers were developed based on ML models: Speaker and Event classifier. As a short-term solution, the Speaker classifier has been suggested to selectively process ATCO utterances, eliminating the need for human intervention. The use of NLP techniques has proven to be valuable. The sequential process developed showed that 100% accuracy can be achieved for Event classification although the main problem regards the first filtering based on Speaker classification.

Finally, this work has proposed research lines that should focus on three crucial areas for further expansion to different ATC roles: to improve the quality of the ASR model, to improve the process for speaker identification, and to evaluate more complex ML models for event classification.

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Sustentabilidade Aérea: Zero Cabin Waste - Modelo de gestão sustentável para os resíduos de cabine

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Abstract/Resumo/Resumen

Este trabalho pretende desenvolver um modelo de gestão sustentável para os resíduos de cabine gerados durante os voos. O objetivo final será oferecer soluções pragmáticas de forma a reduzir, reutilizar e reciclar resíduos, promovendo uma mudança cultural e comportamental na aviação para alcançar padrões sustentáveis de gestão de resíduos. Para alcançar o objetivo da investigação será utilizada uma abordagem que combina métodos qualitativos e quantitativos incluindo análise de estudos sobre gestão de resíduos em aviação, tecnologias atuais e modelos de sustentabilidade, análise de casos de sucesso, desafios na implementação de modelos sustentáveis em companhias aéreas, entrevistas com especialistas e análise de dados. É desenvolvido um modelo de gestão sustentável para os resíduos de cabine que inclua estratégias por forma a reduzir, reutilizar e reciclar resíduos, utilizando as tecnologias mais recentes, práticas eficientes e envolvimento dos passageiros, companhias aéreas e todos os envolvidos no processo. Este estudo faz uma avaliação da viabilidade económica da implementação do modelo de gestão e estudada qual a contribuição para a sustentabilidade da aviação por meio da gestão eficiente dos resíduos de cabine, promovendo práticas sustentáveis e mudanças de comportamento. A originalidade deste estudo reside na sua abrangência e praticidade para enfrentar um dos atuais e principais desafios ambientais da aviação. É expectável que o modelo proposto não só contribua para a redução significativa do impacto ambiental da indústria, mas também como um guia para os principais intervenientes.

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Sustentabilidade Aérea: Zero Cabin *Waste* - Modelo de gestão sustentável para os resíduos de cabine

1. Introdução

A indústria da aviação enfrenta sérios problemas ambientais devido aos resíduos gerados na cabine. Este estudo propõe um estudo para o desenvolvimento de um modelo de gestão sustentável para reduzir o impacto ambiental. O estudo analisará as práticas atuais de companhias aéreas, aeroportos e empresas de catering, bem como as boas práticas implementadas na indústria. Será ainda realizado um estudo caso nos quais serão tidas em consideração indicadores relacionados com a sustentabilidade e a gestão de resíduos gerados na cabine de voo de uma aeronave. Os resultados deste estudo poderão auxiliar companhias aéreas, aeroportos e empresas de catering na implementação de práticas mais sustentáveis de gestão de resíduos de cabine.

Os irmãos Wright são tidos como os pioneiros no primeiro voo controlado com uma aeronave "mais pesada que o ar" na história da aviação em 17 de Dezembro de 1903. Foi durante as duas guerras mundiais que a aviação obteve um impulso significativo, entre 1914-1918 (1º Guerra Mundial) e entre 1939-1945 (2ª Guerra Mundial), contudo foi após o fim da 2º guerra Mundial que a aviação começou a ser utilizada para fins comerciais como transporte de carga, passageiros e correio fazendo uso dos aviões adquiridos para a guerra a aviação comercial viu o seu crescimento a acentuar-se [1] .

Desde o primeiro voo realizado que as principais empresas de fabrico de aeronaves têm se dedicado a reduzir o seu peso de forma a tornar a mesma mais eficiente, utilizando materiais mais resistentes ao desgaste e à corrosão através da aplicação de materiais compósitos. [2].

A aviação é sem dúvida uma das atividades humanas mais amplamente regulamentadas. Tem também um papel muito relevante nos tempos modernos. Apresenta-se como um dos meios de transporte mais rápido e seguro tanto de pessoas como de mercadorias. É uma indústria global que gera indiretamente e diretamente cerca de 87,7 milhões de empregos. Contribui também para o sector do turismo, permitindo o crescimento económico de um país. [3].

De acordo com a [4]estima-se que o transporte aéreo gera 2,8% de anualmente de produto interno bruto (PIB) e que o transporte de passageiros aumente anualmente cerca de 5,0%. (Figura 1) [4].

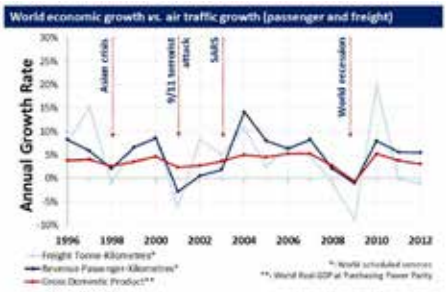

Figura 1 - Crescimento económico vs crescimento passageiros
Fonte: [4]

De acordo com uma pesquisa realizada pela IATA aos passageiros em 11 mercados a nível global, 90% afirmam que a conectividade aérea é fundamental para a economia, 91% em como o transporte aéreo é algo necessário para a vida moderna, 82% que o transporte aéreo é um dos principais contributos para um dos principais objetivos da desenvolvimento sustentável das Nações Unidas [5].

Apesar dos benefícios económicos, a aviação sempre foi alvo de críticas devido aos variados impactes ambientais que a atividade aeroportuária produz como as emissões de gases com efeitos de estufa com diminuição na qualidade do ar, poluição sonora, poluição das águas entre outros.

Desde 1990 e 2019 as emissões têm vindo a aumentar em média 2,3% ano, sendo que grande parte se deve às emissões provenientes da queima de combustíveis fósseis. No contexto da pandemia estas emissões diminuíram, mas devido à recuperação do sector é novamente expectável que as emissões voltem aos níveis pré-pandemia ou sejam até ultrapassados. [6].
Apesar da maior fonte de poluição ter origem nas operações das aeronaves a qualidade do ar também é afetada pelo equipamento de terra utilizado no apoio às operações aeroportuárias. Como poluentes atmosféricos mais significativos a EASA menciona, óxidos de azoto, ozono troposférico e as partículas PM *"Particulate Matter"*[7].
Também a exposição aos ruídos das aeronaves tem impacto em milhões de Europeus, sendo os que residem perto dos aeroportos os mais afetados. O impactos refletem-se na perturbação do sono, aumento dos níveis de stress, doenças cardíacas, dificuldades de aprendizagem nas crianças e até um aumento na mortalidade prematura resultante de doença cardíaca isquémica. [8].

2. Enquadramento

2.1. Sustentabilidade

De forma a diminuir o impacte ambiental a indústria aeronáutica tem tomado medidas em vários campos de forma a reduzir a sua pegada ecológica. Temos como exemplo a adotação de combustíveis sustentáveis, inovação em motores mais sustentáveis e ecológicos, utilizando materiais mais leves e ao melhorar a aerodinâmica das aeronaves. Dado que a aviação é uma atividade global que envolve todos os países do mundo a maioria das questões relacionadas com questões ambientais são estritamente regulamentadas, havendo pouca margem para aplicar novas normas ou melhores práticas. Enquanto outros sectores dependem da tecnologia e outras melhorias técnicas para o seu crescimento o sector aeronáutico está também dependente da regulamentação e acordos realizados entre países [9].
As companhias aéreas têm assim também dirigido a sua atenção para a gestão dos resíduos produzidos durante o voo.

Com a crescente preocupação do sector em reduzir o seu impacto ambiental, as companhias aéreas têm vindo a procurar soluções que possibilitem atingir os objetivos traçados pela IATA de forma a mitigar o impacto da aviação no mundo [10]. O contributo dos resíduos produzidos na cabine, que têm não só vindo a aumentar como consequentemente a contribuir para a pegada ecológica deixada pelo sector aeronáutico. Os resíduos de cabine dividem-se em duas categorias.

Os resíduos descartáveis como os de limpeza são gerados essencialmente através dos serviços prestados aos passageiros, nos quais se incluem a oferta de jornais, revistas, protetores de encosto, cobertores, almofadas, amenity kits, auscultadores e garrafas. Englobam-se também nesta categoria de resíduos os alimentos transportados pelos próprios passageiros, que acabam por ser deixados nos bolsos das cadeiras ou mesmo caídos no chão. Por fim, tem-se ainda os resíduos médicos, resíduos encontrados nos contentores das casas de banho e resíduos que resultam de tratamentos médicos de emergência. Por norma, os resíduos de limpeza são recolhidos em sacos de plástico e colocados para eliminação através do sistema de gestão de resíduos do aeroporto.

São resíduos gerados principalmente através do serviço realizado ao passageiro aquando na distribuição de refeições e bebidas a bordo. Incluem-se nesta categoria comidas e bebidas, independentemente do seu consumo ter ocorrido, e as respetivas embalagens que são devolvidas pelos passageiros após as recolhas efetuadas pela tripulação. Nesta categoria de resíduos é comum verificar-se a existência de grandes quantidades de alimentos e bebidas não consumidas, bem como papel, latas de alumínio e garrafas de plástico. Diferente da forma como é efetuada a recolha de resíduos de limpeza, os resíduos de catering/galley são recolhidos nos carrinhos "trolleys" sendo posteriormente retirados pelas empresas de catering. Estes resíduos podem também ser colocados em contentores fixos e unidades de compactação e removidos pelas equipas de limpeza [10].

2.2. Gestão de Resíduos

As empresas prestadoras de serviços de catering, maioritariamente responsáveis pela gestão de resíduos de catering/galley, têm um papel preponderante neste processo. É, portanto, sobre estas, que através dos acordos contratuais estabelecidos, recai a responsabilidade da gestão dos resíduos. Neste sentido tem-se verificado que vários operadores de companhias aéreas têm vindo a implementar programas de reciclagem de cabine tanto em voos domésticos como internacionais que se baseiam na recolha de materiais recicláveis separadamente (latas de alumínio, garrafas de plástico, garrafas de vidro e papel). São aqui também identificados obstáculos a esta prática: prazos de entrega curtos e falta de armazenamento a bordo para armazenar os materiais recicláveis [11].

Contrariamente ao que ocorre com a quantificação da queima de combustível, em que é possível efetuar análises tendo por base uma vasta quantidade de informação no que diz respeito à análise e compreensão da produção de resíduos de cabine, tendo por base o relativamente recente aumento da atenção dada ao tema, verifica-se que a informação disponível para análise é inferior. Decorrente da limitação identificada quanto à compreensão da produção de resíduos de cabine, em 2012 a *WSP Environmental* efetuou um estudo solicitado pela IATA tendo concluído que 60% das 44 empresas participantes no inquérito, não efetuavam registos de volumes ou pesos dos resíduos produzidos nas suas aeronaves e apenas 25% tinha efetuado análise da composição dos resíduos. [10]

2.2.1. Análises de composição dos resíduos: Waste composition analyses (WCA's)

Na sequência do Estudo de 2012 acima referido, novamente por solicitação da IATA, foi efetuada uma análise à composição dos resíduos de cabine provenientes de 17 voos internacionais, entre setembro de 2013 e janeiro de 2014, no Aeroporto de Heathrow [10]. Conclui-se que foram gerados em média 352,71 kg de resíduos por voo, decompondo-se conforme a Figura 2 esquematiza.

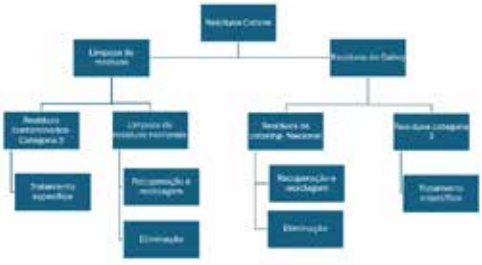

Figura 2 - Categorização dos resíduos
Fonte: [10]

Não obstante o crescente enfoque sobre esta temática, verifica-se que existem poucos dados disponíveis no que diz respeito aos custos específicos dos resíduos aplicados às companhias aéreas e aos seus fornecedores. Neste sentido, as companhias aéreas desconhecem o efetivo impacto dos custos de gestão dos resíduos de cabine, o que limita a avaliação financeira dos mesmos e consequente compreensão do impacto económico. Deste modo, por forma a lidar com questões relacionadas com resíduos produzidos na cabine durante o voo, o Concelho Consultivo de Sustentabilidade e Ambiente (SEAC), criou um grupo, denominado *"Sustainable Cabin Working Group"* que tem como objetivo identificar e dar resposta a questões resultantes dos resíduos produzidos na cabine de voo, legislação aplicável e tecnologias de forma a permitir que as companhias aéreas partilhem entre si boas práticas que possam ser aplicáveis, aconselhamento técnico de investigação e regulamentação aplicável [12].

Vários estudos foram também financiados pela União Europeia de forma a incentivar as companhias aéreas a adotar medidas mais sustentáveis possibilitando uma melhor gestão dos resíduos produzidos. Um desses estudos, "Zero Cabin *Waste*", uma iniciativa cofinanciada pela União Europeia através do programa LIFE [13]. O estudo envolve vários intervenientes envolvidos no processo. O objetivo do estudo

é melhorar a gestão dos resíduos provenientes do serviço de catering categorizados como categoria 3 (dentro da EU) e de categoria 1 (voos internacionais).

2.2.2. Regulamentação

A gestão dos resíduos passa por uma caracterização dos mesmos de acordo com a sua proveniência. De acordo com a legislação da União Europeia, regulamento 852/2004, é referido que todos os voos feitos exclusivamente em espaço aéreo europeu, os resíduos gerados desses mesmos voos, categorizados como categoria 3 (CAT 3), são processados, reciclados e reutilizáveis. Sendo assim possível verificar as oportunidades económicas existentes ao minimizar os resíduos e por consequência reduzir os impactos ambientais e custos.

Para voos provenientes fora do espaço aéreo europeu a União Europeia (UE), de acordo com o regulamento (EU) (1069/2009) que se define como *"International Catering Waste"* (ICW), todos os resíduos provenientes de voos operados internacionalmente, sendo assim classificados com categoria 1 (CAT 1), prevê-se a obrigação de eliminar quaisquer resíduos produzidos, através da incineração ou da colocação em aterros previamente autorizados. Desta forma é inibida a reutilização, reciclagem ou o tratamento de resíduos, contrariamente aos voos realizados unicamente em espaço aéreo europeu. A aplicação deste regulamento tem como objetivo evitar a propagação de doenças animais que possam colocar em risco a fauna, flora e representem um risco para a saúde humana [14].

Apesar desta categorização dos resíduos de forma a delinear estratégias de tratamento e eliminação, as duas categorias são, na maioria das vezes tratadas da mesma forma devido à complexidade e custos do processamento [15].

3. Metodologia

Os dados utilizados neste estudo foram dados secundários, recolhidos de relatórios de sustentabilidade e relatórios financeiros. Os dados são provenientes de relatórios anuais compreendidos entre os anos 2014 a 2023 de informações coletadas pela entidade responsável pela realização do relatório para um outro propósito, tais como a comunicação do desempenho económico da companhia, dos seus impactes ambientais, sociais e das suas contribuições. Uma vez que os dados utilizados para este estudo foram recolhidos nos relatórios de sustentabilidade da companhia aérea Virgin Atlantic tratam-se assim de dados secundários.

3.1. Escolha de indicadores

Os indicadores de sustentabilidade são instrumentos para monitorar e medir a eficiência e eficácia da gestão de resíduos dentro da cabine. O processo de elaboração dos indicadores para a gestão de resíduos contribui para melhorar a compreensão do que é realmente sustentabilidade. E, como a adoção de práticas sustentáveis auxilia na gestão eficaz de resíduos. Com base na revisão da literatura foi possível fazer a escolha das métricas e indicadores relacionados com a sustentabilidade e a gestão dos resíduos que serão assim objetos de análise neste estudo entre os quais resíduos de cabine, resíduos de catering, quantidade de resíduos incinerados, quantidade de resíduos reciclados, quantidade de resíduos para aterro, passageiros pagantes entre os anos de 2014 a 2023, a análise recai sobre o *key perfomance indicator*: PRASK, que trata do cálculo da eficiência operacional.

3.2. Metodologia para a análise de dados

Correlação de Pearson trata-se de uma medida estatística que mede a direção e o grau de relação linear entre duas variáveis quantitativas. Representada pelo coeficiente de correlação r, esta técnica estabelece a força e a direção dessa relação, variando entre -1 e 1. Um valor de 1 indica uma correlação positiva perfeita, onde as variáveis movem-se na mesma direção, enquanto -1 indica uma correlação negativa perfeita, onde as variáveis movem-se em direções opostas. Um valor de 0 sugere ausência de correlação

linear. Amplamente utilizada em diversas áreas, desde economia até ciências sociais, a correlação de Pearson é uma ferramenta valiosa para compreender a associação entre variáveis e auxiliar na tomada de decisões fundamentadas em dados. Entretanto, é importante ressaltar que a correlação de Pearson é sensível apenas a relações lineares entre variáveis, podendo subestimar ou superestimar a relação se houver uma relação não linear. Ao interpretar os resultados da correlação de Pearson, é crucial considerar o contexto específico do problema e utilizar outras técnicas estatísticas para uma análise mais abrangente e precisa. Será determinado o valor da correlação, entre as variáveis em estudo, em função da correlação do produto momentâneo, ou função de Pearson [16].

A estatística descritiva permite reunir, apresentar e interpretar um conjunto de dados, tem como objetivo permitir uma visão global dos valores observados, organizando e descrevendo os mesmos através de tabelas, figuras entre outros. A correlação de uma linha de tendência é uma técnica estatística utilizada para quantificar a relação entre duas variáveis. Essa linha de tendência, muitas vezes ajustada através de técnicas como regressão linear, procura representar a tendência geral dos dados e é frequentemente acompanhada por um coeficiente de correlação, como o coeficiente de determinação (R^2). Este coeficiente fornece uma medida da proporção da variação em uma variável explicada pela outra, indicando a força e a direção dessa relação. Uma linha de tendência com um R^2 próximo de 1 sugere uma relação linear forte entre as variáveis, enquanto valores próximos de 0 indicam uma relação mais fraca.

No entanto, é importante reconhecer as limitações da correlação de uma linha de tendência. Embora seja útil para visualizar padrões gerais nos dados e fazer previsões aproximadas, ela pode ser sensível a outliers e não capturar adequadamente relações não lineares entre as variáveis [17].

4. Apresentação de Resultados e Discussão

Nesta secção serão apresentados os resultados e posteriormente será realizada uma discussão dos mesmos.

Com recurso aos relatórios anuais de 2014 a 2023 da companhia aérea Virgin Atlantic, foram sistematizados os dados relativos a número de passageiros, PRASK e quantidades de *waste.* No que diz respeito a quantidades de *waste*, procurou-se também analisar quais as quantidades que têm como fim a reciclagem, a incineração e o aterro.

As tabelas e figuras foram construídas com os dados supracitados, com o objetivo de auxiliar a exposição que se visa efetuar sobre a matéria em análise, sendo o primeiro ponto em análise a variação do número de passageiros e da quantidade total de *waste*.

Note-se que para os anos de 2019, 2020 e 2021 (conforme destacado na tabela abaixo através de asteriscos), os valores de *waste* apresentados traduzem uma proporção e não dados reais, uma vez que os mesmos não foram divulgados anualmente na sequência da pandemia Covid-19. Ocorre que no reporte de 2021 foram divulgados em acumulado os valores de 2019, 2020 e 2021 pelo que, para efeitos de apuramento das quantidades de *waste* a associar a cada ano individualmente, fez-se uma proporção de acordo com o número de passageiros verificado nos anos em apreciação. Desta forma, ao valor acumulado divulgado em 2021, calculou-se que 72% corresponde a 2019, 15% a 2020 e 13% a 2021.

Estes dados, ainda que possam não espelhar a realidade a 100%, permitem que se efetue uma análise de correlação com uma quantidade de dados superior, uma vez que se agregam 10 anos de dados. Não obstante, e com o objetivo de não efetuar uma análise desvirtuada da realidade, as variações verificadas entre 2019 e 2021 não serão alvo de análise crítica detalhada.

Tabela 1- Variação percentual.
Fonte: Elaboração Própria

Ano	Nº de passageiros	Total *waste* (Ton)	Δ% Nº de passageiros	Δ% Total *waste*
2014	6 156 000	3056,3	---	---
2015	5 939 000	3056,1	0,0	0,0
2016	5 436 000	3261,4	-0,1	0,1
2017	5 300 000	3 323,7	0,0	0,0
2018	5 400 000	3 495,0	0,0	0,0
2019 (*)	5 900 000	5 760,0	0,1	0,4
2020 (*)	1 192 000	1 163,7	-3,9	-3,9

Ano	Nº de passageiros	Total *waste* (Ton)	Δ% Nº de passageiros	Δ% Total *waste*
2021(*)	1 104 000	1 077,8	-0,1	-0,1
2022	4 380 000	2 738,0	0,7	0,6
2023	5 300 000	3 693,0	0,2	0,3

(*) Para calcular a quantidade de resíduos por ano, foram utilizados os valores totais de passageiros, ajustados proporcionalmente ao número de passageiros verificados em cada ano.

Conforme se observa na Tabela 1, verifica-se uma tendência de ligeira redução do número de passageiros entre 2014 e 2022, entre os anos de 2020 a 2022 o decréscimo no número de passageiros deve-se principalmente pelo impacto da pandemia Covid-19 que afetou a indústria aeronáutica globalmente obrigando as companhias aéreas a cancelar vários voos, tendo em 2023 voltado aos números pré-Covid. Entre os anos de 2015 a 2019 as variações do número de passageiros foi ligeira, tendo em 2016 e 2017 ocorrido uma ligeira descida face ao ano anterior. Ao mesmo tempo que se verifica uma tendência de descida no número de passageiros (2015-2016) é verificada uma subida na quantidade de *waste*, estes dados contrariam a tendência de 2019, 2022 e 2023 na qual podemos observar que face a uma subida de passageiros temos um aumento do *waste* produzido, Figura 4.

Assim sendo é nos possível verificar que dos anos de 2022 e 2023 à medida que se verifica uma tendência de aumento no número de passageiros a tendência na produção de *waste* é igualmente proporcional. Não obstante da tendência acima referida, é possível verificar que o aumento de passageiros e aumento de *waste* não aumentam na mesma proporção. De 2014 a 2015 a tanto a variação de passageiros como de *waste* foi imaterial, aproximando-se de 0%. De 2015 para 2016 verificaram-se também variações residuais, embora com tendências contrárias, isto é, verificou-se uma diminuição de passageiros de -0,1% e um aumento de 0,1% na produção de *waste*.

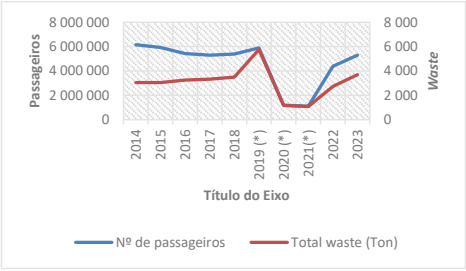

Figura 3 - nº Passageiros vs total *waste*.
Fonte: Elaboração Própria

No que diz respeito à variação de 2016 para 2017 o cenário manteve-se constante, apesar da ligeira diminuição de passageiros a variação foi próxima de 0% sendo contrariada pelo aumento ligeiro de *waste* produzido, contudo, com uma variação semelhante à do número de passageiros, mantendo-se perto de 0%. Com respeito à variação de número de passageiros e de quantidades de *waste* produzidas de 2017 para 2018, a tendência foi semelhante à verificada no ano anterior, tendo-se mantido perto dos 0%.

Como referido anteriormente, decorrente da falta de dados relativamente aos anos afetados pela pandemia, foi feita uma proporção tendo em conta o número de passageiros, por esta razão o número de passageiros e a quantidade de *waste* produzido apresentam sempre uma variação proporcional nos dados apresentados neste estudo. No que diz respeito às quantidades de passageiros de 2019, 2020 e 2021, os dados apresentados são reais pelo que podemos atentar a uma diminuição muito acentuada de 2019 para 2020, ano em que se verificaram os primeiros confinamentos impostos.

A destrinça dos valores acima, permitem, com alguma segurança, a identificação de um padrão constante relativo ao que é a correlação entre aumento de número de passageiros e aumento de quantidades totais de *waste*, contudo, aquilo que se pode efetivamente constatar, salvo 2016, em todos os anos em que é verificado um aumento de passageiros é também verificado um aumento na produção de *waste*. Não deixa de ser relevante também observar que em 2017 e em 2018 a variação entre o número de passageiros e a quantidade de *waste* produzido são semelhantes, observando-se estando assim que estão

relacionadas. Tendo por base a constante referência às diferentes tipologias de *waste*, com especial enfase dado ao catering *waste*, procurou-se analisar a proporção do mesmo face às quantidades totais através da elaboração da tabela 2.
(*) Para calcular a quantidade de resíduos por ano, foram utilizados os valores totais de passageiros, ajustados proporcionalmente ao número de passageiros verificados em cada ano.

Tabela 2- Proporção de *Waste*.
Fonte: Elaboração Própria

Ano	Total *waste*	Cabin *waste*	Catering *waste*	% Catering *waste*
2014	3 056,3	461,2	2 595,1	85%
2015	3 056,1	481,0	2 575,1	84%
2016	3 261,4	453,4	2 808,0	86%
2017	3 323,7	418,7	2 905,0	87%
2018	3 495,0	499,9	2 995,1	86%
2019 (*)	5 760,0	5 088,9	671,1	12%
2020 (*)	1 163,7	1 028,1	135,6	12%
2021(*)	1 077,8	952,2	125,6	12%
2022	2 738,0	432,0	2 306,0	84%
2023	3 693,0	617,0	3 076,0	83%

Esta análise permite constatar uma constante preponderância de catering *waste*, representando na maioria dos anos em análise – exceção para o período compreendido entre 2019 e 2021 – aproximadamente 85% do que são os totais de *waste* da companhia Virgin Atlantic. Torna-se assim evidente, que medidas que visem o catering *waste* abrangem aquilo que é largamente a maior parcela de *waste* gerado. Nos anos compreendidos entre 2019 e 2021, verificou-se uma mudança de padrão muito acentuada; o catering *waste* passou a representar apenas uma parcela de 12% no que diz respeito ao *waste* total. Face ao exposto, procurou-se indagar sobre quais poderiam ser as razões por detrás desta alteração, tendo-se chegado à seguinte listagem:

- Redução da ocupação dos voos: as medidas de distanciamento social e a consequente diminuição das taxas de ocupação dos voos pode ter levado a uma diminuição de produtos de catering consumidos;
- Reforço das medidas de higiene: a intensificação das medidas de higiene como a utilização de embalagens descartáveis, a higienização frequente da cabine e das áreas em comum pode ter contribuído para o aumento dos resíduos produzidos;
- Mudanças nos hábitos de consumo: a facilidade de contágio do vírus sars-cov-2 influenciou os hábitos de consumo do passageiro e o serviço realizado a bordo pelas companhias. De forma a prevenir o contágio o serviço a bordo em várias companhias foi eliminado ou adaptado.

Prosseguindo com a análise, e com o objetivo de estudar em maior detalhe o tratamento dado ao *waste* gerado, foi elaborada a Tabela 3, e Figura 5, que permitem observar a proporção das finalidades dadas ao *waste*, designadamente a reciclagem, a incineração e o aterro.

Tabela 3- Finalidades dadas ao *Waste*.
Fonte: Elaboração Própria 1

Ano	Total *waste*	Reciclagem	Reciclagem % Total *waste*	Incineração	Incineração % Total *waste*	Aterro	Aterro % Total *waste*
2014	3 056,3	682,7	22,3%	2 233,6	73,1%	140,0	4,6%
2015	3 056,1	692,3	22,7%	2 087,8	68,3%	276,0	9,0%
2016	3 261,4	764,2	23,4%	2 131,2	65,3%	366,0	11,2%
2017	3 323,7	890,2	26,8%	2 095,5	63,0%	338,0	10,2%
2018	3 495,0	1 005,4	28,8%	2 219,6	63,5%	270,0	7,7%
2019 (*)	5 760,0	5 087,6	88,3%	639,2	11,1%	33,2	0,6%
2020 (*)	1 163,7	1 027,9	88,3%	129,1	11,1%	6,7	0,6%
2021(*)	1 077,8	952,0	88,3%	119,6	11,1%	6,2	0,6%
2022	2 738,0	556,0	20,3%	1 861,0	68,0%	321,0	11,7%
2023	3 693,0	972,0	26,3%	2 469,0	66,9%	252,0	6,8%

(*) Para calcular a quantidade de resíduos por ano, foram utilizados os valores totais de passageiros, ajustados proporcionalmente ao número de passageiros verificados em cada ano.

Da Tabela 3, constata-se, que de uma forma constante, é a incineração que representa a maior parcela das finalidades dadas ao *waste*, com uma preponderância entre os 63% e os 73%. Em sentido inverso, é no aterro que se verifica a menor percentagem de destino dado ao *waste*, apresentando valores entre os 4% e os 11%. Por fim, com uma preponderância entre os 22% e os 28% encontra-se a reciclagem, com uma representação maior do que a do aterro, ainda assim, significativamente inferior à incineração. Procurou-se também compreender a variação das preponderâncias acima detalhadas. Entre 2014 e 2018 verificou-se constantemente um aumento da quantidade total de *waste*, conforme ilustrado através da área acima representada a azul. Espelha-se também, através da linha cinzenta, aquilo que tem sido uma constante diminuição da preponderância da incineração enquanto, em sentido contrário, a reciclagem, acima representada pela linha laranja, verifica um constante aumento de preponderância. A oscilar entre aumentos entre 2014 a 2016, e diminuições entre 2016 e 2018, encontra-se o *waste* que tem como destino o aterro, conforme ilustrado pela linha amarela. Face às variações observadas e analisadas entre 2014 e 2018, parece evidenciar-se uma relação direta entre o aumento da preponderância da reciclagem face à diminuição da preponderância da incineração. De 2022 para 2023, aquilo que se verificou foi um padrão semelhante ao anteriormente verificado; uma tendência de crescimento da preponderância da reciclagem, e de diminuição da mesma para a incineração e de aterro.

Com o objetivo de analisar individualmente a variação das quantidades de reciclagem, incineração e aterro, apresenta-se a Tabela 4 com o detalhe das respetivas variações verificadas entre 2014 e 2023.

Tabela 4- Variação da Reciclagem, Incineração e aterro.
Fonte: Elaboração Própria

Ano	Total *waste*	Reciclagem	Δ% Reciclagem	Incineração	Δ% Incineração	Aterro	Δ% Aterro
2014	3 056,3	682,7	---	2 233,6	---	140,0	---
2015	3 056,1	692,3	1,4%	2 087,8	-7,0%	276,0	49,3%
2016	3 261,4	764,2	9,4%	2 131,2	2,0%	366,0	24,6%
2017	3 323,7	890,2	14,2%	2 095,5	-1,7%	338,0	-8,3%
2018	3 495,0	1 005,4	11,5%	2 219,6	5,6%	270,0	-25,2%
2019 (*)	5 760,0	5 087,6	80,2%	639,2	-247,3%	33,2	-713,6%
2020 (*)	1 163,7	1 027,9	-395,0%	129,1	-395,0%	6,7	-395,0%
2021(*)	1 077,8	952,0	-8,0%	119,6	-8,0%	6,2	-8,0%
2022	2 738,0	556,0	-71,2%	1 861,0	93,6%	321,0	98,1%
2023	3 693,0	972,0	42,8%	2 469,0	24,6%	252,0	-27,4%

(*) Para calcular a quantidade de resíduos por ano, foram utilizados os valores totais de passageiros, ajustados proporcionalmente ao número de passageiros verificados em cada ano.

A análise da Tabela 4 permite compreender, que em termos globais, têm-se verificado oscilações nem sempre com sentido único, entre cada tipologia de finalidade dada ao *waste*. Por forma a compreender o comportamento de cada uma das mesmas, elaboraram-se as figuras individuais que de seguida se apresentam, com o objetivo de visualmente espelhar individualmente aquilo que foram as variações de crescimento/diminuição de cada. Reforça-se, novamente, que tendo em conta as proporções efetuadas por forma a obter os dados individuais de 2019 a 2021, a análise apresentada não recairá sobre os mesmos.

5. Conclusão

Concluída a análise em detalhe efetuada sobre dados compreendidos entre o período de 2014 a 2023 da companhia aérea Virgin Atlantic, procurou-se agregar aquilo que foram interpretações efetuadas e respetivas conclusões. Neste sentido, a primeira conclusão a que se chega, com algum grau de confiança, é a de que o aumento da quantidade de passageiros é regra geral acompanhado de um proporcional aumento da quantidade de *waste* gerado. Posto isto, aparenta existir uma falta de aproveitamento de economias de escala que permitam que as quantidades de *waste* gerado não acompanhem o aumento do número de passageiros. Dado que se constatou uma forte preponderância do catering *waste* no universo de quantidades totais de *waste* geradas, correspondendo de uma forma constante nos anos em análise a uma parcela de aproximadamente 85%, considera-se que a procurar obter economias de escala, poderão as medidas e iniciativas a tomar incidir, numa primeira fase, sobre esta mesma tipologia de *waste* uma vez que tendo em conta a sua preponderância poderão mais facilmente gerar os resultados pretendidos. Atentou-se também às preponderâncias das diversas finalidades dadas ao *waste* gerado,

sendo que se evidenciou que a incineração representou de forma constante uma parcela na ordem dos 63%/73%, a reciclagem na ordem dos 20%/25% e, por fim, o aterro com uma expressão residual entre os 4% e os 11%. Face ao exposto, torna-se evidente que o pretendido, aos olhos da sustentabilidade, seria inverter a predominância da incineração pela da reciclagem. Paralelamente à análise das respetivas preponderâncias, procurou-se analisar as variações verificadas anualmente em cada tipologia de *waste*. A este nível, verificou-se que a tipologia com comportamento mais estável é a reciclagem, no sentido em que anualmente se têm verificado aumentos. No que diz respeito às quantidades de *waste* que têm o destino como aterro, estas têm, apenas a partir de 2016, apresentado um comportamento de constante diminuição, e, por fim, no que diz respeito à incineração, não foi possível identificar um padrão uma vez tanto se verificam aumentos como diminuições, sem que uma clara tendência quer para um lado quer para outro. Face ao exposto, tem-se como positivo o constante aumento do número de quantidades que têm como desígnio a reciclagem, contudo, é evidente que em paralelo se têm de verificar diminuições nas demais finalidades dadas ao *waste*, o que não foi o verificado. A análise supra efetuada sobre a realidade da companhia aérea Virgin Atlantic permite identificar padrões de comportamento e áreas chave sobre as quais podem ser tomadas medidas com o objetivo máximo de contribuir para o desenvolvimento de iniciativas que possibilitem exponenciar a sustentabilidade no seio das companhias aéreas.

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Benchmarking of Key Sensory Airports Associated with a Level of Service Scale

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Abstract/Resumo/Resumen

This paper proposes the integration of friendly initiatives as a means of inclusion for all passengers prone to feelings of anxiety and insecurity during air travel, through the provision of sensory experiences in public and/or restricted areas before the scheduled flight. The article will present an analysis of airports with sensory environments, providing a review of the literature on possible friendly initiatives already implemented by passenger terminals in Brazil and around the world. With the aim of provoking a new perspective on the level of service of airport passenger terminals, the study presents a benchmarking analysis of airports with sensory environments. Using the Quintile Separatrix Method, it was possible to classify the level of service according to the presence of elements presented in the Sensory Design Matrix. The results enabled the benchmarking of the Study's Sensory Airports. The main purpose of the classification is to understand how airports have responded to the demand for new types of service, given that there is still no regulation standardizing the minimum physical and eligibility attributes required for the implementation of a sensory room in passenger terminals. Furthermore, it is worth noting that the adoption of sensory rooms can cater to the entire public with invisible disabilities, thus enhancing inclusion and providing a new experience at the passenger terminal, consequently contributing to a fresh perception of service level and performance in air transportation.

Benchmarking of Key Sensory Airports Associated with a Level of Service Scale

1. INTRODUCTION

Airports worldwide have tried modernizing passenger terminals to enhance service efficiency, reduce wait times, and consequently boost user satisfaction. The primary agent in passenger terminal modernizations (TPS) has been self-service technology, heightened by the health-protective measures against COVID-19 starting in 2020. Significant development activities include identity verification, baggage retrieval, boarding information, queue times on digital panels, and self-check-in kiosks, among others [1].

New service approaches have been incorporated to enhance user perception, extending beyond the mere presence of technology in terminals. Three aspects are noteworthy in this context: natural, cultural, and, more recently, social.

Airport management companies have increasingly invested in areas that emphasize natural aspects with rainwater harvesting and natural light; and cultural aspects involving the 'sense of place' of the locations, enriching the physical spaces with local identity. Regarding social aspects, the latest transformation in TPS user perception has been the addition of more inclusive and friendly environments termed "Sensory Airports." [2].

At the heart of these friendly initiatives are sensory rooms, specially designed spaces equipped with soothing elements to cater to various sensory needs. These elements, such as soft lighting and music, comfortable seating, and cushions for a relaxing atmosphere, tactile toys for sensory stimulation and relaxation, and noise-canceling headphones to block unwanted sounds, are carefully chosen to create a calming environment for passengers.

This paper proposes introducing friendly initiatives as a form of inclusion for all passengers prone to feelings of anxiety and insecurity on aircraft. These initiatives would involve sensory experiences in public and/or restricted areas before the planned flight.

This article takes a global perspective, presenting an analysis of airports with sensory environments and offering a comprehensive literature review on possible and/or implemented friendly initiatives by passenger terminals worldwide, including Brazil.

The objective is to advocate for the inclusion of these spaces in terminals and stimulate a fresh perception of service levels by users. The study will also introduce a sensory design scale for assessing the service level of passenger terminals.

With this approach, the article will analyze airports with sensory environments, offering a literature review on possible and/or implemented friendly initiatives by passenger terminals in Brazil and worldwide. The goal is to encourage the inclusion of these spaces in terminals and provoke a new vision of users' service level perception. The study will present a sensory design scale capable of assessing the service level of passenger terminals.

2. LITERATURE REVIEW

It should be acknowledged that an air journey consists of phases preceding airport arrival, which can trigger anxiety at various levels depending on the passenger [3] [4]. For individuals with Autism Spectrum Disorder (ASD), who often experience sensory overload, these rooms can revolutionize an environment that naturally induces anxiety. Studies have shown that access to sensory rooms can significantly reduce anxiety, balance emotional regulation, and enhance the overall travel experience for neurodivergent individuals and their families [5].

Air travel can be a daunting experience for anyone, but for individuals with ASD and/or other sensory sensitivities, it can be particularly paralyzing. Crowded environments, loud announcements, and unpredictable settings can provoke anxiety, emotional collapse, and even physical discomfort. Fortunately, an increasing number of sensory airports recognize the need for more inclusive travel experiences and implement dedicated sensory rooms.

It is essential to consider that air travel consists of several phases that precede the arrival at the airport, which can trigger anxiety at varying levels depending on the passenger. For individuals with Autism Spectrum Disorder (ASD), who often experience sensory overload, these rooms can revolutionize an environment that naturally induces anxiety. Studies have shown that access to sensory rooms can significantly reduce anxiety, balance emotional regulation, and improve the overall travel experience for neurodivergent individuals and their families.

Cerdan Chiscano highlighted in his research "ASD and Family Inclusion: Experiences in Airport Design," specifically in phase 2 of the methodology, that the availability of a sensory room or quiet space "proved to be of great value in helping children and their families feel calm during the airport experience." In a report, a passenger's statement reinforces this idea: "My child has autism, so I knew how much a facility like this could improve the travel experience for him and many others living with sensory, cognitive, or physical disabilities." [7].

These havens of calm provide a safe space for neurodivergent travelers to de-stress, regulate their senses, and prepare for their flights. This study will examine the characteristics that guide the motivation of the work, the scope of the study's objective, and from these, the methodological process will be developed.

2.1. Anxiety

Anxiety, as defined by lexicographer Débora Ribeiro, is "physical and psychological discomfort; agony, affliction, anguish." According to psychology, it is "an emotional condition of suffering defined by the anticipation that something unexpected and dangerous is about to happen, against which the individual feels helpless." [8].

In air travel, anxiety can manifest in a passenger upon arrival at the airport or suddenly when above 30,000 feet, where there is a strict need to adhere to safety standards that ensure everyone's protection on the aircraft.

According to the American Psychiatric Association (APA), anxiety is defined as an emotional state with psychological and physiological alterations considered a natural emotion among individuals [4]. Further, as noted by the author, anxiety can trigger a state of hypoxia (a condition of low oxygen content in body tissues), which in the case of air travel can occur with the increase in altitude and consequent reduction of atmospheric pressure, impairing the individual's functions.

Finally, Parra [3] emphasizes the significant focus by the media on airplane accidents, causing a sensation of insecurity among travelers about flying (despite statistics proving aviation as a safe mode of transportation).

2.2. Sensory Initiatives

Friendly or sensory initiatives can be understood as actions aimed at sparing the intensity of an external stimulus through one of the individual's five senses: auditory, gustatory, olfactory, tactile, and/or visual.

In 2002, architect Magda Mostafa began studies related to architecture and design with a focus on sensorially controlled environments to aid in constructing a school for autistic students. However, she argued that not only schools could benefit from the sensory design but also an environment where attention is demanded over extended periods [9]. The so-called "Sensory Design Matrix" aims to organize the architectural environment of an infrastructure to meet mainly autistic sensory needs. This matrix includes 28 design guidelines that will be detailed in Table 1. In this work, the mitigating solutions proposed by Mostafa will be used to minimize cases of anxiety and other atypicalities of passengers during the pre-boarding phase.

Table 1: Sensory Design Matrix.
Source: adapted by the authors of Mostafa (2008) apud Oliveira (2020).

Item	Design Guideline	Suggested objective
1	Enclosed environments	1. Reduce external visual and acoustic distraction for the hyper auditory and hypervisual; 2. Provide tactile stimulation through tight spaces and containment to the hypo tactile; 3. Create visual focus in cases of visual interference; 4. Reduce olfactory stimuli through ventilation to the olfactory hyper.
2	Open environments	1. Increase opportunities for auditory stimulation for the hypo auditory; 2. Provide visual stimulation to the hypovisual; 3. Reduce the feeling of containment for the hypo-tactile.
3	Low ceilings and moderate proportions	1. Reduce echoes for the hyper auditory; 2. Reduce visual distortion and space illusions for the hypervisual; 3. Promote balance for proprioceptive interference; 4. Create a more acoustically controllable environment to avoid interference from other sounds.
4	High ceilings and exaggerated proportions	1. Increase echoes and auditory stimulation for the hyper auditory; 2. Create visual stimulation for the hypovisual; 3. Stimulate the proprioceptive sense of space to the hyper-proprioceptive.
5	Use of reduced human scale	1. Reduce echoes to the hyper auditory; 2. Create a controllable listening environment for auditory interference; 3. Create a controllable space for the hypervisual. 4. Increase tactile stimulation from proximity to the limit for the hypo tactile; 5. Increase proprioceptive stimulation from proximity to the limits for proprioceptive hypo; 6. Create a controllable environment for auditory and proprioceptive interference.
6	Use of large-scale	1. Create auditory stimulation through echoes to the auditory hypo; 2. Create visual stimulation through spatial enlargement for the hypovisual; 3. To reduce overstimulation of spatial limits or boundaries for the hyper-tactile and hyper-proprioceptive.
7	Orientation toward external views and points of interest	1. Create focus and attraction for the hypovisual; 2. Introduce balance and direction to the hypo-proprioceptive.
8	Use the activity focus to organize the space	1. Increase attention and reduce distraction for the hyperauditory and hypervisual; 2. Create a behavioural and geometric reference point for hypo-proprioceptive and proprioceptive interference.
9	Symmetrical organization	1. Create predictability for the hypervisual; 2. Create acoustic balance for the hyperauditory; 3. Increase the feeling of balance for hypoproprioceptive interference; 4. Create a controllable environment to reduce visual interference.

Item	Design Guideline	Suggested objective
10	Asymmetric organization	1. Create auditory and visual stimulation for the hypoauditory and hypovisual; 2. Create proprioceptive stimulation for those with hypo-proprioception.
11	Use of visual or spatial rhythm	1. Create opportunities for visual stimulation for the hypovisual; 2. Create predictability and coherence in the spatial environment for the hypovisual.
12	Visually harmonious space without contrast or discordance	1. Create a visually neutral space for the hypervisual; 2. Create a neutral tactile space for the hyper-tactile.
13	Visually discordant spaces using contrasts	1. Create visual stimulation for the hypovisual; 2. Create proprioceptive stimulation for those with hypo proprioception.
14	Use of dynamic and statically balanced space	1. Create guidance and stability for those who are hyper-proprioceptive.
15	Use of unbalanced or imbalanced spaces	1. Create visual stimulation for the hypovisual.
16	Use of bright (shining) colors	1. Create visual stimulation for the hypovisual.
17	Smooth neutral colors	1. Create serenity for the hypervisual.
18	Use of warm colors	1. Create a psychologically warm environment for the hypo tactile.
19	Indirect natural lighting	1. Minimize glare and visual distraction for hypervisual; 2. It is less distracting than artificial light, and also reduces tinnitus for the hyper-auditory.
20	Direct natural lighting and views	1. Creates visual stimulation for the hypovisual.
21	Noise and echoes	1. Creates a conducive environment for the hyper-auditory; 2. Removes the opportunity for distraction through echoes to the auditory hypo; 3. Creates a neutral auditory background preventing auditory interference.
22	Use of smooth textures	1. Calms the hypo tactile; 2. Creates echo and stimulates reverberation to the auditory hypo.
23	Use of rough textures	1. Stimulates the hypo tactile.
24	Cross ventilation	1. Reduce smells and odors for the hyper olfactory.
25	Closed ventilation	1. Can help contain aromas during aromatherapy for hyper olfactory.
26	Organized compartmentalization using visual cues	1. Helps guide and adjust the hypervisual; 2. Helps stimulate hypovisual action; 3. Helps organize visual interference; 4. Creates necessary boundaries for the hypotactile.
27	Spatial organization according to sensory characteristics	1. Helps orient and adjust the hypervisual; 2. Helps organize visual interference; 3. Helps guide proprioceptive hypo
28	Use of unidirectional circulation patterns to capitalize on routine	1. Helps guide and adjust the hypervisual; 2. Helps organize visual interference; 3. Helps create overall predictability across the spectrum, particularly in the hyper-auditory.

In this context, Brazil already has several airports. However, such airports have initiated this implementation by targeting only autistic passengers as their primary audience.

In countries such as the United States and Europe, airport administrators encompass all categories of hidden disabilities, including auditory, visual, intellectual disabilities, cerebral palsy, and/or autism (anxiety, panic, and post-traumatic stress disorder are also included). Table 2 displays the airports

that have implemented the sensory room in the respective Passenger Terminal System (PTS), as identified in this study, and incorporated with any guideline from Mostafa's Sensory Design Matrix.

Table 2: Systematic Review of Airports with Multisensory Rooms.
Source: Authors.

Year	Airport	Code	Location TPS	Attributions present in the TPS	TPS Observations	Design Guideline
2024	Newark (New Jersey, USA)	IATA: EWR ICAO: KEWR	Departures Hall (Terminal A)	1. Soft/colorful carpet; 2. Cloud-shaped luminaires; 3. Mountains mural; 4. Bubble tubes; 5. Illuminated and constantly moving sensory element	-	11 16 20 27
2023	Congonhas (São Paulo, Brazil)	IATA: CGH ICAO: SBSP	Boarding area	1. Special lighting; 2. Activity panels; 3. Bubble columns; 4. Acoustically treated ceiling; 5. Customized furniture	-	1 8 12 17
2023	Florianópolis (Santa Catarina, Brazil)	IATA: FLN ICAO: SBFL	Boarding area	1. Soft lighting; 2. Varied stimuli; 3. Quiet environment	-	1 17
2023	Santos Dumont (Rio de janeiro Brazil)	IATA: SDU ICAO: SBRJ	Boarding area	1. Aromatherapy; 2. Light globe; 3. Sound equipment	-	17 21 24
2023	Vitória (Espírito Santo, Brazil)	IATA: VIX ICAO: SBVT	Boarding area	1. Soft lighting; 2. Varied stimuli; 3. Quiet environment	-	10 17 21
2022	LaGuardia (New York, USA)	IATA: LGA ICAO: KLGA	Terminal C	1. Aircraft simulation; 2. Bubble column; 3. Customized furniture; 4. Quiet environment	-	1 12 21
2022	Kansas City (Missouri, USA)	IATA: MCI ICAO: KMCI	Boarding area	1. Customized furniture; 2. Soft lighting; 3. Quiet environment	24H operation; No reservation required.	12 17 21
2021	Phoenix (Arizona, USA)	IATA: PHR ICAO: KPHX	Chapel in Terminal 4	1. Customized furniture; 2. Quiet environment	Open from 8 am to 8 pm and Saturday from 8am to 4pm.	12 21
2019	Dublin (Dublin, Ireland)	IATA: DUB ICAO: EIDW	Terminal 2	1. Relaxing music; 2. Ambient lighting; 3. Comfortable seating; 4. Digital display panels; 4. Touch panels; 5. Tactile panels; 6. Games	Free; 60-minute sessions; Limit of 6 people at a time; Reservations via email.	8 12 13 17 21 23
2019	Pittsburgh (Pennsylvania, USA)	IATA: PIT ICAO: KPIT	After Gate A-7	1. Soundproof rooms; 2. Comfortable seats; 3. Flight cabin simulation	Free	12 21

Year	Airport	Code	Location TPS	Attributions present in the TPS	TPS Observations	Design Guideline
2018	Gatwick (London, England)	IATA: EGKK ICAO: LGW	North Terminal	1. Color and sound displays; 2. Abstract tactile panels; 3. Color matching panel; 4. Sound to light show; 5. Waterless rainbow tuber; 6. Interactive giant sidewalk; 7. Activity Board 8. Infinity and Beyond panels	Free; Opening hours from 6am to 8 pm; 30-minute sessions; Limit of 4 people at a time; No reservations required.	13 18 21 23
2018	Miami (Florida, USA)	IATA: MIA ICAO: KMIA	South Terminal and Concourse D	1. Calming sensory luminaries; 2. Aquatic bubble bath; 3. Wall puzzles; 4. Padded seating; 5. Light projector; 6. Dimly lit space	Opening hours from 6 am - 10 pm;	17 13 12
2017	Shannon (Shannon, Ireland)	IATA: SNN ICAO: EINN	Departures hall	1. Quiet spot; 2. Wavy wall; 3. Lighting system	First to implement in Europe	17 21 23
2016	Atlanta (Georgia, USA)	IATA: ATL ICAO: KATL	Concourse F	1. Ball pool; 2. Interactive objects; 3. Tactile activity panel	-	13 23
2016	Minneapolis - Saint Paul (Minnesota, USA)	IATA: MSP ICAO: KMSP	Terminal 1	1. Soft lighting; 2. Comfortable seating; 3. Interactive sensory elements	-	12 17 23
2015	Myrtle Beach (South Carolina, USA)	IATA: MYR ICAO: KMYR	Baggage claim	1. Padded cubicles; 2. Pillows and chairs	-	12 23

2.3. Service Level in Passenger Terminals (PTS)

According to Castro [10], the Passenger Terminal (PTS) is "the facility where a series of processes associated with intermodal passenger transfer are performed." This terminal should consist of operational elements (boarding area, check-in area, boarding and disembarking gates, anti-hijacking inspection, passport control, phytosanitary inspection, customs...) and non-operational elements (duty-free shops, restrooms, stores/bookstores, restaurants, banks/post offices...) that influence both directly and indirectly the user experience. The waiting time between flight connections or before boarding demands an infrastructure that provides passengers comfort, security, and efficiency.

Since 2016, AirHelp [11] has been conducting a unique ranking survey, evaluating all airports worldwide based on three distinct criteria: punctuality, customer opinion, and food and shopping options. This approach highlights the diversity of evaluation criteria in benchmarking service levels. The top-ranked airports for 2023 were: Muscat International Airport (Oman - ICAO: MCT), Recife International Airport (Brazil - ICAO: SBRF), and Cape Town International Airport (South Africa - ICAO: FACT) (AirHelp 2023). These airports, among many others, have the capacity to handle more than 10 million passengers annually, catering to diverse social and economic classes, with potential service distinctions such as VIP lounges (which offer a tranquil and pleasant environment).

In Bandeira et al. [12], the leading indicators affecting the perception of service quality in critical boarding areas of the PTS are portrayed, including check-in area and security inspection. The study utilizes variables such as time, space, number of staff in service, trust, cordiality in procedures, and the number

of conveyor belts. However, some needs related to the emotional state of the passenger, such as anxiety which can occur with any passenger, are not always met. Thus, the importance of a neutralized environment from externalities that create conflicts and internal triggers to the passenger's senses, potentially compromising their experience and safety onboard the aircraft, is evident.

3. METHODOLOGY

3.1. Methodological process

Initially, we conducted a random survey of airports, focusing on those with the necessary information available about sensory room infrastructures (Table 2). The research was carried out through websites [13 - 27], such as the respective airport's portal, news, among others. We then evaluated the present attributes in the TPS, correlating them with Mostafa's methodology. In the benchmarking phase, we assigned a weight of 1 to the Present Attributes and a weight of 2 to the Design Guidelines. This step is crucial in the point scale, as it allows for the summation of values, which can then be related to the service level.

The service level of each airport was rigorously assessed using the "Quintile Separator Method", a robust tool that divides an ordered series into five parts, each representing 20% of its resource. By summing up the total points, we could classify the service level provided by the airports based on the sensory room criterion. This method's robustness ensures the credibility of our service level assessment. Based on the sum of points for each airport, the service level was assessed using the "Quintile Separator Method." According to Cavalcante et al. [28], this method involves dividing an ordered series into five parts, each equivalent to 20% of its total. This method identifies a maximum and minimum scoring interval, dividing the result accordingly. By adding up the total points, a classification of the service level provided by the airports, specifically regarding the sensory rooms, is obtained.

Table 3: Service of Level Classification.
Source: Authors.

Quintile (Qi)	Calculation of Service Level Range	Maximum Quintile Limit	Service of Level (LoS)		
1st quintile	3.6 + 6 = 9.6	9.6	24	> LoS A ≥	20.4
2nd quintile	3.6 + 9.6 = 13.2	13.2	20.4	> LoS B ≥	16.8
3rd quintile	3.6 + 13.6 = 16.8	16.8	16.8	> LoS C ≥	13.2
4th quintile	3.6 + 16.8 = 20.4	20.4	13.2	> LoSL D ≥	9.6
5th quintile	3.6 + 20.4 = 24	24	9.6	> LoS E	—---

4. RESULTS ANALYSIS AND FINAL CONSIDERATIONS

This study presents a thorough benchmarking analysis of airports with sensory environments, with the goal of transforming the service level of airport passenger terminals. Leveraging the Quintile Separator Method, we have been able to classify the service level based on the presence of elements in the Sensory Design Matrix. The results achieved the benchmarking of the Sensory Airports under study, which has the potential to reshape the future of airport service. Table 4 presents the final results of the Sensory Airports Benchmarking.

Table 4: Sensory Airports Benchmark
Source: Authors.

Airports	Attributes present in the TPS (weight 1)	Design Guideline met (weight 2)	Total points (sum)	Level of Service (LoS)
Gatwick (London, England)	8	4	24	A
Dublin (Dublin, Ireland)	6	6	18	B
Miami (Florida, USA)	6	3	15	C

Newark (New Jersey, USA)	5	4	13	D
Congonhas (São Paulo, Brazil)	5	4	13	D
LaGuardia (New York, USA)	4	4	12	D
Kansas City (Missouri, USA)	3	4	11	D
Santos Dumont (Rio de Janeiro, Brazil)	3	4	11	D
Vitória (Espírito Santo, Brazil)	3	4	11	D
Shannon (Shannon, Ireland)	3	3	9	E
Minneapolis - Saint Paul (Minnesota, USA)	3	3	9	E
Florianópolis (Santa Catarina, Brazil)	3	2	7	E
Pittsburgh (Pennsylvania, USA)	3	2	7	E
Atlanta (Georgia, USA)	3	2	7	E
Phoenix (Arizona, USA)	2	2	6	E
Myrtle Beach (South Carolina, USA)	2	2	6	E

The airports we analysed were recognized for their sensory features, and the sensory infrastructure and elements at these airports were thoroughly examined. According to the analysis, Gatwick Airport presented the best level of service, achieving level A in the ranking. According to the analysis, Gatwick Airport presented the best level of service, achieving level A in the ranking. Following were Dublin Airport with service level B, and Miami Airport, with service level C.

It is essential to highlight that this classification was made among the 16 airports collected and is not global. Should additional airports be added or removed, the classification may change.

The primary purpose of this classification is to understand how airports have responded to the demand for new types of service, as there is currently no regulation that standardizes the minimum physical and eligible attributes necessary for implementing a sensory room in Passenger Terminal Systems (PTS). Moreover, it is worth noting that adopting sensory rooms can accommodate the entire public with invisible atypicalities. Thus, this enhances inclusion and fosters a new experience in the passenger terminal, consequently contributing to a new perception of the level of service and performance in air transport.

As this is a pioneering study on Sensory Airports, it's important to acknowledge the limitations we faced, particularly with airport databases. We relied on bibliographic references for the initial categorization of guidelines, and field research was conducted at Congonhas/São Paulo Airport (SBSP). However, there is a clear need for more comprehensive research in this area.

For future studies, the number of airports under study will be expanded, and field research in the terminals and data collection from passengers will be extended. Future analysis is suggested to adopt weights defined using other criteria and even comparative methods that take into account users' perceptions through field research.

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Vertiporto, Desafios e Oportunidades do Transporte Aéreo. Caso de estudo do Vertiporto em Oeiras

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Abstract/Resumo/Resumen

O foco de estudo consiste na avaliação do impacte da introdução da UAM através da implementação de Vertiportos em pontos das cidades, bem como fornecer uma análise abrangente do papel dos Vertiportos e da Mobilidade Aérea Urbana.Este estudo será baseado em artigos e análises de relatórios realizados por diversos autores, organizações internacionais. São realizados também inquéritos de aceitação por questionário, e entrevistas de caracter livre e semiestruturada com especialistas.Esta investigação procura explorar a conceção e implementação de vertiportos na região de Oeiras, a sua influência e contribuição para a mobilidade urbana e para a sociedade geral. Estima-se que os resultados sejam positivos, uma vez que os aderentes vão beneficiar, não apenas pelas deslocações entre pontos em tempos reduzidos, mas também pela qualidade de vida, uma vez que as suas operações não produzirão emissões, mitigando assim os impactes da poluição.A investigação desenvolvida procura contribuir para a identificação das dimensões que devem ser tidas em conta na implementação da mobilidade aérea urbana de forma sustentável em cidades com problemas de congestionamento de tráfego rodoviário, bem como, com a qualidade de vida no meio urbano mitigando as emissões poluentes nas cidades ao adotar este meio de transporte mais limpo e sustentável.

Vertiporto, Desafios e Oportunidades da Gestão Aeroportuária

1. INTRODUÇÃO

Com a constante evolução da tecnologia de um modo geral, o mundo vem se desenvolvendo de uma maneira incansável. Neste sentido, a aviação no seu todo sempre esteve passos a frente no que concerne ao desenvolvimento e introdução de soluções inovadoras, mais eficientes e seguras. O crescimento do tráfego nas áreas urbanas tem agravado e prejudicando a qualidade de vida da população, através da poluição e do ruído. Desta forma, sente-se a necessidade de promover uma mudança mais eficiente e inovadora para a mobilidade urbana. Este crescimento poderia ser gerido pelo espaço aéreo ao integrar sistemas convencionais e emergentes de transporte terrestre, por meio da implementação da mobilidade aérea urbana a nível global.

Grandes e pequenas cidades, vêm apresentado tempos excessivos de deslocamento, com destaque nas horas de ponta, devido as enormes filas de veículos, este, causado pelo aumento populacional nos centros urbanos e, também, pela presença das empresas no centro. Daí emerge a Mobilidade aérea urbana como uma solução promissora para a mobilidade. Nestes últimos anos, graças a inovação tecnológica surge a ideia de introduzir um novo conceito de UAM, esta que prima pela sustentabilidade, através da utilização de aeronaves totalmente elétricas, não poluentes em relação às presentes e que de certa forma não contribuem para a poluição (eVTOL). Estas, vão desempenhar a tarefa de "táxis aéreos" para pessoas, bens e outros serviços (por exemplo: transporte de cidadão com mobilidade reduzida, serviços de assistência médica, missões humanitárias, etc), juntamente com os meios de transporte alternativos (comboio, metro, autocarros, carros) podendo contribuir para um melhor fluxo para mobilidade urbana. Estes veículos (eVTOL), para que possam realizar as suas operações, nomeadamente descolar e aterrar, necessitam de uma infraestruturas físicas (Vertiportos).

2. ENQUADRAMENTO

2.1. MOBILIDADE AÉREA URBANA

A mobilidade urbana está se tornando um problema cada vez maior, devido a sua crescente complexidade, resultado do aumento da população nos centros das cidades. Desta forma, a procura por novos meios de transporte intraurbanos mais eficientes e económicos vem aumentado, tornando se cada vez mais presente e prevalente [1]. Nesse contexto, a mobilidade aérea urbana (UAM) emerge como uma solução viável e promissora. Utilizando aeronaves de decolagem e pouso vertical (eVTOL) para operações de baixa altitude em áreas urbanas [2]. A UAM visa melhorar a acessibilidade às diferentes localidades, reduzir os tempos de viagem e as emissões de gases. Esta pode ser usada em vários modelos de negócios, além do transporte de passageiros como serviços de mobilidade para pessoas com deficiência, passeios turísticos e missões de emergência e resgate [3]. O conceito de decolagem e pouso vertical (VTOL) foi introduzido pela ideia da UAM nos anos 1940, quando helicópteros que podiam voar em áreas urbanas. Na época, havia pouco desenvolvimento tecnológico, o que levou a vários acidentes e altos custos operacionais e ruído dos helicópteros [4]. Isso levou a maioria das operadoras por toda Europa e Estados Unidos a diminuir as operações no final da década de 1960 até 1970. Atualmente, o mercado da UAM está em rápido crescimento e a mobilidade urbana terá um novo capítulo a ser explorado nos próximos anos [4].

Ao contrário dos Helicópteros tradicionais, esses veículos, são projetados para serem mais seguros, silenciosos e economicamente viáveis. Devido as limitações das baterias, atualmente a pesquisa se concentra em viagens intraurbanas, no entanto, nas próximas décadas, é previsto que esses sistemas se expandam para viagens regionais e intermunicipais [2]. A Expectativa é que a Mobilidade Aérea Urbana seja uma alternativa promissora para melhor o transporte de passageiros e mercadorias em áreas da cidade (Intraurbanas), utilizando o espaço aéreo a baixa atitude [2]. Por possuírem esta flexibilidade de decolar e pousar verticalmente (eVTOL), têm a vantagem de não exigir grandes investimentos em infraestrutura, relativamente a qualquer uma outra aeronave [5].

A implementação da UAM é vista como uma chance de criar grandes oportunidades económicas como empregos e outras. Até 2030 esse mercado na Europa está previsto que valerá 4,2 bilhões de euros e criará cerca de 90 mil empregos. Singapura, EUA, Emirados Árabes Unidos, Japão, China e países do Leste Asiático, entre outros, são mercados potenciais para eVTOL e UAM nos próximos anos [2].

2.2. Segurança e controle de tráfego aéreo

A funcionalidade segura dos Vertiportos está intrinsecamente ligada à atuação rigorosa na segurança e controle de tráfego aéreo [2]. Administração competente exige a observância dos padrões regulatórios, empregando sistemas de controle sofisticados e comunicação via rádio eficiente para a troca de informações pertinentes. A previsão climatológica e a preparação para emergências são igualmente relevantes, sendo que a colaboração inter-aeroportuária fortalece as práticas de segurança [2]. Essa complexidade implica em uma gestão onde sistemas de vanguarda, a habilitação profissional e a cooperação mútua asseguram operações aéreas seguras e eficazes, elevando a confiança dos viajantes [6]. É fundamental investir na capacitação dos funcionários, fornecendo treinamentos específicos e atualizados. No que diz respeito à segurança de passageiros e bagagens, é necessário implementar procedimentos rigorosos de verificação. Isso inclui a utilização de scanners de alta precisão, que detetam de forma eficaz qualquer objeto ou substância suspeita [6]. Além disso, é imprescindível contar com um sistema de vigilância eficiente, composto por câmaras de segurança estrategicamente posicionadas [6]. Outro ponto importante é a necessidade de promover a segurança cibernética nos Vertiportos. Com o avanço da tecnologia, os sistemas informatizados se tornaram vulneráveis a ataques virtuais. Por isso, é fundamental adotar medidas de proteção, como firewall e programas de deteção de intrusos [4].

2.3. Desafios de infraestruturas

Existem algumas restrições e limitações de disponibilidade para as áreas de inserção dos vertiportos. Estes devem cumprir alguns requisitos como por exemplo, infraestrutura adicional como uma zona de espera/check-in, instalações para efetuar as manutenções após voos, de forma a garantir a segurança nas operações e uma zona de aterragem e descolagem (*Final Approach and Take Off Area* - FATO). De acordo com uma pesquisa realizada por uma empresa no setor do transporte, em 2016, são necessárias estratégias para a identificação de localizações próximas das áreas de circulação de pessoas para a implementação em grande escala de operações da UAM. [6].

2.4. Desafios Regulatórios

Relativamente a *"Regulamentação e certificação das aeronaves"*, a inserção de veículos VTOL em contexto urbano aéreo é um processo complexo. Este, é considerado um dos principais desafios, pois num contexto de aviação é importante ter regulamentos apropriados para as certificações de aeronavegabilidade de modo a garantir a segurança nas operações. As autoridades e entidades reguladoras europeias e mundiais têm discutido a melhor forma de introduzir estes veículos no espaço aéreo urbano em segurança, sem afetar a economia social [1].

Embora os requisitos e as certificações para os operadores ainda não tenham sido desenvolvidos, as Autoridades competentes da União Europeia têm trabalhado em conjunto para padronizar todas as medidas de segurança aeronáutica. A redução do excesso de ruído e as emissões zero em zonas residenciais, têm levado à submissão a testes rigorosos que cumpram com os padrões de segurança, através de métodos de propulsão (híbrida ou elétrica) direcionados para o meio ambiente e sustentabilidade [7]. A minimização do ruído, passa pela utilização de hélices mais silenciosas, da implementação de rotas de voo que minimizam o impacto sonoro e da definição de horários de operação ajustados para evitar voos noturnos [2].

2.5. Desafios de Aceitação Social

Um dos maiores obstáculos da UAM é principalmente fazer com que as pessoas aceitem e adiram a essa nova realidade dos carros voadores. A Figura 1 apresenta quatro componentes relativamente a aceitação publica. Para que a aceitação pública seja possível relativamente a UAM é necessário conquistar a confiança dos aderentes e demonstrar o benefício público [2].

Figura 1- Avaliação da Aceitação Social
Fonte: [3]

3. VERTIPORTOS

A UAM precisa de infraestruturas que permitem a conectividade multimodal, estas que vão facilitar ou contribuir para a inserção do UAM nas aéreas urbanas, Vertiporto [3]. Vertiportos são estruturas ou infraestruturas projetadas para a operação de Decolagem, Aterragem e Manutenção de Aeronaves de Decolagem e Aterragem Vertical (eVTOL), bem como todo o processamento de passageiros e bagagens [8]. Segundo a EASA (Agência Europeia de Segurança da Aviação), Vertiporto é definido como uma área na água, solo ou estrutura projetada a aterragem e descolagem de aeronaves VTOL. São áreas que fornecem toda a segurança necessária para o transporte aéreo comercial de passageiros e mercadorias. Estas infraestruturas permitem que os drones ou aeronaves eVTOL operem como pontes aéreas, desta forma, são vistos como uma solução para a mobilidade urbana [1].

3.1. INFRAESTRUTURA

A infraestrutura aeroportuária consiste na estrutura apropriada para as operações do UAM, Figura 2. Um dos desafios das Infraestruturas aeroportuárias, é de compreender melhor as operações e a capacidade de processamento dos vertiportos em nomeadamente em locais de restrições de espaço [5].

Relativamente às áreas funcionais, um vertiporto deve ter [9]:

- *Final Approach and Take Off Area* (FATO): área para a realização das manobras de aterragem e descolagem de veículos VTOL;
- *Touchdown and Lift Off Area* (TLOF): área para a aterragem e descolagem de VTOL;
- *Safety/Protection Area*: área de segurança para eventuais desvios de VTOL durante as manobras de aterragem e descolagem;
- *Pad*: área de aterragem e descolagem;
- *Taxyway*: caminho de circulação do veículo VTOL até o local de paragem;
- *Stand/Gate*: local de paragem do veículo VTOL adequado para a movimentação de passageiros e carga, ou para a realização de atividades de manutenção e apoio (ex.: carregamento);
- *Towing Cart*: veículo de apoio que faz a movimentação do veículo VTOL entre o TLOF e o *Stand/Gate*;
- Vertiport (*airside*): área do lado ar do vertiporto (acesso condicionado a pessoas autorizadas);
- Vertiport (*land side*): área do lado terra do vertiporto, onde são realizados os diversos serviços de apoio.

Figura 2- Prototipo de um Vertiporto, áreas funcionais
Fonte: [8]

3.2. O Veículo eVTOL

No início do século XXI, a revolução e autonomia tecnológica, contribuíram para o acelerado desenvolvimento de uma nova era da aviação, a era da eletrificação de aeronaves [10]. O nome eVTOL é a junção das siglas em inglês: ("e" de *eletric*), um veículo movido a eletricidade, que descola e aterra verticalmente ("VTOL" de *vertical take-off and landing*). O conceito de eVTOL pode ser definido como mistura de um carro voador com um helicóptero elétrico [5].

Estes veículos são movidos a motores elétricos (Baterias de íon lítio) e destinam-se ao transporte de mercadorias e passageiros, podendo ser tripuladas ou não tripuladas. Em termos de tripulação, os eVTOLs podem acomodar, em média, seis passageiros, dependendo do seu modelo, Figura 5. A principal tecnologia é a propulsão elétrica distribuída (DEP), que oferece novas oportunidades, permitindo reduções significativas nos custos operacionais, ruído e emissões [5].

4. Metodologia

Para esta investigação, o autor optou por seguir a metodologia mista, esta que retrata uma abordagem de investigação que combina as duas formas, qualitativas e quantitativas, permitindo obter uma visão mais abrangente e uma compreensão mais profunda do caso em estudo. Serão consultados documentos, artigos científicos, pesquisas bibliográficas, teses e inquéritos, relativo ao tema estudado, como base para a realização da investigação.

Figura 3- Esquema do desenvolvimento do cenário
Fonte: Elaborado pelo autor

Oeiras é o 5º município mais povoado de Portugal, constituído por 10 freguesias, sendo conhecido pelos seus pontos turísticos e históricos, que incluem museus, praias, parques, fortes, Palácios, entre outros, sendo esses considerados pontos de interesse e de grande atração turística da região. Para esta investigação, o autor apresenta o Caso de estudo de um Vertiporto em Oeiras, que consiste no estudo da viabilidade social numa primeira fase e de seguida, viabilidade técnica conforme indicado na figura abaixo.

Para esta investigação, foi dividido o estudo em duas (2) fases, sendo a:

Fase 1: viabilidade social que consiste em compreender as preocupações e necessidades das pessoas em relação à aceitação e integração de Vertiportos, que serão utilizados futuramente para os seus deslocamentos pela cidade;

Fase 2: a viabilidade técnica, que analisa a logística e viabilidade da integração de Vertiportos. Visto que as partes interessadas também influenciam os resultados, o autor recorreu a política governamental, nomeadamente, entidades, a fim da realização de uma análise, permitindo assim, avaliar a viabilidade da possível integração da UAM. Sendo assim, seguiu os seguintes passos:

1. Definir os interessados;
2. Identificar motivos de resistência das partes interessadas, sendo essas, preocupações, relativas a integração do UAM.

5. Apresentação e Discussão dos Resultados

Para a 1ª fase de investigação (Viabilidade Social), contabilizou-se 100 respostas. Os resultados são apresentados em forma de gráficos (Pizza e Barras) e tabelas, sendo as unidades apresentadas em percentagens, exceto para os gráficos de barra que incluem números, correspondentes as respostas individuais obtidas. No geral, as mulheres representam cerca de 47% dos inqueridos, a maioria, e os homens um pouco abaixo, 45%. Também, contou-se com 8% de inqueridos que se identificaram com outros tipos de género. A faixa etária da maioria dos inqueridos é compreendida no intervalo de 20 à 30 anos de idade (54%), representando assim a camada jovem, seguida do grupo dos 31 aos 40 com 24% e o grupo mais velho, com mais de 40 anos de idade com 12%. Por ultimo , 12% do total das respostas são provenientes de inqueridos com, ou menos de 20 anos de idade. Quanto a Ocupação Profissional, maior parte dos inqueridos encontram-se empregados, na qual representam 41%, 29% apenas estudantes, 20% trabalhores estudantes, 7% desempregados e 3% encontram-se em outras situações profissionais. Relativamente aos Salários líquidos, conforme a Tabela 1 demonstra, mais de metade dos Inqueridos tem um salários liquido no intervalo de 1000€ à 1500€ (59.6%), seguido daqueles que recebem menos de 1000€ com 29.8%. A menoria é representada pelos inqueridos que ganham e recebem mais de 1500€ (10.6%).

Tabela 1- Demografia da amostra da população
Fonte: Elaboração própria baseado em [11]

Categoria	Subcategoria	Percentagem [por cento]
Gênero	Masculino	45
	Feminino	47
	Outro	8
Faixa etária	Menos de 20 anos	12
	Entre 20 e 30	54
	Entre 31 e 40	24
	Mais de 40	10
Ocupação Profissional	Empregado	41
	Desempregado	7
	Estudante	29
	Trabalhador Estudante	20
	Outro	3

Relativamente aos Salários líquidos, conforme a Figura 4 demonstra, mais de metade dos Inqueridos tem um salário liquido no intervalo de 1000€ à 1500€ (59.6%), seguido daqueles que recebem menos de 1000€ com 29.8%. A menoria é representada pelos inqueridos que ganham e recebem mais de 1500€ (10.6%). A maior parte das respostas são provenientes de inqueridos que residem em Lisboa (45,5%), segundo a Figura 7, seguido de residentes de outros concelhos não mencionados, Oeiras e Sintra (24.2%) (18,2%) (12.1%). Maior parte deles utiliza frequentemente os meios de transporte Púlbico e Privado simultanaeamente (35%), como mostra a Figura 5 . 33% dos inqueridos utilizam apenas transportes privados para as suas deslocações, pessoais ou não, seguidos dos inqueridos que utilizam apenas os transportes públicos para se deslocarem e outros que não são mencionados (29%) (3%).

Figura 4- Salário Líquido
Fonte: Elaboração própria baseado em [11]

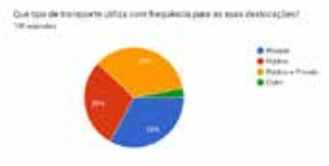

Figura 5- Tipo de transporte utilizado frequentemente para as deslocações
Fonte: Elaboração própria baseado em [11]

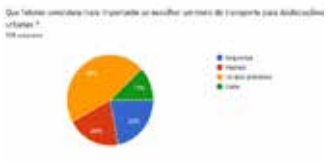

Figura 6 - Fatores que consideram mais importante para escolher o meio de transporte para as deslocações Fonte: Elaboração própria baseado em [11]

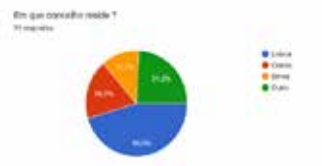

Figura 7- Concelho Fonte: Elaboração própria baseado em [11]

De acordo a Figura 6, 45% dos inqueridos consideram a rapidez e a segurança em simultaneo, como fatores mais importante ao escolher um meio de transporte para as suas deslocações urbanas. Outros consideram apenas a segurança, e os restantes apenas a rapidez e outros fatores que não foram mencionados (22%) (20%) (12%).

Segundo a Figura 8, o número de pessoas que já ouviram falar sobre a UAM(41%) é inferior aos que nunca ouviram falar (46%), seguido daqueles que talvez já ouviram (13%). A Figura 9 mostra o grau de satisfação da população/inqueridos em relação a atual mobilidade urbana nos dias de hoje em Lisboa. A partir deste gráfico de pizza, podemos perceber que maior parte dos inqueridos se sente satisfeito (42.4%), e muito satisfeito (13.1%), porém, muitos deles se sentem insatisfeitos e até mesmo indiferente (33.3%) (11.1%).

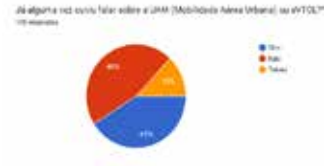

Figura 8 - Conhecimento sobre a UAM (Mobilidade Aérea Urbana) ou eVTOL Fonte: Elaboração própria baseado em [11]

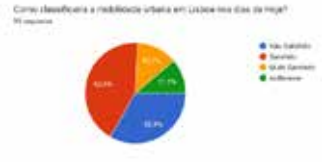

Figura 9- Classificação da mobilidade urbana em Lisboa
Fonte: Elaboração própria baseado em [11]

Dos inqueridos, maior parte deles possui algum conhecimento sobre Vertiporto (44%), 37% não tem conhecimento nenhum sobre o assunto e 8% talvez, segundo a Figura 11. Ainda assim, de acordo a figura 10 , a maior parte dos inqueridos acreditam na ideia de introdução de nova forma de transporte urbano (67%), a outra parte restante desaprova essa ideia.

Figura 10 - Necessidade de introdução de uma nova forma de transporte urbano Fonte: Elaboração própria baseado em [11]

Figura 11 - Conhecimento do objetivo de um Vertiporto Fonte: Elaboração própria baseado em [11]

Passando agora para a 3ª parte do inquérito, de acordo a Figura 12 , 41% dos inqueridos, levam entre 20 a 30 minutos para se deslocarem de suas residencias ao local de trabalho, 31% mais de 30 minutos e 28% menos de 20 minutos. Tendo em conta o transito exposto, a maioria considera utilizar um eVTOL para se deslocar, sendo este, mais rapido comparado a outros, 32% encontram-se numa situacao de indecisao, e os restantes, que contabilizam a menoria, de acordo a Figura 13, não utilizaria para o seu deslocamento aeronave eVTOL.

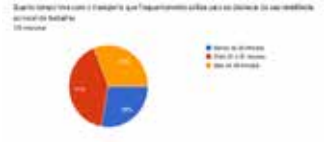

Figura 12 - Tempo de deslocação da sua residencia até ao local de trabalho Fonte: Elaboração própria baseado em [11]

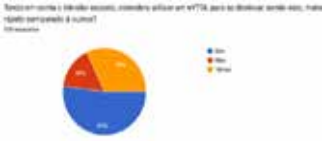

Figura 13 - Disposição para utilizar um eVTOL para se deslocar Fonte: Elaboração própria baseado em [11]

As Figuras 14 e 15 apresentam as razões que os levariam a utilizar e/ou rejeitar o UAM, especificamente o eVTOL. A primeira Figura, como já referido, está relacionado com o que as pessoas pretendem, as suas necessidades, e o último aborda os problemas ou preocupações, sendo externas ou internas, das pessoas relacionados com a UAM. Nesta Questão em específico, as pessoas poderiam selecionar mais de um motivo. Visivelmente, as pessoas procuram o UAM, porque buscam mais economia de tempo, e contribuição para menos poluição do ar. No entanto, as principais preocupações, ou, as principais razoes que o levariam a rejeitar um eVTOL são tecnologia desconhecida, preocupações com a segurança e o sentimento inseguro de aeronaves não tripuladas. A última questão do inquérito, abrange os locais preferenciais dos inqueridos para a colocação de vertiportos. A Figura 16 ilustra os resultados nesta questão, os inqueridos podiam livremente escolher mais de uma opção, desta forma, a maioria prefere que os vertiportos estejam em estrutura existentes, nomeadamente Heliportos ou Helipontos, e próximo a estacoes de metros e comboios. Muitos demonstraram a sua preferência também em parques de estacionamentos.

Figura 14 - Motivos que levam a rejeitar o UAM baseado em [11]

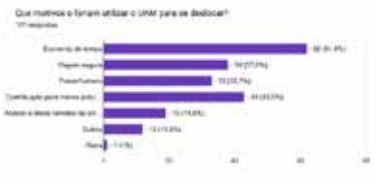

Figura 5 - Motivos que levam a utilizar a UAM para se deslocar
Fonte: Elaboração própria baeado em [11]

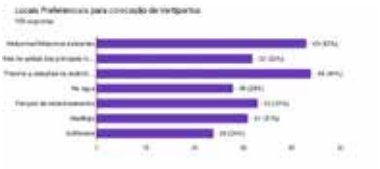

Figura 6 - Locais preferencias para integrar os Vertiportos
Fonte: Elaboração própria baseado em [11]

De um modo geral, mais de 50% dos entrevistados estão satisfeitos com a mobilidade urbana atual em Lisboa, classificando assim como satisfeito (42,4%) e muito satisfeito (13,1%), totalizando 55,5% dos inqueridos satisfeitos. Por outro lado, cerca de 33,3% dos entrevistados estão insatisfeitos com o sistema, e 11,1 % mostram-se indiferentes.

6. Conclusões

Apesar das dificuldades existentes na cidade de Lisboa, como as grandes filas de congestionamento, a poluição por parte dos transportes, a infraestrutura existente na cidade ainda é bastante apreciada por parte dos utentes/residentes. Ainda assim, os dados indicam que ainda existe muito por melhorar no que concerne a mobilidade urbana, através dos resultados apresentados. O valor da indiferença pode ser resultado de um desengajamento por parte dos inqueridos.

A maior parte dos entrevistados, não se encontram familiarizados com a ideia e o propósito do UAM. De um ponto de vista pessoal, a probabilidade de experimentar um voo eVTOL em Lisboa aumenta com o número de pessoas que aprendem sobre esta tecnologia emergente, ou seja, quanto mais estiverem familiarizados e obtiverem algum conhecimento sobre, maior será a probabilidade de utilizarem um eVtol, apesar de que menos de 16% demonstraram o seu desinteresse a usar o UAM em viagens futuras, cerca de 52% expressou um grande interesse em usá-lo. Desta maneira, para que se possa alcançar o sucesso e garantir a aceitação e engajamento de mais participantes, podendo ser a maioria, é importante realizar campanhas de conscientização e educação acerca desta tecnologia emergente.

Constatou-se também que maior parte dos entrevistados procura o UAM para economizar tempo, ajudar a reduzir a poluição do ar e para realizarem viagens seguras, segundo a Figura 16. Sendo assim, os motivos citados anteriormente refletem as prioridades dos entrevistados, sendo estas, a eficiência, a sustentabilidade e a segurança. A tecnologia desconhecida, preocupações com a segurança, e o sentimento inseguro de aeronaves não tripuladas, são os três principais motivos que preocupam os entrevistados e que consequentemente fariam rejeitar. Estas, acabam por ser “normais” ou comuns, quando se insere uma nova matéria desconhecida no mercado, ainda mais, quando se fala de tecnologia, e que, de alguma forma pode colocar em risco milhares de vidas humanas. Podem ser mitigadas, através da realização de garantias regulatórias, demonstrações práticas e provas de conceito bem-sucedidas, construindo e passando maior confiança para os futuros utilizadores, respondendo assim as necessidades e preocupações de cada um. Os três locais mais populares escolhidos livremente pelos inqueridos, para colocar os vertiportos incluem parques de estacionamentos, helipontos existentes, próximos a estações de comboio e metro, rooftop e nos nós de saída das principais rodovias. A localização destes é um fator crucial, podendo contribuir para a sua eficiência. Com os dados obtidos por parte das preferências dos inqueridos, indicam a busca pela conveniência e pela integração com a infraestrutura existente de transporte.

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