Brazil/Europe Comparison of Operational ANS Performance

DECEA Performance Section
EUROCONTROL Performance Review Unit

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Preface

This report represents the 2nd edition of the Brazil-Europe Comparison of Operational Air Navigation System Performance. It characterises and compares operational performance in both regions on the basis of a set of harmonised performance measures. The report is jointly developed by the Performance Section of the Department of Airspace Control (DECEA) and EUROCONTROL's Performance Review Unit (PRU).

This report was published in October 2022. The online version is available at .

For any questions, please do not hesitate to contact one of the authoring organisations. Enjoy the read!

Performance Section, DECEA
Performance Review Unit, EUROCONTROL

Forewords

EUROCONTROL PRC

Marinus de Jong
EUROCONTROL PRC Chairman

Collaboration and harmonisation are key and intrinsic principles of the aviation world. These principles were never as important as they are today, as the aviation community emerges from its worst crisis ever in the last two and half years. Since the outbreak of COVID-19, pressure on the air transportation system tested the resilience of the most integrated and interdependent mode of transport. When the pandemic was finally relieved, the Russian invasion of Ukraine raised the bar against recovery even higher, with rising fuel costs and much uncertainty once again. More than ever, the aviation system should look to its principles.

Without collaboration - both on regional and international level - and the promotion and application of standards, the aviation system we know today, would never have come to pass, and will undoubtedly fail in the future. With that in mind, this second comparison report reflects the efforts of Brazil and Europe to keep moving in the direction of cooperation and standardisation in the field of operational air navigation system performance. Furthermore, the global community is asking for all its sectors to improve efficiency and reduce environmental impact. Additionally to the challenges mentioned above, addressing the carbon footprint of air transportation and how air navigation can help in this context is mandatory. In this context transparency plays a fundamental role. This comparison report adds to providing a transparent basis for an informed discussion by providing data-driven analyses to identify performance gaps and allow stakeholders to understand better and even participate in finding solutions to the issues on the table.

DECEA SDOP

Brig. Eduardo Miguel Soares
Head of SDOP/DECEA

Even though the scars of the greatest crisis of the aviation system are not fully healed yet, it is already time to assess its impact on the ATM systems, understand how the regions dealt with the challenges and learn from mistakes and successes. Therefore, the partnership with EUROCONTROL became even more valuable for DECEA during the difficult period of the pandemic and post-pandemic. The historic drop in traffic volume has significantly impacted the investment capacity of air navigation service providers making the scrutiny of resource allocation an even more complex and error-intolerant activity.

Moreover, the European institution's culture of structuring strategic planning supported by robust indicators and performance frameworks inspires us to maintain the path of clear goals and well-defined indicators for attention to strategic objectives. The SIRIUS Program's projects are examples of planning already based on performance management and further strengthened after our agencies' partnership. For instance, in the 2021 SIRIUS Program report [1], it is possible to verify that projects management, as such the TMA SP NEO, were carried out within the performance based approach and with some of their outputs expressed in metrics directly related to the well establish indicators in Europe.

This standardization of performance management also facilitates communication with the entire aviation community, contributing to the necessary transparency of today, in addition to strengthening our partnership with EUROCONTROL, our most significant source of inspiration in the area of performance.

[1](https://www.decea.mil.br/static/uploads/2022/04/Realizacoes-SIRIUS-2021.pdf)

Executive Summary

Air transportation contributes a significant percentage to the global economy and is a key sector in Brazil and Europe. Despite the impact of COVID-19, the sector is set for growth in the long term. Within this context, air navigation plays a major enabler role. On one side, air navigation facilitates economic recovery by responding to varying demand by airspace users, with re-emerging or new network connections. On the other side, there is an increased focus on reducing the impact of aviation on the climate, through a continual reduction of environmental impacts due to operational constraints as an immediate measure. Other measures, like market-based mechanism, global uptake of sustainable aviation fuel, or novel engine techniques and aircraft design will require more time.

The Brazilian Department of Airspace Control (DECEA) Performance Section and the EUROCONTROL Performance Review Unit (PRU) jointly produced this second edition of the Brazil-Europe comparison. This bi-regional operational performance report uses commonly agreed metrics and definitions to compare, understand, and improve air the performance of navigation services (ANS). This report, and previous reports, are available online at https://ansperformance.eu/global/brazil/. It is also planned to augment the reporting with a supporting dashboard.

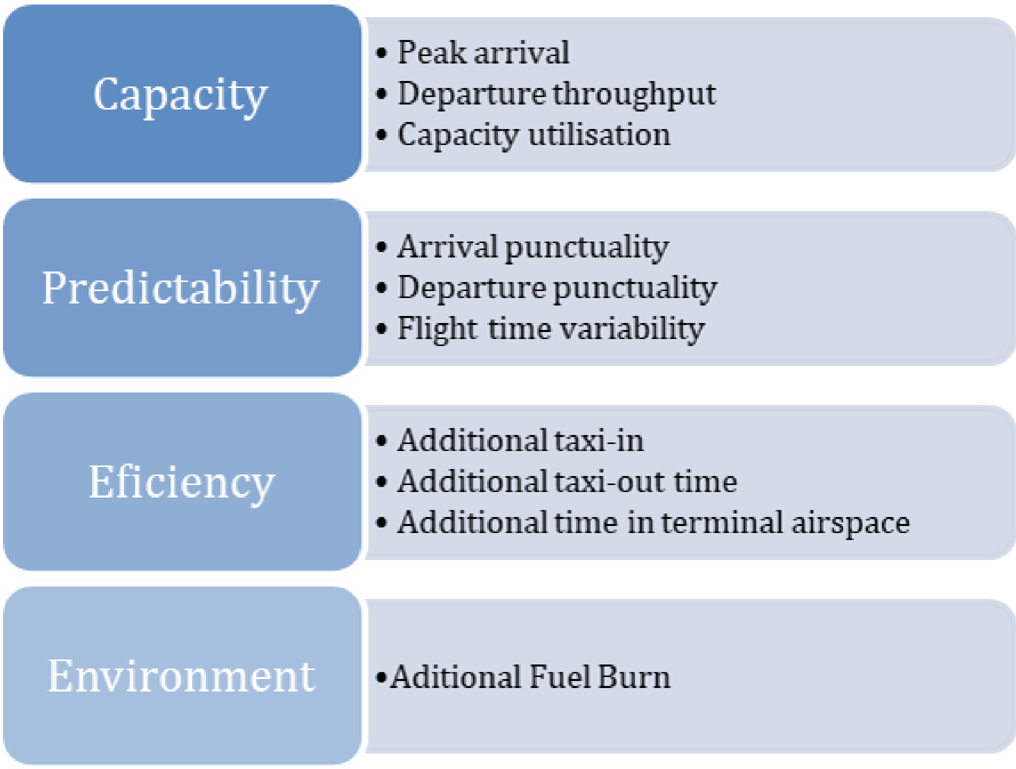
This second edition aims to consolidate the existing comparison process and expand its scope. This report updates the overview on both (Brazilian and European) air navigation systems; broadens the temporal scope, and adds new analyses. The report focuses on a subset of the eleven Key Performance Areas identified by the ICAO Global Air Navigation Plan (ICAO 2005, Appendix D).

While the primacy of Safety is fully recognised, the scope of this report is limited to operational ANS performance due to data constraints. In particular, Predictability, Capacity, Efficiency and Environment, as shown below.

This second report also introduces an initial approach to quantify the environmental impact of operational inefficiencies.

The comparison shows similarities and differences in the air navigation service provision and observed performance in both regions. Major take-aways of this report include:

- Overall, air navigation service provision is more fragmented in Europe with a higher number of local/national air navigation service providers and their respective control units. Integrated civil/military service provision is inherent to the organisation of DECEA and the Brazilian system, while in Europe a mix of co-location and integration exists, according to local/national arrangements.
- COVID measures strongly impacted air transportation demand in both regions and affected almost all air navigation system parameters.
- The difference between Brazil's and Europe's systems reacting to the seasons became more evident during the pandemic recovery. When not hit by another COVID-19 wave, the European region had greater variations in demand between the winter



and summer seasons. The Brazilian flow recovered more gradually, showing a more continuous demand.

- Predictability in both systems degraded during and post COVID phase and is slowly recovering to pre-COVID-19 levels.
- Airport runway system capacities in both systems are designed to meet the traffic levels. Capacities at the Brazilian airports were increased in light of a change of methodology to determine these capacities and changed procedures.
- The European system showed a higher association between lower demand and increased efficiency considering additional taxi time, additional time in terminal airspace and flight time variability. Taxi performance in Brazil follows similar principles and operational procedures with no significant differences. The partial analysis of additional time in terminal airspace revealed that on average traffic in Brazil observed higher times during the arrival phase in 2021 suggesting a system-wide change. The level of variability of flight times reflected the overall trend.
- An initial approach to quantifying the emission benefit pool on the basis of the observed additional taxi-times was developed. Emissions and the improvement pool - next to operational constraints and inefficiencies - are dependent on the fleet mix operated at the different airports. This includes the role of the airport within the respective system. Larger hubs with a higher share of traffic - and in particular heavy aircraft operations - showed a higher contribution to the overall emission benefit pool.

This report will be updated throughout the coming years under the umbrella of the DECEA-EUROCONTROL memorandum of cooperation. It is also planned to establish a web-based rolling monitoring updated on a regular basis. Future editions will complement the data time series and support the development of further use-case analyses. The lessons learnt of this joint project will be coordinated with the multi-national Performance Benchmarking Working Group (PBWG) and the ICAO GANP Study sub-group concerned with the further development of the GANP Key Performance Indicators (KPIs).

1 Introduction

1.1 Background

Since its first flights, the aviation world has learned that standardisation is the key to healthy and prosperous growth. Over the years, the good lessons experienced in sharing standards in operational activities have spread to all areas, including organisational management and strategic planning. In the early 2000s, ICAO proposed an approach inspired by the renowned PDCA cycle, adding performance-based management to it. Although ICAO emphasises the importance of a performance-based approach, the lack of a common understanding of establishing and calculating the indicators would make them internationally useless. Therefore, in 2016, interested stakeholders developed a set of key performance indicators used by a variety of organisations to establish a common set of indicators. This set of indicators is proposed as part of the ICAO Global Air Navigation Plan update cycle and the related Aviation System Block Upgrades. Stakeholders are encouraged to share their common understanding and lessons learnt from measuring air navigation system performance and providing input to the decision making process in terms of operational procedure changes and deployment of novel enabling technologies.

With this willingness to partner and share, Brazil and Europe, represented by DECEA and EUROCONTROL, signed a cooperation agreement in 2015. Amongst other activities, this agreement entails the collaboration and joint developments in the field of operational performance benchmarking of Air Navigation Services (ANS).

Based on this agreement, the Brazilian Department of Airspace Control (DECEA) started a Working Group, which has become the ATM Performance Indicators Management Committee, aiming at improving performance-based management. Through lessons learnt from the best practices observed at EUROCONTROL, and in particular its Performance Review Unit (PRU), DECEA established the Performance Section.

DECEA Performance Section and the PRU have established a joint project to foster the common understanding and harmonised interpretation of the proposed ICAO GANP indicators. The technical work has been conducted throughout the recent years comprising joint face-to-face workshops/meetings and a series of web-based discussions. An essential part of the work entailed the identification and validation of comparable data sources, the development of a joint data preparatory process, and supporting analyses to produce this report.

1.2 Scope

Comparisons and operational benchmarking activities require common definitions and joint understanding. Hence the work in this report draws from commonly accepted outputs of previous work from ICAO, other bi- or multi-regional operational benchmarking activities (e.g. PBWG [1]), and regional or organisational practices. The key performance indicators (KPIs) used in this report are developed using procedures on best available data from both the DECEA Performance Section and PRU. The comparison described in this report does not address all eleven Key Performance Areas (KPA). From an indicator perspective, DECEA Performance Section and PRU agreed to focus on an operational benchmarking and to collaborate on the basis of the currently proposed performance indicators coordinated by ICAO in conjunction with the update of the Global Air Navigation Plan (GANP). This second edition builds on the initial report and focuses on system characteristics and the KPAs Capacity, Efficiency, Predictability and Environment. The report also presents an initial approach to quantifying potential inefficiencies in terms of fuel burn and CO_2 emissions.

1.3 Geographical Scope

The geographical scope of this report relates to Brazil and Europe.

Brazil is defined as the sovereign airspace of the national territory of Brazil. In Brazil, airspace control is performed in an integrated civil-military manner. The same institution performs both the air defence and air traffic control functions: the Brazilian Air Force. The Department of Airspace Control (DECEA) is a governmental organization subordinated to the Brazilian Air Force Command. That Department coordinates and provides human resources and technical equipment for all air traffic units within Brazilian territory, ensuring the safety of air traffic and, at the same time, contributing to military defence.

DECEA is the main body of the Brazilian Airspace Control System (SISCEAB). The department is in charge of providing the Air Navigation Services for the 22 million km^2 of airspace jurisdiction, including oceanic areas. The Brazilian airspace is composed of 5 Flight Information Regions (FIR). Air traffic within these FIRs is managed by 4 operational bases subordinated to DECEA. The areas of responsibility of these integrated Centres for Air Defence and Air Traffic Control (CINDACTA) are depicted in Figure 1.1).

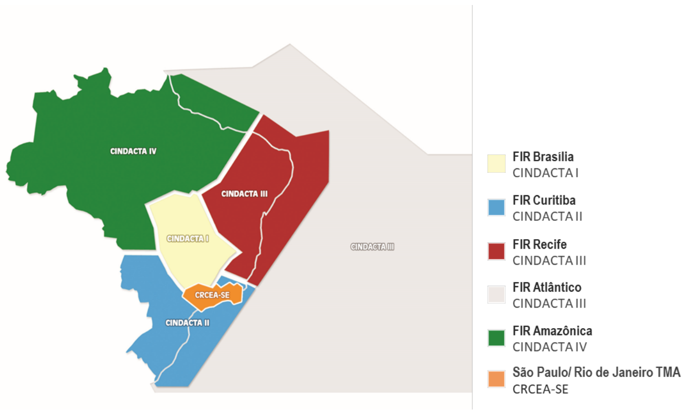


Figure 1.1: Brazilian Airspace Structure/FIRs (CINDACTAs)

The CINDACTAs combine civil air traffic control and air defence military operations. In addition to CINDACTAs, there is also the Regional Center of Southeast Airspace Control

[1]The Performance Benchmarking Working Group (PBWG) is a multi-regional group with participation from Singapore, Thailand, Japan, Brazil, China, United States, and Europe.

(CRCEA-SE), which is responsible for servicing air traffic for the high density air flow in the terminal areas of São Paulo and Rio de Janeiro.

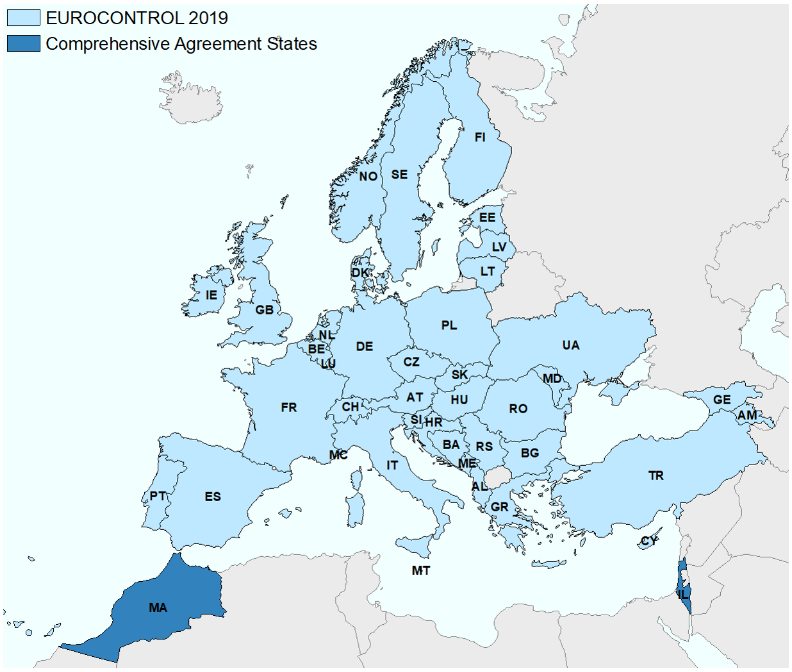


Figure 1.2: European Airspace and EUROCONTROL Member States

In this report, Europe, i.e. the European airspace, is defined as the area where the 41 EUROCONTROL member states provide air navigation services, excluding the oceanic areas and the Canary islands (c.f. Figure 1.2). In 2016, EUROCONTROL signed a comprehensive agreement with Israel and Morocco. Both comprehensive agreement States will be successively fully integrated into the working structures including performance monitoring. Within this report, these states are included in the reported network traffic volume.
EUROCONTROL is an inter-governmental organisation working towards a highly harmonized European air traffic management system. Air traffic services are provided by air navigation service providers entrusted by the different EUROCONTROL member states. Dependent on the local and national regimes, there is a mix of civil and military service providers, and integrated service provision. The Maastricht Upper Area Control Center is operated by EUROCONTROL on behalf of 4 States (Netherlands, Belgium, Luxemburg, and Germany). It is the only multi-national cross-border air traffic unit in Europe at the time being. Given the European context and airspace structure, the European area comprises 37 ANSPs with 62 en-route centres and 16 stand-alone Approach Control Units (i.e. totalling 78 air traffic service units).

Europe employs a collaborative approach to manage and service airspace and air traffic. This includes the integration of military objectives and requirements which need to be fully coordinated within the ATM System. A variety of coordination cells/procedures exists between civil air traffic control centres and air defence units reflecting the local practices. Many EUROCONTROL member states are members of NATO and have their air defence centres / processes for civil-military coordination aligned under the integrated NATO air defence system.

Further details on the organisation of the regional air navigation systems in Brazil and

Europe will be provided in Section 2.1.

1.3.1 Study Airports

As concerns airport-related air navigation performance, this edition of the comparison report addresses the performance at a set of selected airports. These airports represent the top-10 or most relevant airports in terms of IFR movements in both regions and allow to make meaningful comparisons. In Brazil, the selected airports play a significant role in terms of the national and regional connectivity, including the major hubs for international air traffic. These study airports have consolidated systems and structured processes for data collection in support of this comparison report. For the European context, the study airports comprise the busiest airports in several states exhibiting a mix of national, regional, and international air traffic. These airports are also characterised by varying operational constraints that make them excellent candidates for an international comparison. All of these airports are subject to the performance monitoring under the EUROCONTROL Performance Review System and provide movement related data on the basis of a harmonised data specification.

Figure Figure 1.3 provides an overview of the location of the chosen study airports within the regions. The airports are also listed in **?@tbl-scopetable**.

(ref:scopetable-caption) List of study airports for the Brazil / Europe operational ANS performance comparison

Brazil	Europe
* Brasília (SBBR) * São Paulo Guarulhos (SBGR) * São Paulo Congonhas (SBSP) * Campinas (SBKP) * Rio de Janeiro S. Dumont (SBRJ) * Rio de Janeiro Galeão (SBGL) * Belo Horizonte Confins (SBCF) * Salvador (SBSV) * Porto Alegre (SBPA) * Curitiba (SBCT)	* Amsterdam Schiphol (EHAM) * Paris Charles de Gaulle (LFPG) * London Heathrow (EGLL) * Frankfurt (EDDF) * Munich (EDDM) * Madrid (LEMD) * Rome Fiumicino (LIRF) * Barcelona (LEBL) * London Gatwick (EGKK) * Zurich (LSZH)

1.3.2 Temporal Scope

This report focuses mainly on the period from January 2019 through to June 2021. Based on the initial report and data availability, a longer time series (up to June 2022) will be presented, as far as practicable. With this report the focus is on building a timeline with comparable data to be augmented in future editions.

Throughout the report, summary statistics will be given with reference to calendar years of this comparison study. It must be noted that the data for 2022 covers the first six months, January through June.

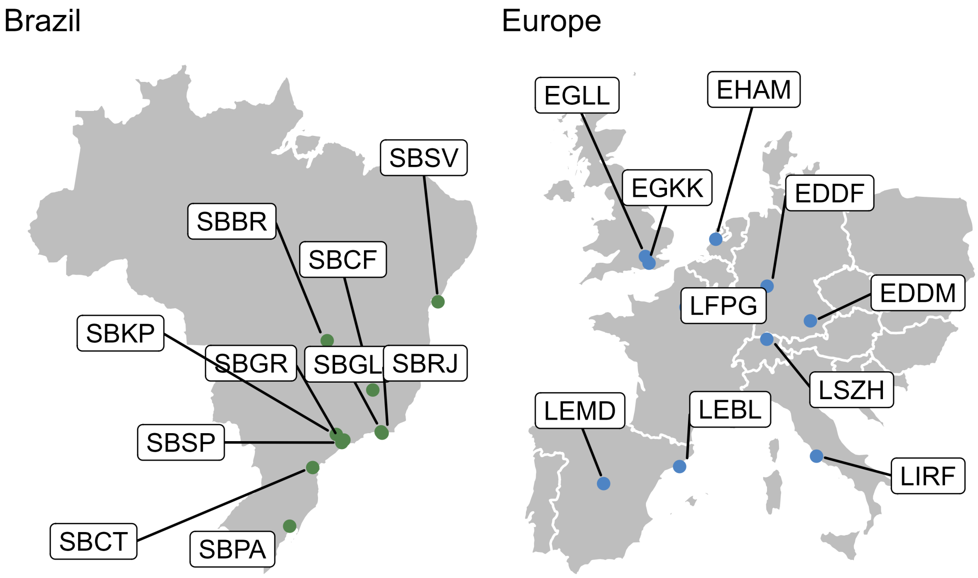


Figure 1.3: Study airports of Brazil/Europe Comparison

1.4 Data Sources

The nature of the performance indicator requires the collection of data from different sources. DECEA Performance Section and PRU investigated the comparability of the data available in both regions, including the data pre-processes, data cleaning and aggregation, to ensure a harmonised set of data for performance comparison purposes.

DECEA mainly uses tower data from the main airports as a data source for performance studies. This was combined with ANAC official and public data for specific indicators. Each landing and take-off operation is collected and provided automatically by the control tower system. The provided data includes such items as the times of operations, gate entry and exit, and flight origin and destination

Within the European context, PRU has established a variety of performance-related data collection processes. For this report the main sources are the European Air Traffic Flow Management System complemented with airport operator data. The sources are combined to establish a flight-by-flight record. This ensures consistent data for arrivals and departures at the chosen study airports. The data is collected on a monthly basis and typically processed for the regular performance reporting under the EUROCONTROL Performance Review System and the Single European Sky Performance and Charging Scheme (EUROCONTROL 2019).

1.5 Structure of the Report

This edition of the Brazil-Europe comparison report is organised as follows:

- **Introduction** overview, purpose and scope of the comparison report; short description of data sources used Air Navigation System Characteristics high-level descrip-

tion of the two regional systems, i.e. areas of responsibility, organisation of ANS, and high-level air navigation system characteristics
- **Traffic Characterisation** air traffic movements, peak day demand, and fleet composition observed at the study airports
- **Predictability** observed arrival and departure punctuality
- **Capacity and Throughput** assessment of the declared capacity at the study airports and the observed throughput, including runway system utilisation comparing achieved peak throughput to the declared capacity.
- **Efficiency** analysis of taxi-in, taxi-out, and terminal airspace operations.
- **Environment** initial analysis of the additional fuel burn and associated CO_2 emissions based on the observed operational inefficiencies.
- **Conclusions** summary of this report and associated conclusions; and next steps.

2 Air Navigation System Characterisation

This section provides a general overview of the Brazilian and European air navigation system. In general terms, the provision of air navigation services in Brazil and Europe are based on similar operational concepts, procedures, and supporting technology. However, there exists a series of differences between the two regional systems. These characteristics help to explain the similarities and differences in terms of key performance indicators observed throughout this report.

2.1 Organisation of Air Navigation Services

A key difference between the Brazilian and European air navigation system is the organisation of ANS in both regions. In Brazil there is one air navigation services provider, while in Europe each member state has assigned the service provision to national or local providers. To date the Maastricht Upper Area Control Centre is the only multi-national air traffic service unit in Europe [1]. Network functions, such as air traffic flow management and airspace management are centrally planned/coordinated by the European Network Manager.

The Department of Airspace Control (DECEA) is responsible for the management of all the activities related to the safety and efficiency of the Brazilian airspace control. DECEA's mission is to manage and control all air traffic in the sovereign Brazilian airspace and to contribute to its defense. In that respect, DECEA operates a fully integrated civil-military system. The airspace covers an area of approximately 22 million km^2 (non-oceanic: 8.5 million NM^2) and is organised into 5 Flight Information Regions comprising 5 area control centres (ACC), 57 towers (TWR) and 42 approach units (APP) (c.f. Figure 1.1).

The European non-oceanic airspace spans over an area of 11.5 million km^2. As concerns the provision of air traffic services, the European approach results in a high number of service providers, i.e. there are 37 different en-route air navigation service providers (ANSPs) with varying geographical areas of responsibility. Next to a limited number of cross-border agreements between adjacent airspaces and air traffic service units, air traffic service provision is predominantly organised along state boundaries / FIR borders. Maastricht UAC represents the only multi-national collaboration providing air traffic services in the upper airspace of northern Germany, the Netherlands, Belgium, and Luxembourg. The level of civil-military integration varies from country to country in Europe. Within the European context, air traffic flow management (ATFM) and airspace management (ASM) are provided/coordinated centrally through the Network Manager. The design of airspace and related procedures is no longer carried out or implemented in isolation in Europe. Inefficiencies in the design and use of the air route network are considered to be a contributing

[1] On behalf of the four member states the EUROCONTROL Maastricht Upper Area Control Centre manages the upper airspace (from 24,500 to 66,000 feet) over Belgium, the Netherlands, Luxembourg and north-west Germany

factor towards flight inefficiencies in Europe. Therefore the development of an integrated European Route Network Design is one of the tasks given to the Network Manager under the European Commission's Single European Sky initiative. This is done through a collaborative decision-making (CDM) process involving all stakeholders. A further task of the Network Manager is to ensure and coordinate that traffic flows do not exceed what can be safely handled by the air traffic service units while trying to optimise the use of available and deployed capacity. For this purpose, the Network Manager Operations Centre (NMOC) monitors the air traffic situation and proposes flow measures coordinated through a CDM process with the respective local authorities. This coordination is typically affected with the local flow management position (FMP) in an area control centre. The NMOC implements then the respective flow management initiative on request of the authority/FMP.

Similar to Europe, the Brazilian CGNA (Air Navigation Management Centre), which is an organisation subordinated to DECEA, performs the same functions as the European NMOC. CGNA manages the Brazilian air traffic flows, applies ATFM measures and facilitates collaborative decision-making with airlines, airports, control and approach centres. In addition, CGNA also coordinates airspace management, the flight plan handling system, the statistical database, and all activities related to air navigation. In summary, CGNA provides the operational management of ATM processes and related infrastructure, and ensures the availability and quality of the services provided under the Brazilian Airspace Control System (SISCEAB).

2.2 High-Level System Comparison

Starting from an initial macro-comparison, it is evident that the European environment is more complex. For example, while the European non-oceanic airspace is about a quarter larger (26%) than Brazil's non-oceanic airspace, the number of 37 Air Navigation Services Providers already shows a totally different system complexity in terms of ATM operations compared to just one ANSP in Brazil. Figure 2.1 summarizes the key characteristics of the Brazilian and European air navigation system for 2021. Both regions operate with similar operational concepts, procedures and supporting technology. However, Brazil, with lower traffic density, finds a more challenging cost-benefit ratio to maintain communications coverage and surveillance for low-traffic regions, while the European region faces more considerable challenges in coordinating efforts to avoid congestion due to a higher density.

In terms of air traffic service provision, the comparison of the number of APP and ACC facilities is less straightforward. Several relevant differences can make conclusions difficult. While in Brazil each Approach Unit (APP) is a stand alone ATC unit, the European model sees a mix of stand alone and co-located units.
Next to the partial co-location of APP and ACC units in Europe, the higher number of ACCs reflects the local/national focus of air traffic service provision. This also becomes visible when comparing the total number of ATCOs in operations. The number of ATCOs in Brazil ranges around 20% of the numbers of ATCOs in Europe. While a crude high-level measure, the ratio of IFR movements per ATCO ranged at the same order of magnitude in 2021 (+3% in Brazil). In 2019 (pre-COVID) the European ratio is about 20% higher than in Brazil. This suggests that the staffing situation in 2021 in comparison to the overall traffic situation in both regions follows similar criteria. This needs to be contrasted with

KPA	Brazil 2019	Brazil 2021	Europe 2019	Europe 2021	BRA/EUR 2019	BRA/EUR 2021
geographic area (million km^2)	8.5 non-oceanic (22.5 Total)		11.5 non-oceanic		74%	
number of en-route ANSPs	1		37		3%	
number of towers	59	57	400+		14%	
number of APP	43	42	16 (stand alone)		263%	
number of ACC	5		62		8%	
number of ATCOs in OPS	3 126	3 549	17 563[1]	17 563[1]	18%	20%
controlled IFR flights	1 594 442	1 286 224	10 995 092	6 173 101	15%	21%
flights/ATCO	510	362	626	351	81%	103,13%
traffic density non Oceanic (flights/km2)	0,187	0,151	0,956	0,536	20%	28%

[1]2018, excluding Georgia and Canary Island

Figure 2.1: High-level comparison 2021

the lower traffic density in Brazil (and overall lower traffic levels). On average, the shift in traffic levels per volume of airspace is significantly lower in Brazil than in Europe. This suggests that the network connectivity in Brazil is more centralised than in Europe (lower density of flights per km^2 vs similar average number of controlled flights per ATCO). The latter can also be derived from the fact that the European network also entertains a high share of intra-European traffic primarily servicing major hubs (i.e. capitals, business centres) between the European states.

2.3 Regional Approaches to Operational Performance Monitoring

2.3.1 Europe

Within Europe, the Performance Review Commission (PRC) was created by the EUROCONTROL States in 1998, following the adoption of the European Civil Aviation Conference (ECAC) Institutional Strategy the previous year. A key feature of this Strategy was that "an independent Performance Review System covering all aspects of ATM in the ECAC area will be established to put greater emphasis on performance and improved cost-effectiveness, in response to objectives set at a political level". Subsequently, the Performance Review Unit (PRU) was established to support the work programme of the PRC. The major objective of the PRC is to provide independent advice to the EUROCONTROL Permanent Commission through the Provisional Council on pan-European ATM performance.

The EUROCONTROL PRC and PRU provide objective information and independent advice based on extensive research, data analysis, and consultation with the governing bodies and interested stakeholders on all aspects of European air navigation performance. EUROCONTROL's performance review system was a world-first at the time it was established in the late 1990s.

The PRC's work has been built on in wider fora, such as ICAO's global performance-based approach, and the performance scheme of the Single European Sky (SES). The EUROCONTROL performance review system and the SES performance scheme jointly contribute towards improving the overall performance of air navigation services and network functions in Europe. PRU also supports the European region efforts of ICAO under the Doc 030 performance framework.

International cooperation and supporting further harmonisation of air navigation performance practices is one of the strategic objectives of the PRC. Within this context, the PRC is engaging with ICAO and international partners. This report is an outcome of the DECEA/EUROCONTROL MoU and the cooperation in the field of operational ANS performance. The findings of bi-lateral comparison reports are carried forward under the umbrella of multi-lateral working arrangements (e.g. PBWG). Through this harmonisation validated approaches and methods are proposed to ICAO's GANP Performance Expert Group.

Next to two major annual pan-European performance oriented publication, i.e. ACE (ATM Cost Effectiveness) and PRR (Performance Review Report), operational performance monitoring includes a series of indicator specific data products (web-pages/dashboards, self-service reports). Within the scope of this report, respective information on operational performance be found at https://ansperformance.eu. The tab "views" provides access to data products related to the ones used in this comparison study on airport, ANSP, and national level. It needs to be noted that the indicator parameterisation used in this report differs from the parameters used within the European performance monitoring (e.g. percentiles and time frame used for the determination of associated reference time). Reported trends of this comparison report are consistent with the regional monitoring, however, the actual values of the indicator may vary. PRU is constantly expanding its online reporting on performance to provide stakeholders with independent performance monitoring data for their decision-making.

2.3.2 Brazil

The performance-based approach was adopted by DECEA as a consequence of ICAO publications in the second half of the 2000s. The concept and this form of planning gained more defined contours with the publication of ICAO DOC 9883 - Manual on Global Performance of the Air Navigation System, in 2009, following DOC 9854 - Global Air Traffic Management Operational Concept, in 2005. DECEA established a project for the development of Performance Management in 2012 within the initial activities of the SIRIUS Brazil Program (https://sirius.decea.mil.br/en/). However, essential details on the definition, metrics, and, especially, the standardisation of indicators were still a regional and global challenge.

Eventually, the effort and opportunity met with the signing of the broad-purpose Cooperation Agreement between DECEA and EUROCONTROL in 2015 and the publication of "Description of the potential Performance Indicators presented in ICAO's Global Air Navigation Plan 2016", which had a fundamental contribution from EUROCONTROL. On the basis of more precise process objectives and requirements, DECEA accelerated its transformation in search of organisational self-knowledge. Since 2017, DECEA published an annual Performance Report and several comparative reports, developed a series of training courses, and continuously expanded the availability of data for performance monitoring purposes including assciated analysis tools.

In 2019, DECEA's ATM Performance Section was born to manage and coordinate activities related to performance management and represent Brazil in international agreements and forums in this field. The setup of the Performance Section was inspired by the Performance Review Unit of EUROCONTROL. With a broad and dedicated virtual environment, the Section publishes its products, data, and - in the future - recommendations for the improvement of ATM Performance (See https://performance.decea.mil.br/).

With increasing levels of expertise in operational performance monitoring and maturity in data collection and processing, DECEA published its first DECEA ATM Performance Plan 2022 - 2023 (https://publicacoes.decea.mil.br/publicaca/pca-100-3). The plan comprises the identification and definition of performance goals for twelve ICAO/Brazilian operational key performance indicators and establishes the monitoring of five complementary performance indicators. The release of this first plan is a key step in the roadmap of DECEA to implement the performance based approach in Brazil.

The performance approach is mainly about an organization's past outcomes compared to its present and future results. However, the comparisons between peers in the universe of air navigation service improve methodologies and present opportunities for advances that would not be identified otherwise.

Within the South American region, DECEA actively promotes the open culture of trust and sharing in operational performance monitoring catalysed by the relationship with EUROCONTROL. In June 2022, DECEA was invited to coordinate a Workshop with the ICAO SAM Regional Office. Participants from Argentina, Bolivia, Chile, Colombia, Ecuador, Panama, Paraguay, Peru, Uruguay and Venezuela exchanged experiences and lessons learned with speakers from DECEA. In late 2022, DECEA will promote a Performance Seminar in the technological cluster of São José dos Campos, Brazil, the host city of the Aeronautics Technological Institute, one of the event's supporters. EUROCONTROL was invited to participate as a partner in the seminar by sending speakers.

DECEA embraces the culture of collaboration and sharing perennially. DECEA made its indicators and databases easily accessible on public dashboards, available at https://performance.decea.mil.br/produtos/dashboard/). Thus, DECEA intends to carry forward the culture of reciprocity and transparency that has been presenting consistent results and benefiting the entire aviation community.

2.4 Summary

This chapter has shown high-level similarities and differences between both regions. The non-oceanic airspace in Brazil is about a quarter smaller than in Europe and is serviced by about 40% less air traffic service units (APP and ACC, Brazil: 47 vs Europe: 78). While on average traffic levels in Brazil ranged in 2019 and 2021 at 20% of the European air traffic, the number of ATCOs is commensurate with the traffic levels and difference in ATCO staffing numbers in Brazil and Europe.
The latter is also evidenced by the similar ratio of air traffic serviced vs numbers of ATCOs in operations in 2021. This suggests that traffic density and complexity during peak times at major hubs in Brazil may be comparable to Europe. More research is needed to asses the overall network composition in both regions. The general spread in numbers highlights that the European system is still dominated by a more nationally oriented approach to air traffic service provision, while Brazil benefits from a single ANSP set up.

The chapter also provides a summary of the regional approach to operational performance monitoring. The Performance Section of DECEA and EUROCONTROL's PRU are actively collaborating on the international level to foster the understanding and application of the ICAO GANP performance framework, and drive the further developments and implementation in both regions. Both groups intend to deepen its cooperation in the future by expanding the scope of this bi-regional comparison report and the joint multi-lateral work.

3 Traffic Characterisation

The overarching objective of air traffic services is the provision of safe, orderly, and efficient flow of air traffic. Accordingly, operational system performance is linked to the actual and serviced demand (i.e. air traffic). It must be noted that the serviced traffic may be different from the actual demand. Constraints, both on the airspace user and air navigation system side may lead to unsatisfied demand. However, the level of these changes is outside the scope of this comparison.
For operational comparisons, it is therefore important to have a good understanding of the level and composition of the air traffic. The previous section provided the high-level context and organisation of air navigation services in Brazil and Europe. This chapter establishes some key air traffic characteristics for both regions to frame the observed operational performance in latter parts of the report.

3.1 Annual Traffic

Figure 3.1 shows the regional traffic development in Brazil and Europe. Pre-COVID air traffic in Brazil showed only mild variation across the year [1]. This is in contrast to the strong seasonal nature of air traffic in Europe and its peaking behaviour during the summer months of 2019. In both regions, the unprecedented decline in air traffic occurred in March 2019 in the aftermath of the pandemic-declaration by the World Health Organisation (WHO).

To understand the magnitude of the impact of COVID on air traffic, Figure 3.2 depicts the regional traffic in a normalised form. The reference level for the normalisation is set at the 90th percentile of the traffic observed in 2019. The initial drop in traffic due to COVID-related travel constraints started a few days earlier in Europe. This was related to the reaction of several air transport operators to limit their flights to Asia. Furthermore, some European states already responded to the initial surge of infections in anticipation of the declaration by the WHO.

Both regions responded initially similar to the world wide restrictions for air travel in combination with immediate regional health measures following the declaration by the WHO. The traffic declined in both regions in the order of magnitude of about 80-90%. While traffic in March through May 2020 showed a similar pattern, Europe experienced a higher share of air traffic in June, July and August of 2020. Traffic levels in Brazil grew gradually and consistently in 2020 and broke even with Europe in the early autumn. At that point in time Europe was facing a second wave of infections following an initial relaxation of health constraints to facilitate the summer vacation season. In consequence, governments had to impose again restrictions on the regional traffic to curb the further spread. While air traffic in Europe declined, traffic in Brazil continued its initial recovery

[1] For Brazil, the depicted volume of air traffic is the sum of all movements at the study airports. This captures a significant share of the total traffic and shows the overall development.

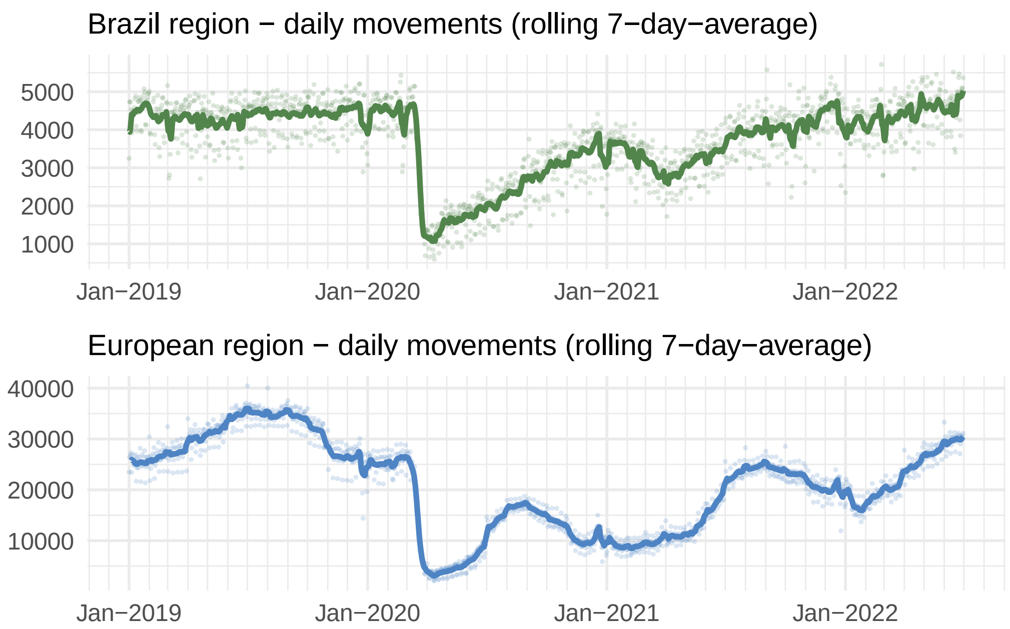


Figure 3.1: Timeline of regional air traffic

until the end of 2020. In both regions the spikes (twin peaks) of the seasonal Christmas and New Year's traffic are visible. A significant change in the pattern developed with the beginning of 2021. Following the seasonal pattern, Europe observed a continual increase in air traffic as of end January/beginning February 2021 and a strong recovery to about the 65-70% pre-COVID level ensued. The pattern of air traffic was different in Brazil. After having reached a level of about 65% at the end of 2020, Brazil also faced a second wave of COVID infections in early 2021. This resulted in a distinct reduction over the first 6 weeks in 2021 followed by a similar recovery rate throughout March and April 2021. Both regions reached 65-70% of their pre-COVID traffic levels in April and May 2021. While traffic continuously increased in Brazil, Europe saw another wave post-summer 2021. Traffic levels reached the pre-COVID 90% (and higher level) in Brazil in early 2022. With the continual relaxation of travel constraints for inner-European traffic in early 2022, Europe also reached the 85% pre-COVID level with July 2022.

In general, the gradual recovery over 2020 and 2021 also suffered severe setbacks by the subsequent reappearances of the virus characterised by the subsequent waves (i.e. ripples) in Figure 3.2. Comparing both regions, the recovery patterns of the two regions show a coherent central tendency, with relevant differences according to the season or increased regional health measures (i.e. travel restrictions). It is pertinent to note that European air traffic was more sensitive to the effects of winter and summer, reflecting the holiday seasons and climatic variations. It is interesting to note, that the Brazilian system shows little sensitivity to calendrical and seasonal effects.

By the time of the publication of this report (October 2022), the world economy and global air transportation is still recovering. There is growing confidence that COVID transitioned from its pandemic stage to an endemic stage. By the end of 2021, traffic volume was 26% and 25.5% higher for Brazil and Europe compared to 2020. The Brazilian Gross Domestic Product grew by 4.6% in 2021 and the World Bank's estimate for 2022 is a growth of

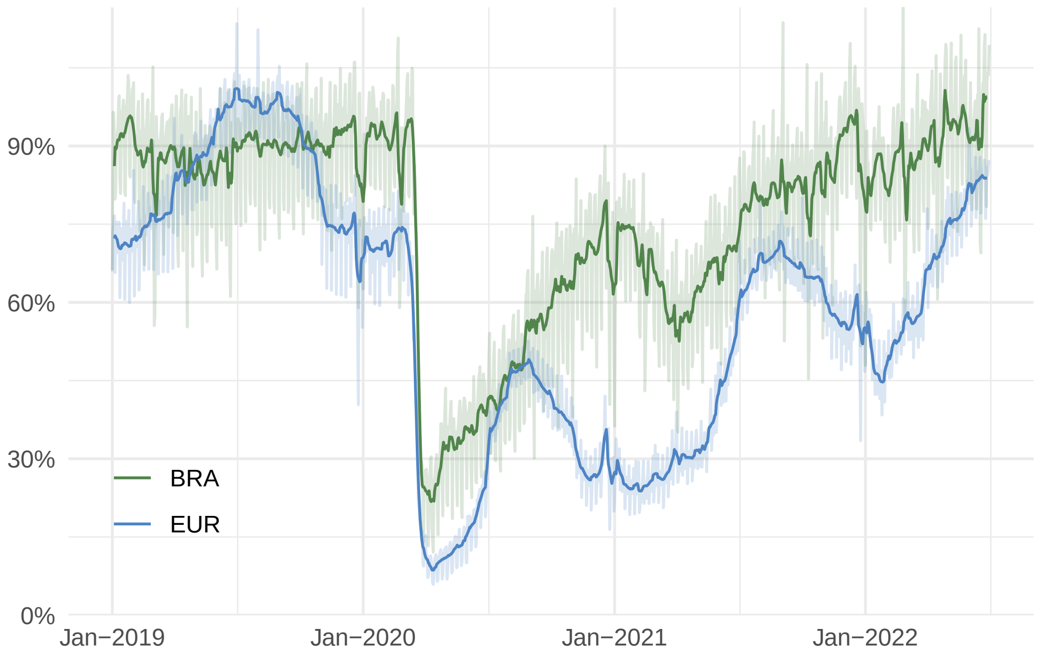


Figure 3.2: Normalised daily traffic in Brazil and Europe

1.4%. The European market has shown a 5.4% GDP [2] increase for EU in 2021. The traffic volume of 2019 is expected to be reached towards end 2023 or beginning of 2024 for both regions, if the economic activity keeps on track.

3.2 Study Airport Level Traffic

The previous section showed the traffic development on the network level and Airports, in turn, represent nodes in this overall network. Thus, changes in the overall traffic situation will ripple down to the airport level. However, connectivity and type of traffic may differ from airport to airport. It is therefore useful to understand how traffic developed locally on the level of the selected study airports.

Figure 3.3 shows the variation of air traffic across the study airports. On average, the annual traffic at the Brazilian airports in 2020 and 2021 ranged about 45% respectively 47% lower than in 2019. The European study airports observed a higher decrease. The airports serviced -60% in 2020 and -55% in 2021. The airports of this study had been selected based on their role in the regional networks. While the numbers vary slightly, a similar pattern is observed in Brazil and Europe. This suggests that the traffic related pressure on air traffic services behaved in a similar fashion. This observation will be relevant for the following chapters. Considering all 10 airports per region may however mask varying behaviour at different airports. It is important to note that the pandemic affected both sets of 10 airports more severely than their national levels, recalling that Brazil closed 2021 with -20% and EUR with -43% compared to 2019 overall aircraft movement.

Figure 3.4 shows the annual traffic observed at the study airports in 2021 and the associated annual variation of traffic comparing 2020 and 2021. On average, traffic levels at all

[2] Source: https://ec.europa.eu/eurostat

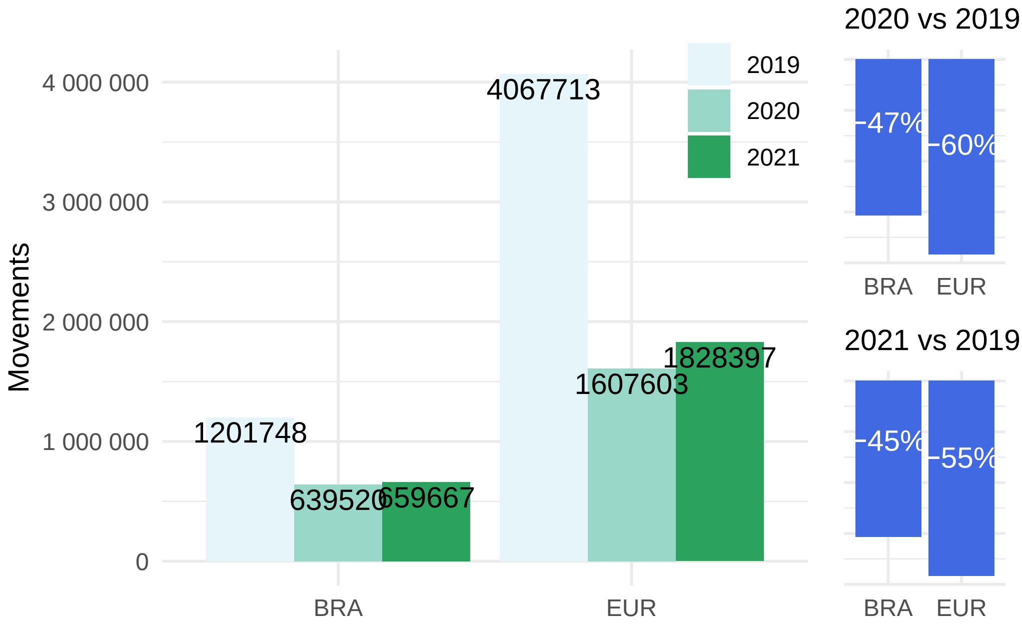


Figure 3.3: Movements at study airports in both regions

airports in both regions increased following the initial drop in 2019. But there are notable exemptions.
São Paulo/Guarulhos (SBGR) in Brazil and London Heathrow (EGLL) in Europe show a similar lagging recovery. This reflects the high share of international air traffic serviced at both airports. Both airports observed an about -5% lower traffic on an annual basis in 2021 than in 2020. Almost -10% lower traffic was observed in 2021 in comparison to 2020 at Curitiba (SBCT).This drop may be related to the strong connection between Curitiba and the Argentine capital, Buenos Aires, which faced more severe travel restrictions due to COVID. London Gatwick (EGKK) serviced about -30% less traffic in 2021 than in 2020, probably reflecting the UK's more severe anti-COVID restrictions at that time. Traffic levels in 2021 at SBGR and São Paulo/Congonhas (SBSP) range in the order of magnitude of the less busy airports in the top-10 of Europe.

3.3 Peak Day Traffic

While the annual traffic provides insights in the total air traffic volume and associated demand, it does not provide insights on the upper bound of achievable daily movement numbers. The latter depends on demand, operational procedures and constraints, and the use of the runway system infrastructure. The peak day traffic is determined as the 99th percentile of the total number of daily movements (arrivals and departures). The measure represents thus an upper bound for comparison purposes.

Figure 3.5 shows the peak day traffic in 2019 with reference to the number of runways.

Figure 3.5 shows the peak day traffic in 2021. Peak traffic at the 2-runway airports Guarulhos (SBGR) and São Paulo Congonhas (SBSP) in Brazil and London Heathrow (EGLL) and Munich (EDDM) in Europe achieve similar or higher peak numbers than

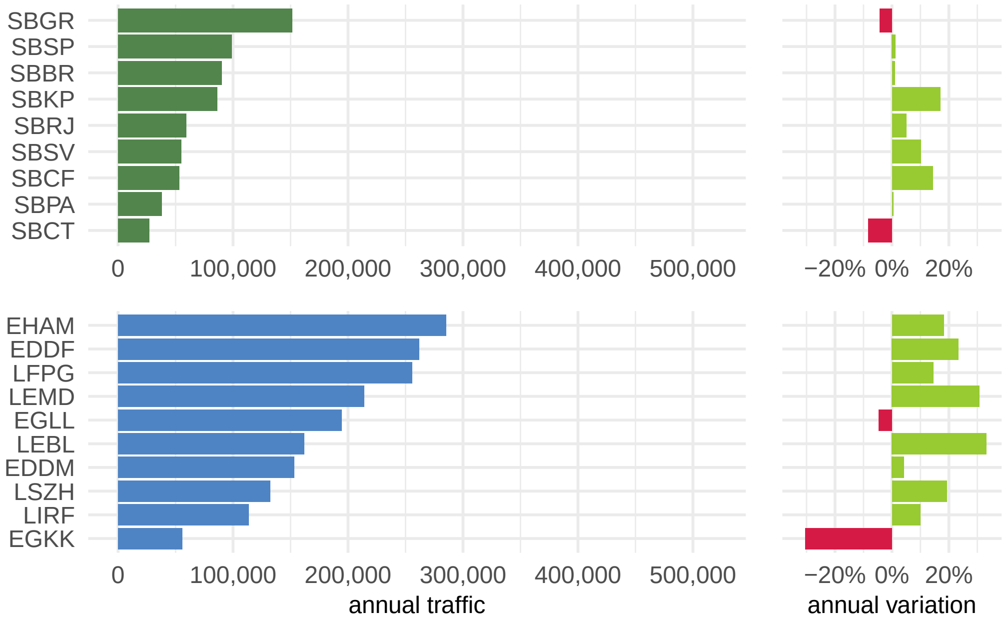


Figure 3.4: Annual traffic at study airport in 2021 and variation 2020/2021

airport with more runways. It's valid to note that Campinas (SBKP) and Salvador (SBSV) were stable due to an already low traffic concentration regarding per day granularity.

For European with more than 2 runways it needs to be noted that the runway system does not support independent operations of all available runways. Thus, the serviced peak traffic is also impacted by the runway system configuration. Peak operations as SBGR range in the same order of magnitude than Munich (EDDM) and exceed the peak movement observed in Zurich (LSZH, 3 runway system) or Rome Fiumincino (LIRF, 4 runway system).

Figure 3.1 and Figure 3.2 depict the decline in air traffic with the start of the COVID pendemic in March 2020 at the same moment in both regions. However in terms of peak movements the seasonal difference between Brazil and Europe become more visible in Figure Figure 3.6. While in Europe a sharp drop in peak day traffic is already observed for the year 2020, the respective peak day movements in the first 3 month in 2020 in Brazil range in the same number than the years before. The recovery seen in 2021 movements did not reflect at Peak Days. The distribution was more equalized, resulting in lower peaks.

3.4 Fleet Mix

The fleet mix - and in particular the separation requirements between the different aircraft types - is an important influencing factor for the capacity and observed (and realisable) throughput. In particular, aircraft with longer runway occupancy times or larger proportions of heavy aircraft may result in lower throughout due to the larger wake turbulence separations. The locally defined capacity values may therefore differ based on the predominant fleet mix and operational characteristics, and ultimately result in different observed Peak Day movement numbers.

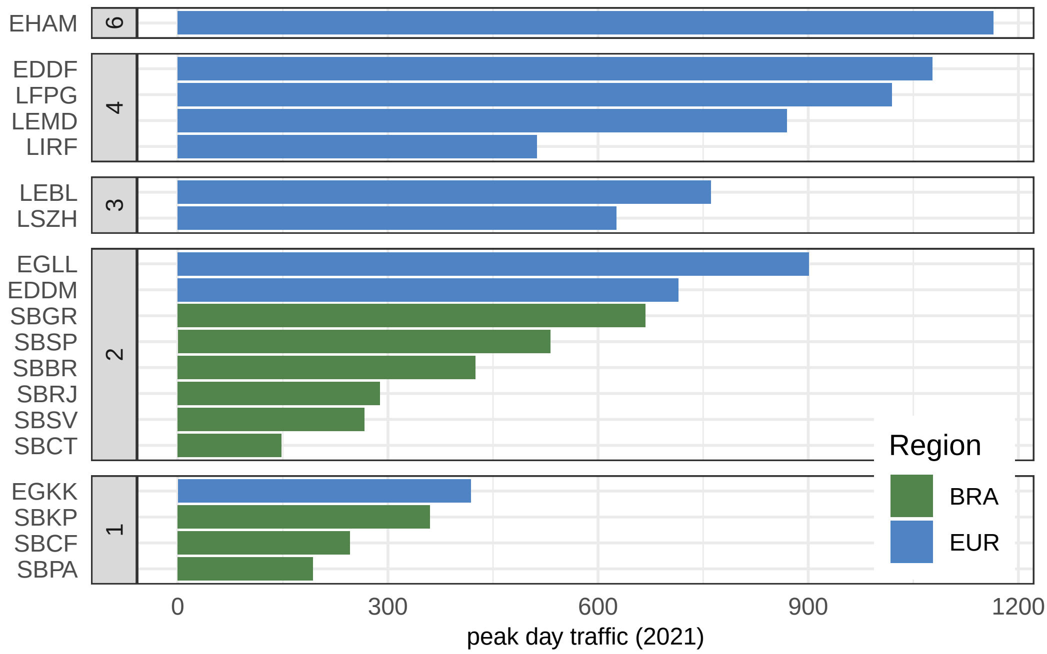


Figure 3.5: Peak day traffic (99th percentile of annual movements)

Figure 3.7 depicts the observed share of different wake turbulence categories (WTC) across the study airports in 2021. In both regions, "medium" aircraft types are the predominant aircraft type.
On average, airports in Europe observed a higher share of "heavy" aircraft in 2021. In Brazil, Guarulhos (SBGR) and Campinas (SBKP) serviced a noticeable share of "heavy" aircraft of around 12% which is comparable to the share at Zurich (LSZH). In Brazil, "light" types play a larger role at the study airports than on the European side. The fleet mix at SBGR and SBKP showed a similar pattern (high share of medium, discernible share of heavy, and shallow share of light types) as observable at European airports. The heavy category represents wide-body passenger aircraft and full cargo flights. Within the European region - and its multitude of national hubs - a significant number of international long-haul flights is operated at the chosen study airports. In Brazil, the highlighted airports, Guarulhos (SBGR) and Campinas (SBKP), play a major role in terms of international connectivity. It follows that medium and light types are used for inter-reginal connections. Based on the selected study airports, the underlying decentralised structure of the European network becomes more visible. While international air traffic is centralised in Brazil with 2 pre-dominant hubs, capital or main national hubs are more frequent in Europe. London Heathrow (EGLL) is a noteworthy exemption. The level of international connectivity can be derived from a 50% share of heavy types.

Figure 3.8 and Figure 3.9 depict the evolution of the annual fleet mix for the years 2019 through 2021 for nine of the study airports in both regions [3]. Two principal patterns emerge: (i) airports with COVID-related contraction of traffic, i.e. the reduction in overall traffic in 2020 and 2019 did not influence the relative share of aircraft types serviced at the airport, and (ii) airport with a reduction of the share of "heavy" aircraft and increase of the relative share of "medium" or "light" types.

[3] To increase readability of the visualisation an airport with low variability has been removed from the figure for both regions.

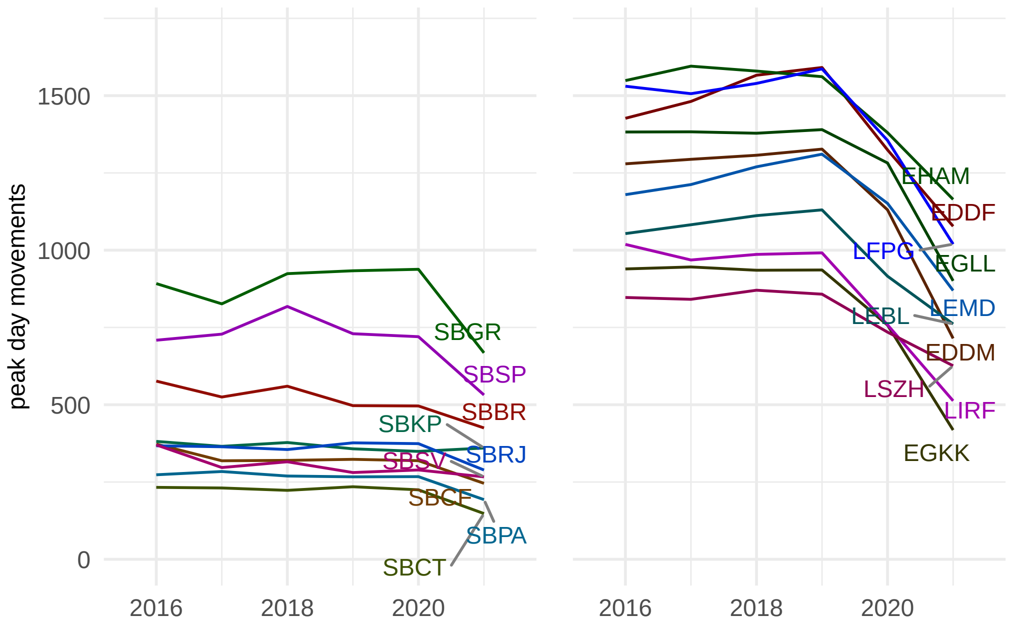


Figure 3.6: Variation of Peak day traffic over time

With the exception of Zurich (LSZH) in Europe, “light” types did not feature widely. There appears to be a reciprocal relationship between the relative share of “heavy” and “medium” types utilised in Europe. At major hubs (e.g. EDDF, EGLL, EHAM, LFPG) the ratio of “heavy” aircraft increased across the years.
The fleet mix in Brazil showed a different pattern. While the share of “heavy” types remained on average constant across the period 2019 through 2021, lower shares of “medium” types resulted in higher utilisation rate of “light” types.

For future reports it will be interesting to investigate also the connectivity in terms of operated aerodrome pairs and aircraft types.

Figure 3.10 and Figure 3.11 focus on the temporal evolution of the fleet mix on a rolling weekly basis (7-days) for heavy and medium type aircraft. This shows a more varied behaviour across all airports.

The synchronicity of the relative reduction and increase can be observed at all European airports. The overall traffic pattern at these airports followed the overall traffic development in Europe for the observed period. The increased share of heavy aircrafts may reflect the resilience of cargo flights over the pandemic. Zurich (LSZH) - based on a structurally overall lower share of heavy aircraft and on the presence of a good share of light types - showed a pattern that reflected the overall trends. With a lower share of heavy aircraft for most Brazilian airports, the evolution of the medium type share follows the overall traffic development in Brazil. The decline in March 2020 is characteristic. For example, in Sao Paulo (SBSP) - with a negligible share of heavy aircraft - the share of medium aircraft mirrors the overall trend in Brazil. This shows that SBSP predominantly serviced domestic or short-range traffic. That is somehow expected for São Paulo (SBSP) and Rio de Janeiro (SBRJ) since their runaway length and airport infrastructure are not suitable for heavies, but it is interesting to note that other Brazilian airports such as Brasília,

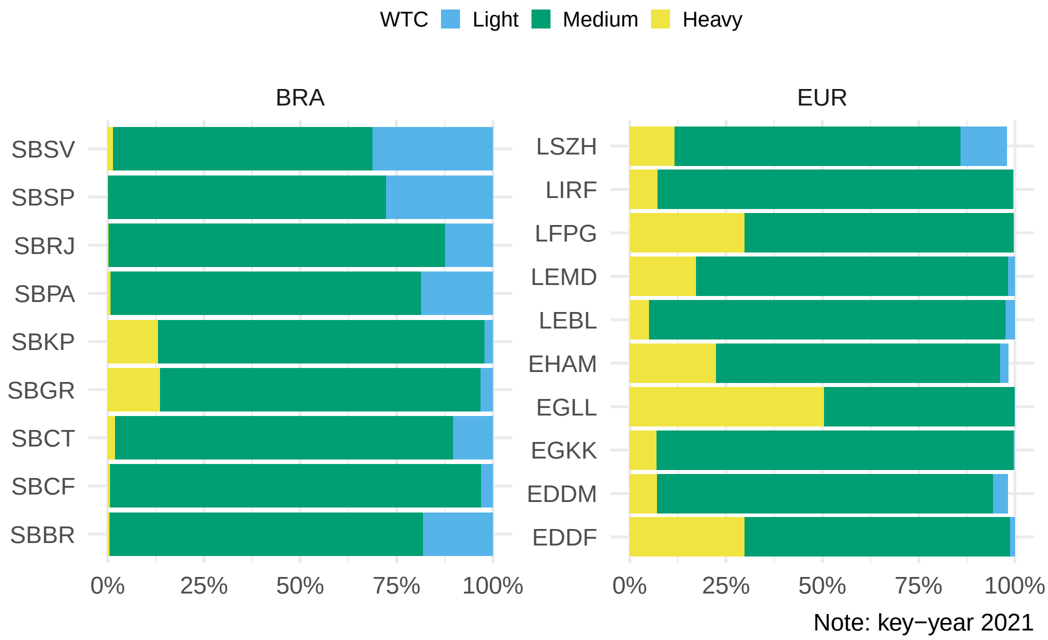


Figure 3.7: Fleet mix observed at study airports in 2021

Confins and Curitiba, which can accommodate heavies, do not serve a significant number of these aircraft. That is a good opportunity for future studies and explorations.

3.5 Summary

This chapter described the overall evolution of air traffic in Brazil and Europe and offered a closer look at the selected subset of study airports. Both regions observed a unprecedented decline in air traffic in March 2020 in response to COVID. However, the response pattern differed. Both regions observed COVID waves resulting in measures to limit air travel and curb the spread of COVID. Despite these waves, the Brazilian system recovered more consistently in structural terms. This shows the effect of the additional coordination and harmonisation effort of policies in Europe. As national governments varied in their assessment and introduction of health measures, including travel restrictions.

An intersting observation is that despite the overall variation of traffic on regional and local level, the share of operated aircraft types varied to a lesser extent on an annual level. However, distinct patterns become visible on the airport level. A central factor is the difference in terms of network connectivity and the role of the selected study airports. Based on the historic context, there exists a higher number of national hubs across Europe. In Brazil, international and cargo air traffic are more centralised and primarily operated to/from SBGR and SBKP. This can be obsered based on the differences of shares of heavy types (predominantly wide-body aircraft = long-haul international and cargo traffic).

These differences may impact - amongst others - separation and throughput. This chapter also highlighted potential areas for further research to better qualify the level of network and pan-regional connectivity.

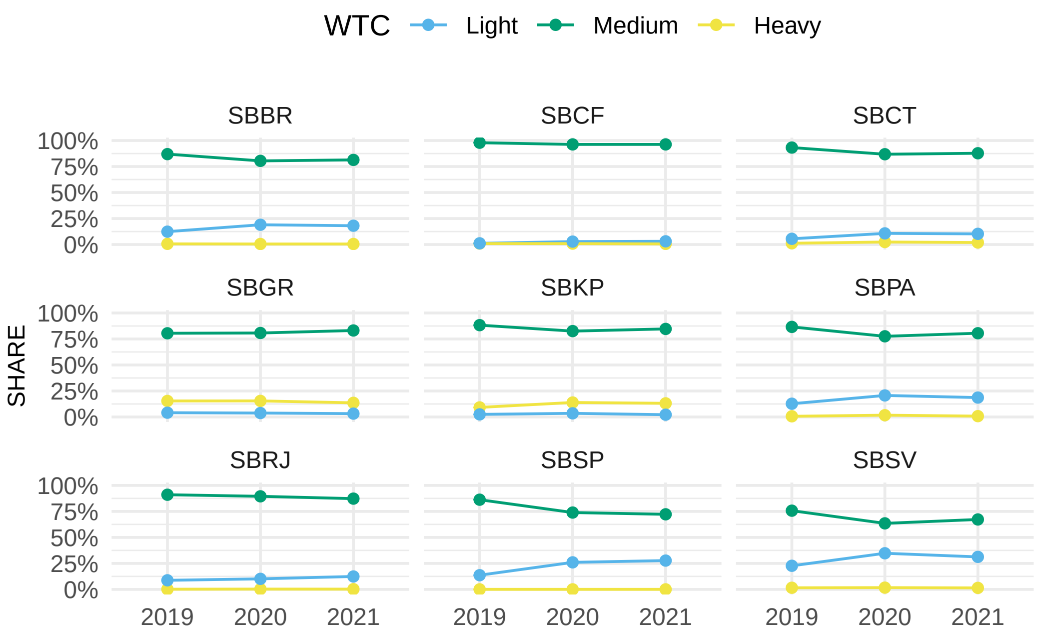


Figure 3.8: Fleet mix change over time observed at study airports in Brazil in 2021

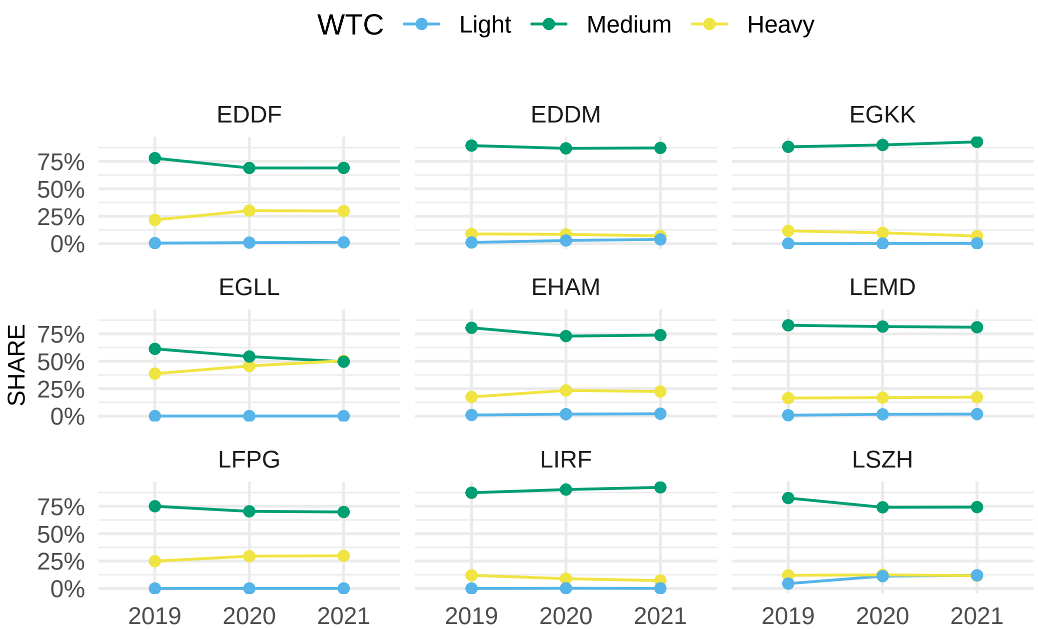


Figure 3.9: Fleet mix change over time observed at study airports in Europe in 2021

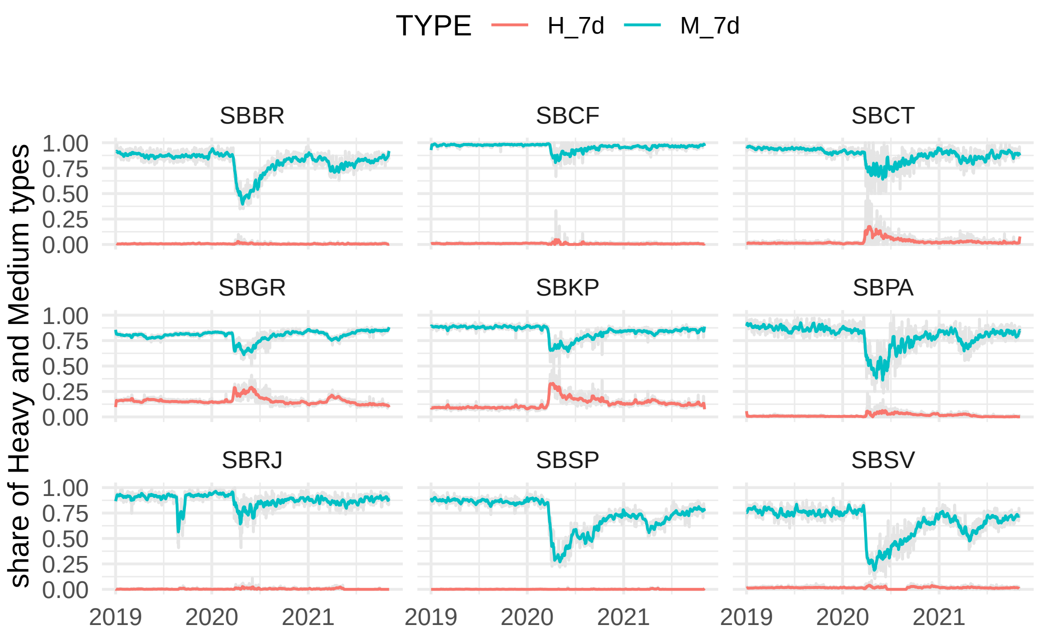


Figure 3.10: Evolution of fleet mix at selected Brazilian airports

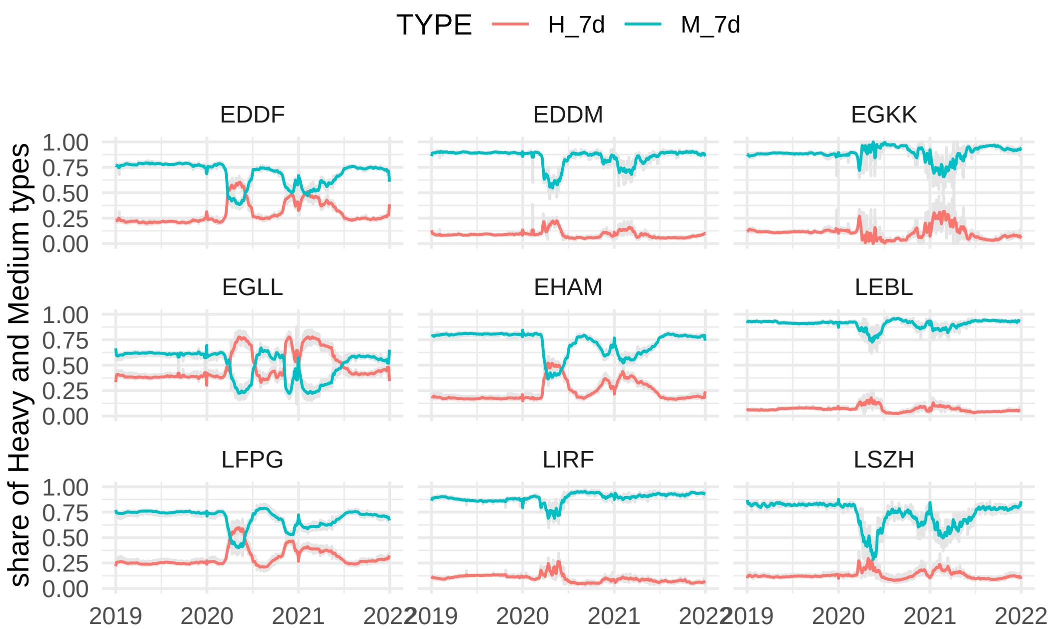


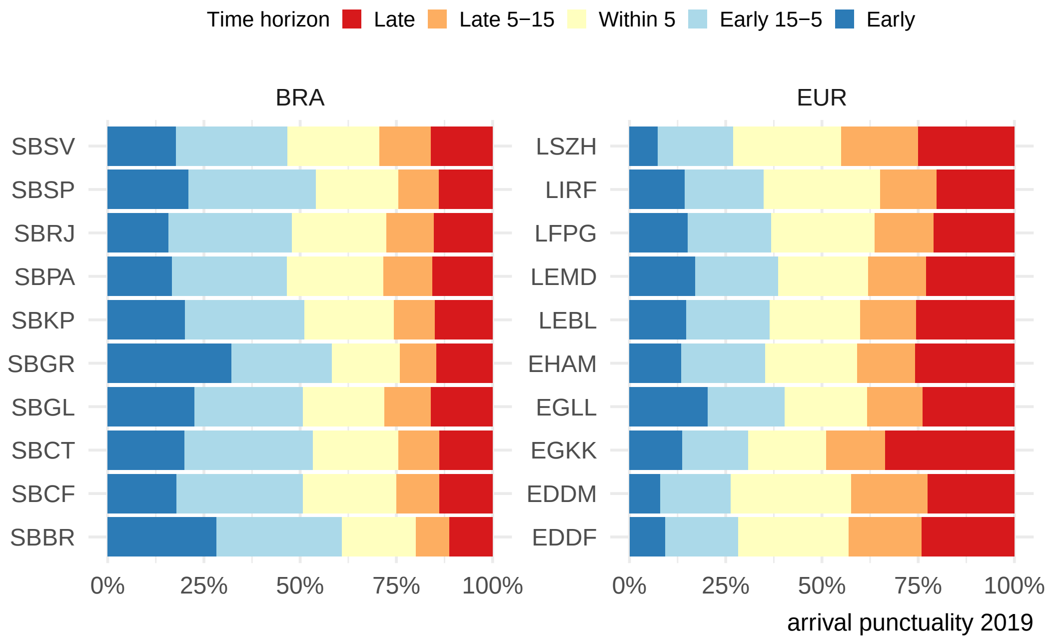
Figure 3.11: Evolution of fleet mix at selected European airports

4 Predictability

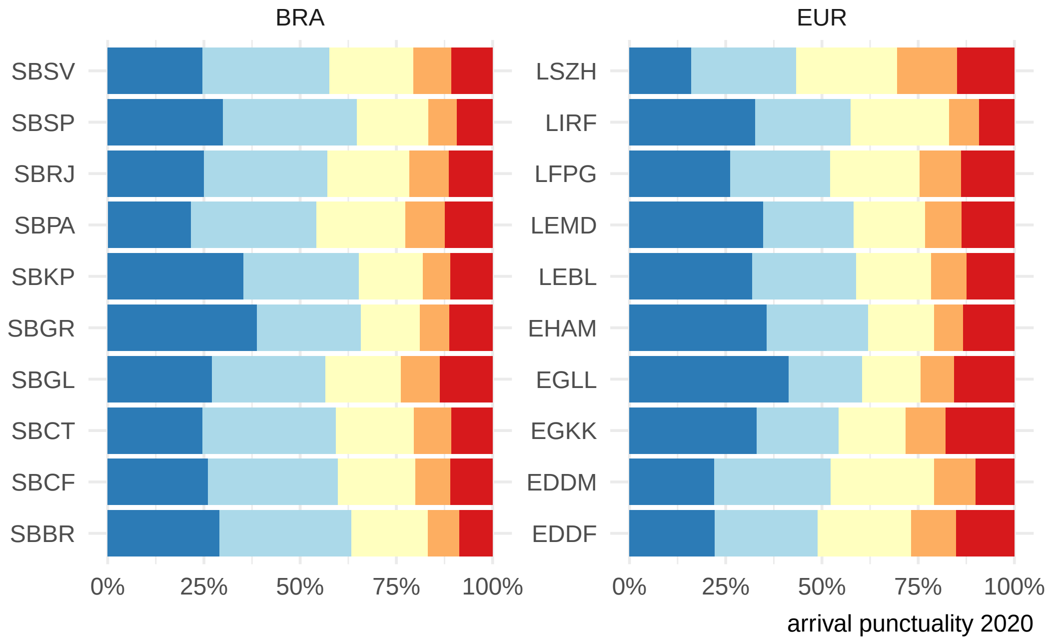
The previous chapters showed distinct responses by both systems to the overall air transport developments. Predictability in the system affects operations in both the strategic phase when airline schedules are produced and in the operating phase when ANSPs and stakeholders are balancing demand and capacity. High levels of predictability will benefit ANSPs servicing airspace users with a view to achieving highly efficient operations also during peak periods. This report focuses on the arrival and departure punctuality as measures of predictability.

4.1 Arrival Punctuality

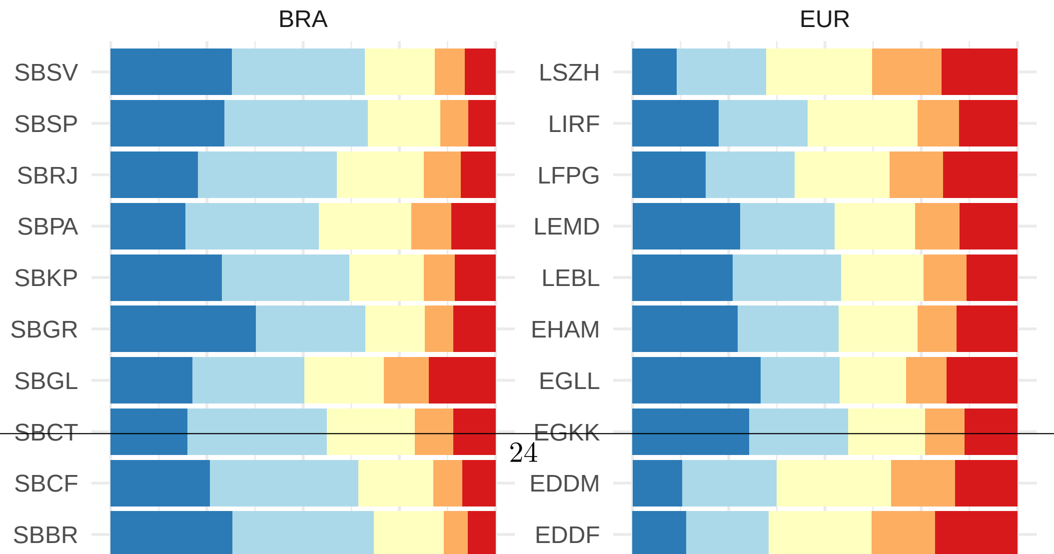
Figure 4.1 shows the evolution of arrival punctuality for the select airports in Brazil and Europe. In 2019, about 70% of flights arrived within 15 minutes of their scheduled arrival time on average in both regions. This raises concerns about schedule stability with a share of about 30% of flights arriving either well before 15 minutes or late when compared to the schedule. However, the punctual portion of the flights was further compressed in 2020, with the crisis peak. This share noticed a brief relief in 2021, with demand resuming its historical levels. The Brazilian data showed a soft advantage in the last year. On average a higher share of traffic at European airports arrives within + 15 minutes late of the scheduled arrival time. Within the European region, arrival punctuality decreased in 2020 with a higher share of early arrivals at all airports. The lower arrival punctuality was also characteristic for arrivals in 2020 in Brazil. TThe larger airports in Brazil, São Paulo/Guarulhos (SBGR), São Paulo/Congonhas (SBSP), Campinas (SBKP), and Rio de Janeiro Galeão (SBGL) observed a higher share of non-punctual arrivals (more/less than 15 minutes compared to the scheduled arrival time). A similar behaviour was also observed in 2021 across the Brazilian airports. In Europe, the schedule reliability has been improved for late arrivals, notably Rome (LIRF) in 2020 and Barcelona (LEBL) in 2021. However, pre-COVID levels have not been fully achieved. It is interesting to observe flights arriving well before their scheduled arrival time. Despite increasing end-user satisfaction, early arrivals did not reflect a healthy system and did contribute to a certain degree of inefficiency in the use of airspace and ground infrastructure due to the lack of predictability. Across the airports this portion of flights varies. However, on average, about 20-30% of flights arrived more than 15 minutes before their scheduled arrival time. The associated pattern and share varied across the 2019-2021 horizon. For a future report it will be interesting to investigate how structural this pattern is (i.e. which connections or service types showed this behaviour). Early arrivals may pose problems to the service delivery as available runway, apron, and stand capacity may negatively impact the management of the arrival flow. Figure 4.2 highlights the share of arrivals with more than 15 minutes compared to the scheduled arrival time. For the European region, the significant lower load on the system is visible. Early arrivals increased roughly doubled in 2020 compared to 2019 and contracted again with 2021 and the overall higher traffic



(a) Arrival Punctuality in 2019



(b) Arrival Puncutality in 2020



levels. This pattern is more diverse at the Brazilian study airports. This suggests that on average a higher level of flights arrive well ahead of their scheduled time.

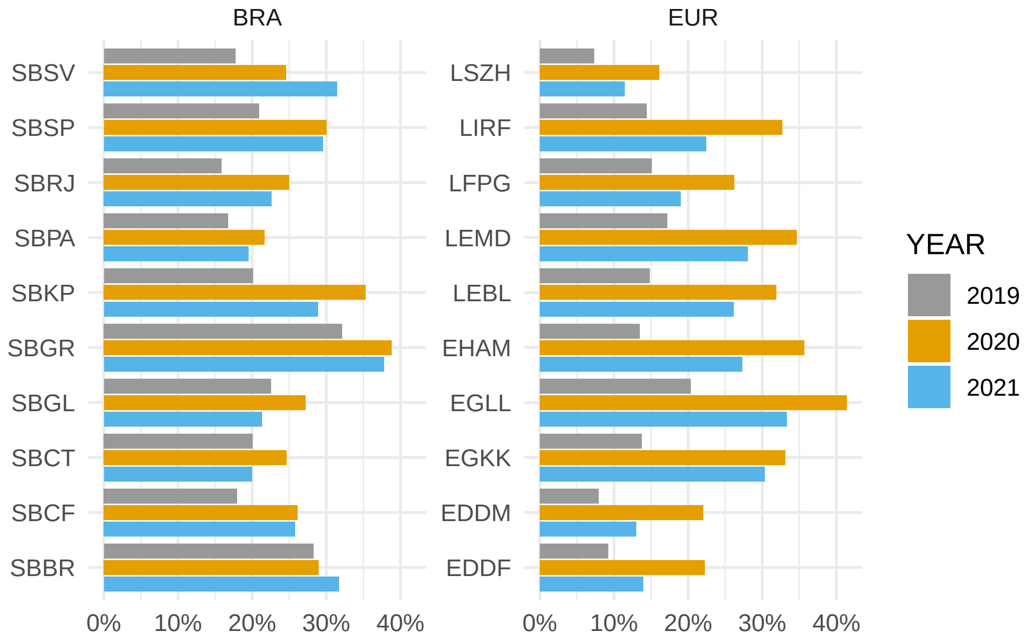


Figure 4.2: Evolution of early arrivals in both regions

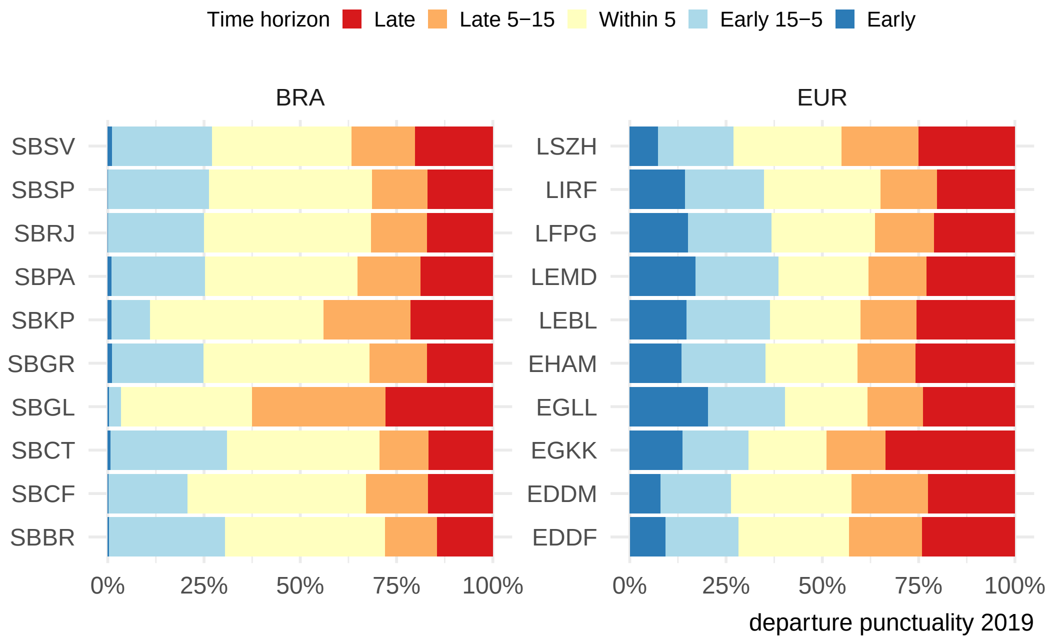
4.2 Departure Punctuality

This section analyses the level of departure punctuality. The previous section showed that the overall traffic situation during the previous years impacted the reliability of schedules for arrivals. Though the overall pattern represented a decline in traffic due to COVID, early arrivals may impact and put an additional strain on the infrastructure (runway system, apron, and stands).

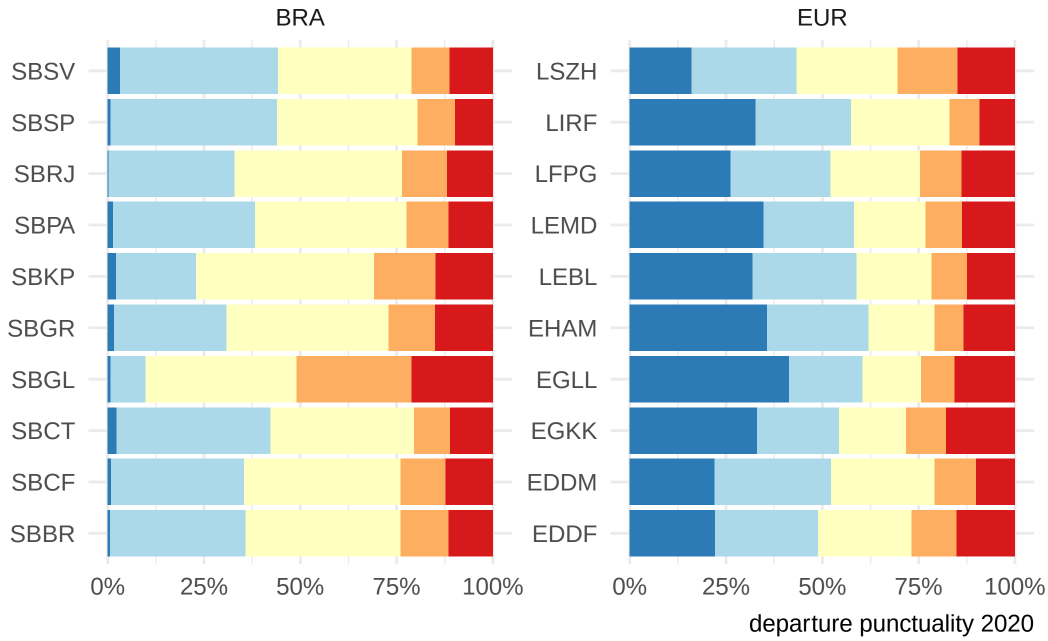
When looking at the interval of -/+15 minutes between actual off-block time and scheduled off-block time, a different pattern than on the arrival side emerges. On average, about 50% of all flights depart within that interval in Europe, with 2019 presenting a sightly larger share of punctual flights while 2020 and 2021 showed a noticeable decreasing in late departures.

For the European airports higher shares of early departures were observed in 2020 and 2021. While schedule reliability improved in 2021 vs 2020, the pre-COVID levels were not reached at the European airports. This suggests that there are still constraints surrounding the facilitation of passengers and turn-around at the airports. London Heathrow (EGLL) was the most affected European Airport, having its punctual portion compressed by the extremes shares.

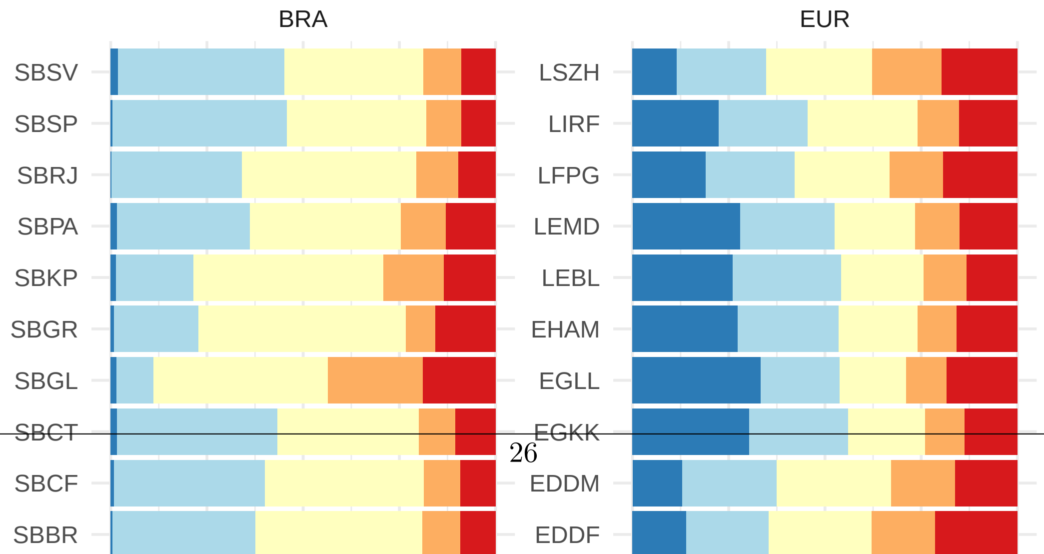
The Brazilian side did not show relevant variations in takeoff punctuality, with early departures (-15 min) barely changing. Actually, there is a negligible number of departure that blocked off less than 15 minutes early.
Interestingly this behavior was not impacted by the distortion of traffic during the COVID



(a) Departure Punctuality in 2019



(b) Departure Puncutality in 2020



phase. However, a soft improvement in late departures (+15 min) is noticed. 2021 performed slightly better than 2020, even with significantly more traffic. Galeão (SBGL) presented the worst indicator in all years but improved throughout the period.
In general, departures in 2020 and 2021 showed similar levels than in 2019.

The following figure highlights the share of late departures across the years. The unprecedented decline in air traffic resulted in significant lower shares of late departures decreased at the all studied airports in 2020 in comparison to 2019. Comparing the difference between 2021 and 2020 shows a similar structural pattern across all European airports. The number of late departures increased in comparison to the peak COVID-year 2020. This may be linked to two drivers. On one hand traffic levels increased again with more states reducing restrictions on air travel while still passenger screening and health measures required heightened processes. In Brazil, higher levels of departure punctuality were observed. Although the change from 2020 to 2021 ranges in the oder of magnitude of under 5%, the same pattern was obsered at all Brazilian airports.

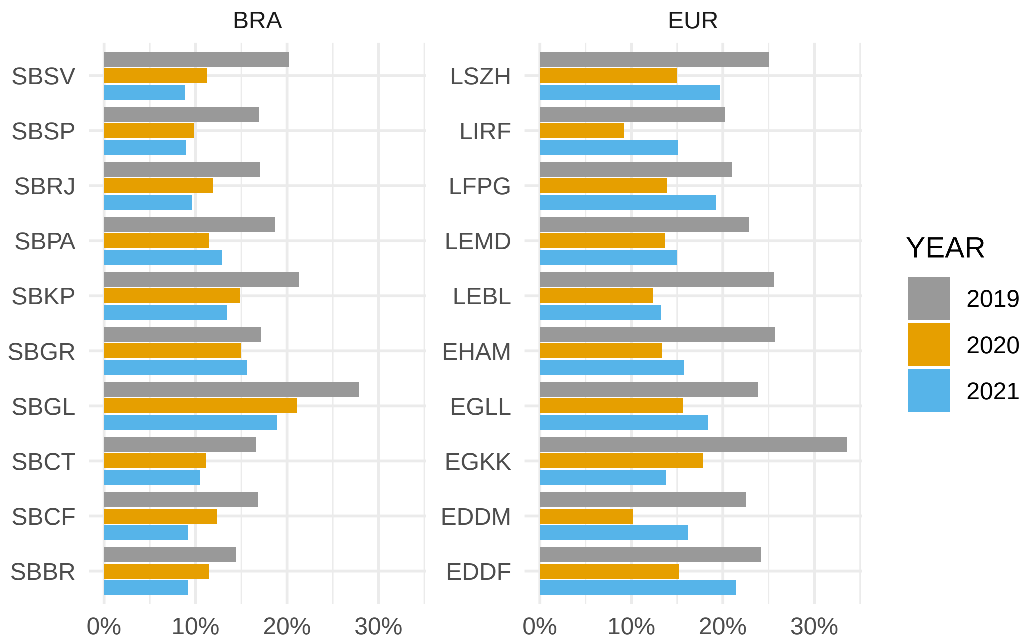


Figure 4.4: Evolution of late departures in both regions

4.3 Summary

Arrival and departure punctuality play an important role in terms of balancing demand and capacity. Punctuality in this chapter is measured as the difference between the actual arrival/departure times versus the respective scheduled times. This also reflects the stability and planning accuracy of the schedule in terms of air navigation services. Distinct patterns were observed in both regions. For example, on average about 50% of all flights arrive and depart within a window of -/+15 minutes in Europe. The influence of slot control is more visible with the demand level of 2019.
On the other hand, a higher share of flights depart within -/+5 minutes of their schedule in Brazil.

In both regions, the impact of the decline of air traffic is observable in the predictability in 2020 and 2021. However, there are different patterns in Brazil than in Europe. Europe showed a stronger reaction in terms of early arrivals (i.e. arriving more than 15 minutes before schedule) and departures (departing later than 15 minutes after the scheduled departure time). Traffic at Brazilian airports showed a similar reaction to the declining traffic in 2020 only in the arrival phase. The departure flights did not showed significant change in their punctuality. The behavior in 2021 is still far from the 2019 pattern in both regions. However, it appears that returning air traffic and load on the system drives the move towards pre-COVID levels in Europe. For example, the share of arrivals punctuality in 2021 ranges closer to the 2019 levels (i.e. Guarulhos SBGR, and Heathrow EGLL). Early arrivals, in its turn, doubled in Europe when comparing 2020 to 2019 level, and dropped again in 2021 broadly reversing the trend while not reaching 2019 levels.

This suggests that there is higher uncertainty in terms of movements with the returning traffic in both regions. More research is needed to investigate the underlying drivers and to what extent regional connectivity influences these behaviors.

5 Capacity and Throughput

A proper balance between airport capacity and flight demand is paramount to an adjusted network flow. This section addresses the capacity and throughput dimensions as measured by a variety of KPIs at the airport level. Airspace users expect sufficient capacity provision addressing the levels of demand. With higher levels of capacity utilisation, airspace users will experience congestion and constraints (e.g. higher inefficiency, c.f. previous chapter). However, planning and staffing for peak situations may come at significant costs to airspace user as well. In that respect it is essential to understand the trade-off between capacity provision and capacity consumption (i.e. traffic demand) as it impacts the overall system performance. Capacity and throughput analyses are therefore showing to what extent air navigation services are capable to accommodate the demand.

5.1 Peak Declared Capacity

Peak Declared Capacity refers to the highest movement rate (arrivals and landings) at an airport using the most favourable runway configuration under optimal conditions. The capacity value might be subject to local or national decision-making processes. The indicator represents the highest number of landings an airport can accept in a one-hour period.

In Brazil, the peak capacity is determined by DECEA considering local operational constraints. Within the European region, the airport capacity is determined locally or nationally as part of the capacity declaration process. This considers local operational constraints (e.g. political caps, noise quota and abatement procedures), infrastructure related limitations (e.g. apron/stand availability, passenger facilities). The declaration process considers typically IMC separation minima for runway movements. [1]

All European airports in this study are Category 3 - fully slot controlled. The slot and capacity declaration process is undertaken on the local or national level. Throughout the last years additional political caps in terms of maximum number of annual movements (e.g. Amsterdam (EHAM) movement cap of 500.000 commercial operations) or permissible night and day time restrictions (e.g. London Heathrow night operation cap) have been introduced widely. Accordingly, capacity values in Europe vary despite the local runway system capabilities. [2]

Throughout the last years, no substantial change in the declared capacity was observed at European airports. In Brazil, on the other hand, 2019 showed a revised capacity declaration for most of the airports throughout the country, c.f. Figure Figure 5.1).

[1] The Brazilian airports that have more than one operational runway are: Brasília (SBBR) with 2 independent runways; Guarulhos (SBGR) with 2 parallel runways (simultaneous but not independent operations); and Galeão (SBGL), Curitiba (SBCT) and Salvador (SBSV) with 2 intersecting runways.

[2] Amsterdam (EHAM) operates at fixed capacity with 6 runways, London Heathrow has maximised the runway throughput with 2 independent runways, Gatwick airport is reportedly the most efficient single runway operation in Europe.

Since the end 2018, CGNA worked on the enhancement of the methodology for the determination of the runway system capacity. The previous methodology used conservative limitations for the declaration of airport capacity. Capacity was limited to the maximum of 80% of its real value due to additional parameters taken into account (e.g. local specifics). The best practice approach included a 50%-50% division between arrivals and departures. The process and refined analysis methodology has evolved in such ways that these mentioned concepts are no longer in use. The capacity is declared on the basis of its actual value considering all variables that can restrain and impact the achievable capacity. It is applied in accordance with the operational conditions at the airport or the prevailing meteorological condition.

These changes significantly increased runway systems capacity for most of Brazilian airports. Airports such as SBGR, SBGL, SBCF, SBBR and SBSV benefited from the changes made, including changes in their runway system configurations. CGNA continues developing enhancements to the runway capacity analysis process. This resulted in the publication of a refined process by the end of 2020. The impact of the revision will likely influence the Brazilian airport capacity declaration.

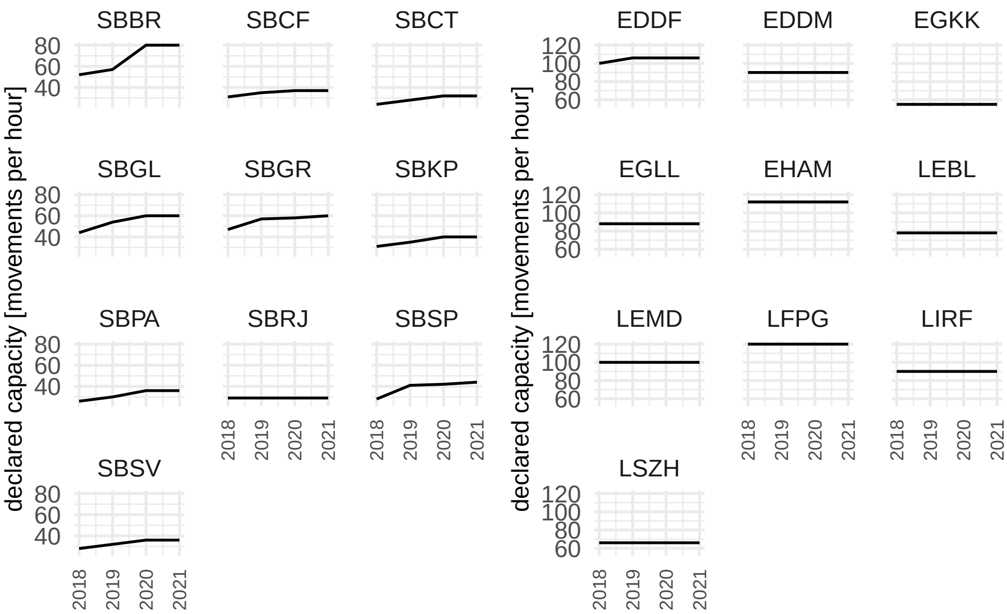


Figure 5.1: Evolution of Declared Capacities at Brazilian Airports.

Figure 5.2 the peak declared capacity per hour for each of the study airports in Europe and Brazil in 2021. In general, the declared capacity for all airports in Europe exceeds the respective declared capacity levels in Brazil.

The peak capacity for Brasília (SBBR) approached to Munich (EDDM) and Heathrow (EGLL) due to the implantation of independent operarions and the methodology calculation review. Those tree airports, with similar layout, show bigger capacity than Barcelona e Zurich which have tree runway. Galeão (SBGL) and Guarulhos (SBGR) are now above the peak capacity declared for the single-runway airport Gatwick (EGKK). But still, the declared capacity values at those airports ranged around 50% of the major hubs in Europe, i.e. Paris Charles de Gaulle (LFPG), Amsterdam (EHAM), and Frankfurt (EDDF).

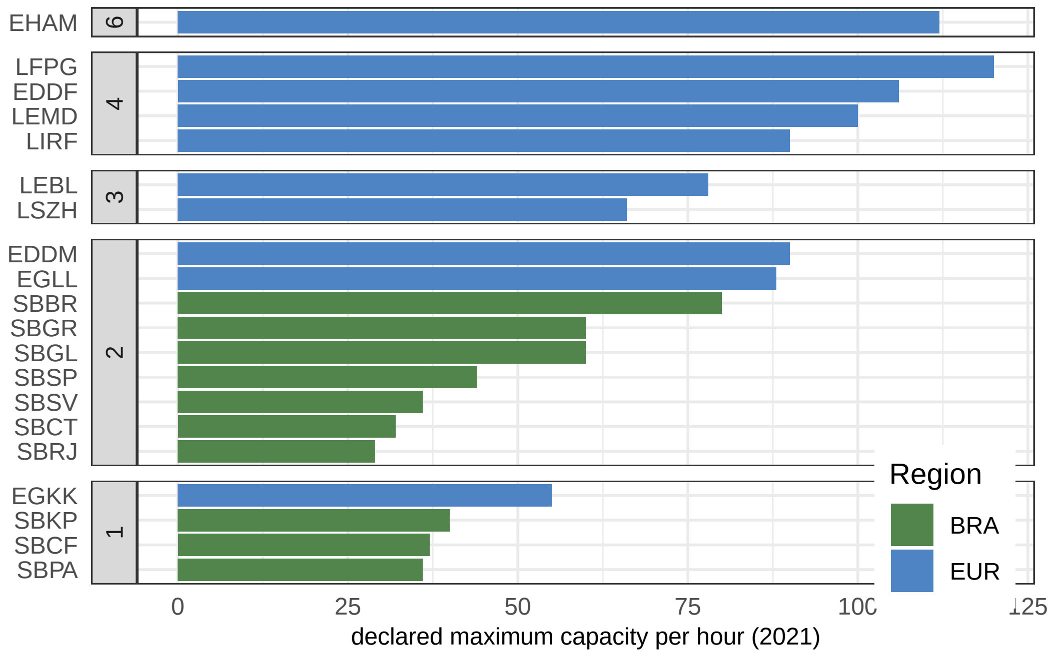


Figure 5.2: Peak declared capacity

As mentioned before, the capacity process takes into account a variety of local considerations. A potential avenue for further research could be a closer investigation of the variances of the declared capacity in line with the local runway system characteristics.

5.2 Peak Arrival Throughput

The peak arrival throughput measures the 95th percentile of the hourly number of landings observed at an airport. The measure gives an indication of the "busy-hour" landing rates. It is an indication to what extent arrival traffic is serviced at an airport. For congested airports, the throughput provides a measure of the effectively realized capacity. Throughput is a measure of demand and comprises already air traffic flow or sequencing measures applied by ATM or ATC in the en-route and terminal phase. For non-congested airports, throughput serves as a measure of showing the level of (peak) demand at this airport. Unlike the day Peak Day indicator, the busiest hour of the airports under study did not suffer a significant reduction in their values even with the crisis. The demand peak during the last two years and the natural tendency of traffic concentration in more attractive hours were enough to keep the values at level with the historical data.

Figure 5.3 shows a constant behaviour of the peak arrival throughput across the whole time horizon. A noteworthy exemption is Brasilia (SBBR). At SBBR, a reduction of the peak arrival throughput was observed in 2019 in comparison to the previous year. Brasilia Airport started independent operations on its two runways back in 2016. As a result - and after a period of standardisation of procedures for aircrew and controllers - its traffic was possibly better dispersed throughout the day.

For the majority of the European airports, Figure 5.3 depicts little variation over the years. These study airports represent the busiest 10 airports and accordingly the peak

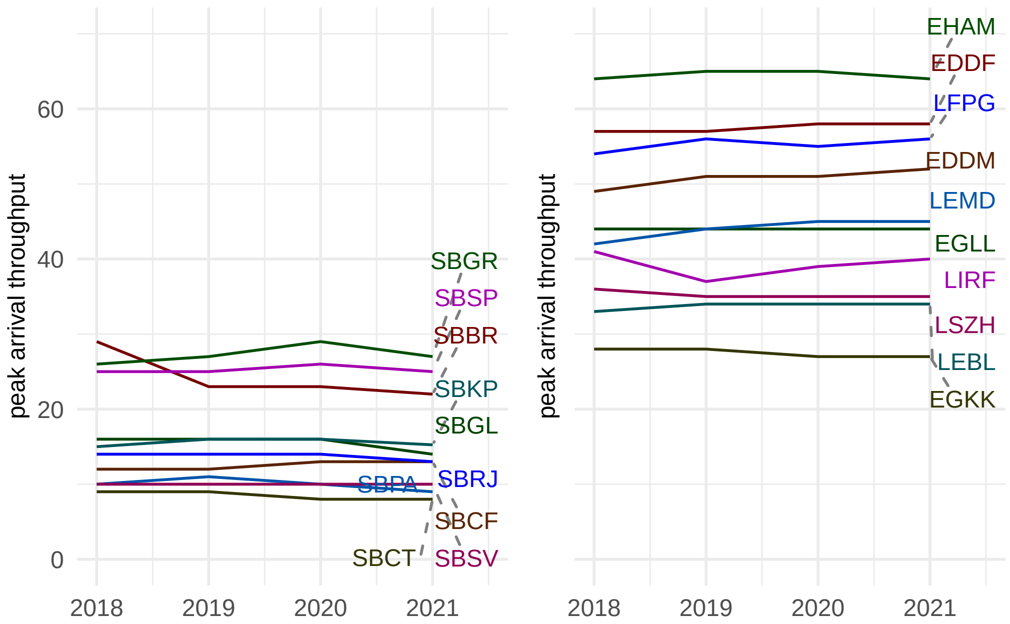


Figure 5.3: Variation of arrival throughput at study airports

arrival throughput per hour presents an upper limit based on the airspace user demand and traffic patterns. The increase observed in peak arrival throughput at Paris (LFPG), Madrid (LEMD), Rome (LIRF), and Munich (EDDM) was in line with additional demand during peak hours. The continual increase in peak arrival throughput signals a potential concentration of feeder flights for international / long-range traffic.

The relative constant pattern of the peak arrival throughput observed for many airports suggests that traffic patterns during the busiest hours remained fairly constant. Potential changes to the airspace user demand widely occurred outside the peak hours. This suggests that arrival management of air traffic services in Brazil and Europe is able to sustain the observed demand.

5.3 Peak Departure Throughput

In analogy to the arrival throughput, the departure throughput is determined as the 95th percentile of the hourly number of departures. The measure serves as an indication of the "busy-hour" departure rates. As seen in the previous indicator, the pandemic crisis did not influence the values significantly.

The peak departure throughput at the study airports shows a similar behaviour than the behaviour observed for the arrival throughput (c.f. above). This suggests widely homogeneous demand patterns, i.e. schedules, across the different seasons.

Peak departure throughput at SBBR showed a similar decrease as for the arrival peak throughput as reported above.

In Europe, Rome (LIRF) saw a drop in departure throughput in 2017 as well, which then remained fairly constant until 2019. The observed decrease is linked to a de-peaking of the

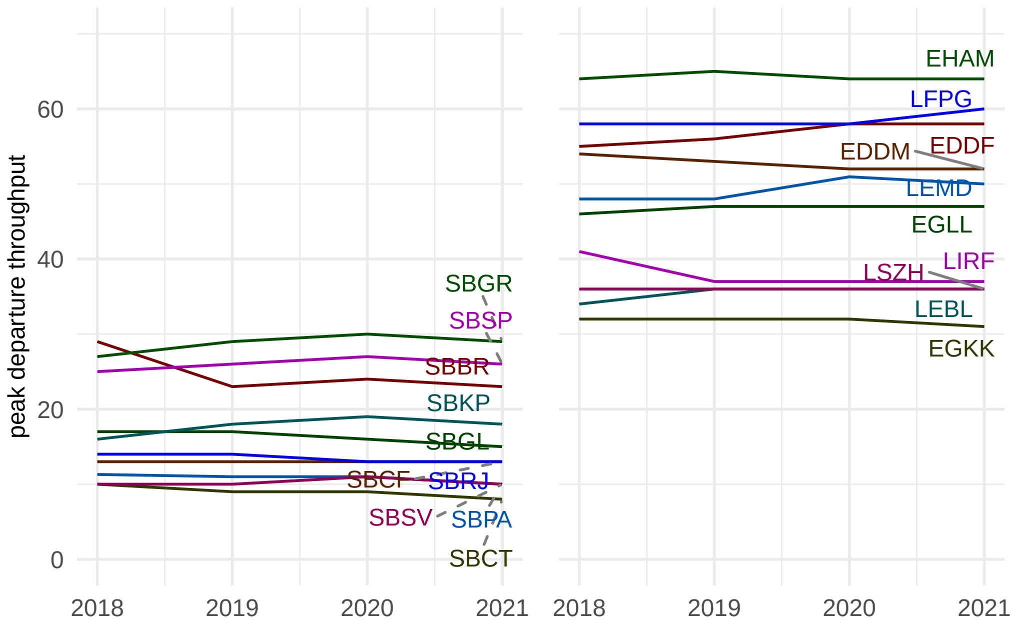


Figure 5.4: Variation of departure throughput at study airports

outbounds. Frankfurt (EDDF) and Madrid (LEMD) experienced a step as of 2019 that is in line with additional routes served. The annual traffic increase observed at Paris (LFPG) resulted in an increase in the peak departure throughput accommodating these additional flights also during peak hours. The observed systematic constant performance levels at Heathrow (EGLL), Gatwick (EGKK), Barcelona (LEBL), and Zurich (LSZH) evidences that these airports and air traffic services operated at their capacity limits during peak hours throughout the time horizon of this report.

5.4 Declared Capacity and Peak Throughput

Effective utilisation of the deployed capacity during peak times drives operational efficiency. In this initial comparison report, the difference between the peak arrival rate and the declared capacity is analysed in order to demonstrate which airports have more and less "slack" between the peak movement levels and their capacity. Figure 5.5 orders all study airports based on their declared arrival capacities and compares these values with the observed peak arrival throughput.

For the majority of the airports, the approximated arrival capacity is higher than the observed peak throughput. In Europe, Amsterdam (EHAM), Frankfurt (EDDF), and Munich (EDDM) showed a higher peak throughput than the respective declared capacity. Peak arrival operations at Zurich (LSZH) were slightly higher than the declared capacity. In Brazil, the realised peak arrival throughput at Sao Paulo (SBSP) exceeded the capacity value as well. At these airports, it appears that during the peak hours (i.e. the top 5% of all hourly arrivals) in 2021 better than declared arrival throughputs were realised. This might be linked to the methodology used for the capacity declaration process following a more modulated approach and accounting for a wider varied aircraft mix. It will be

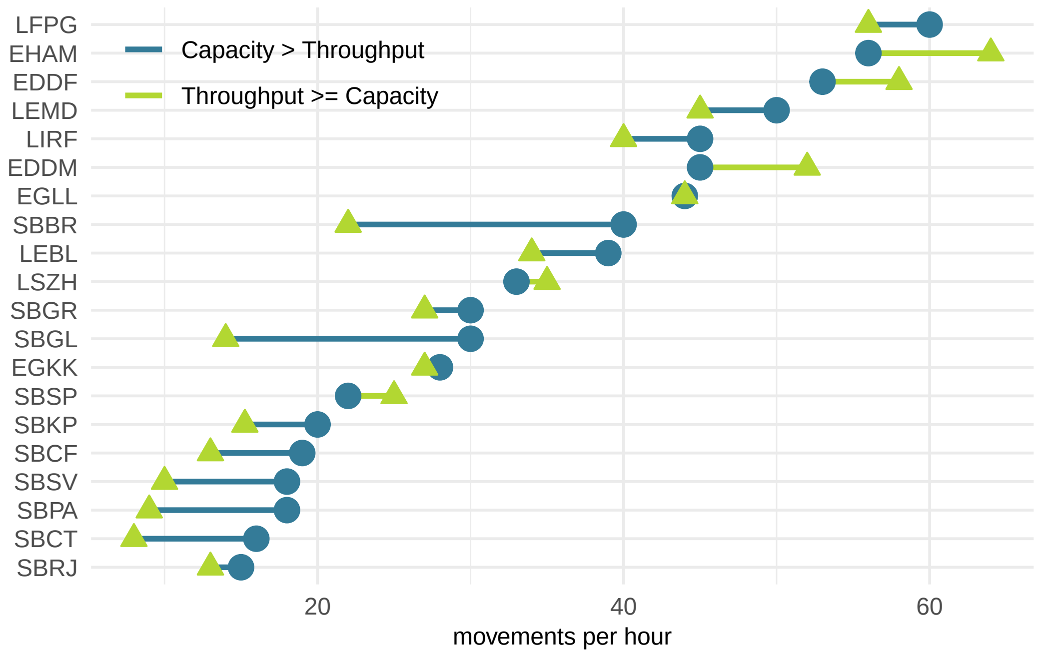


Figure 5.5: Comparison of declared capacity and throughput for arrival phase.

interesting to research in future comparisons how the peak hour demand is managed in comparison to less busier hours and its underlying driving factors.

5.5 Summary

The maximum capacities of Brazilian airports tend to be lower than the declared capacities at European airports. Throughout the past years, Brazil changed its methodology to identify and declare arrival and departure capacities. In light of this change and on the basis of operational improvements, Brazilian airports have been showing consistent growth in their capacities. This growth of traffic is widely completed for the top 10 airports in Europe and the associated capacities were constant over the past years.

Another highlight is the resilience of peak hours against demand variations. Despite the unprecendented decline of air traffic due to COVID19, demand remained concentrated during peak operating hours. On average, the declared arrival capacity is commensurate with the peak traffic observed at the airports. This suggests that runway system capacities is not a limitation for servicing traffic demand in both regions.

6 Efficiency

Operational efficiency is a critical component in assessing the management and execution of operations. It provides insights in the management of arrival and departure flows and the associated separation and synchronisation activities. Inefficiencies can have an impact on user operations in terms of delays or excessive fuel burn.

The measures reported in this study are based on the observed travel time for surface operations (i.e. taxi-in and taxi-out) and during the arrival phase. These travel times are compared with an associated reference time for a group of flights showing similar operational characteristics. The determined difference (i.e. additional times) measures the level of inefficiencies. It must be noted that high performance operations will still yield a certain share of measured additional times. Operational efficiency is therefore aiming at the minimizing rather than eliminating these additional times as they cannot be zero.

6.1 Additional Taxi-In Time

The additional taxi-in time measures the travel time of an arriving flight from its touchdown (i.e. actual landing time [ALDT]) to its stand/gate position (i.e. actual in-block time [AIBT]). The observed travel time (i.e. taxi time) is compared to a reference time. The reference time is determined for flights arriving at the same runway and/or the same stand/gate position. Research showed that the taxi-times are not dependent on the type of aircraft. The additional taxi-in time provides a pointer for the management of the inbound surface traffic.

Due to data availability constraints (i.e. no stand/gate information), the reference times for the Brazilian airports have been computed on the airport level. It needs to be noted that such aggregation at the airport level may be influenced by the predominant runway configuration and frequently used stand/parking positions. This phenomenon merits further study in one of the future editions.

Figure 6.1 shows the variation of the observed additional taxi-in times.

The observed additional taxi-in times vary across the different airports. The majority of airports have average additional taxi-in times at or below 2 minutes per arrival. This suggests that arrivals are rarely subject to taxi constraints.

In Europe, Rome Fiumicino (LIRF) observed additional taxi-in times of higher than 4 minutes per arrival in 2019. With the decreasing traffic load during 2020 and 2021, additional taxi-in times fell sharply to 2,5 min in 2020 and 2,15 minutes per arrival. At London Heathrow (EGLL), average additional taxi-in times improved in 2020 by about three quarters of a minute. However, with increasing traffic load in 2021, higher additional taxi-in times were accrued again. A similar pattern was observed at other European airports with increasing additional taxi-in times, e.g. Zurich (LSZH), Paris Charles de Gaulle (LFPG), Madrid (LEMD), Amsterdam (EHAM), Munich (EDDM), and Frankfurt

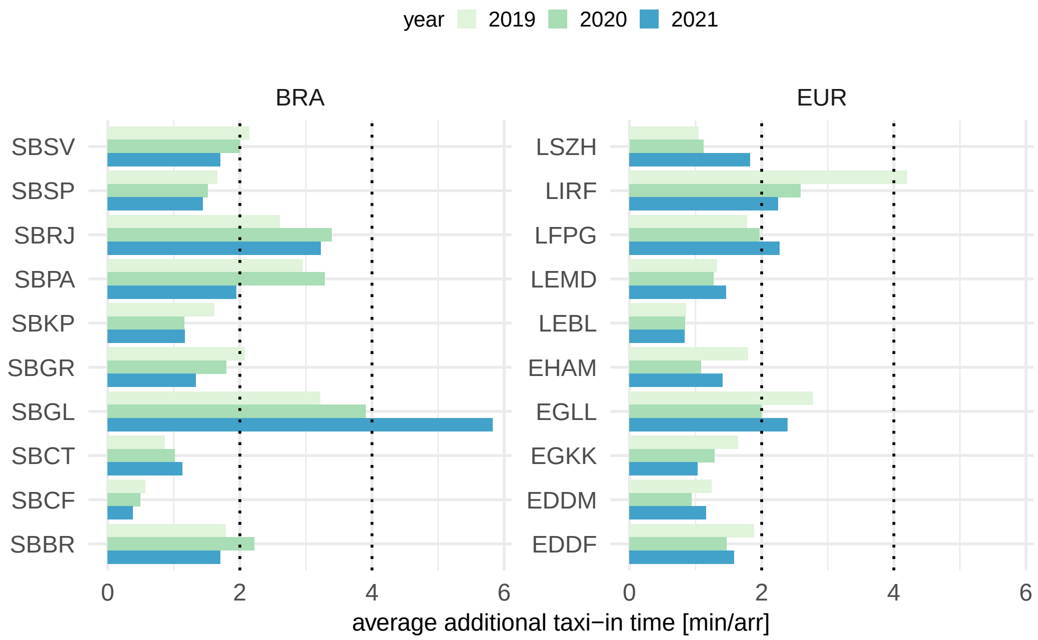


Figure 6.1: Additional taxi-in time

(EDDF). This suggests that there are still local procedures in place to address COVID or post-COVID related utilisation of stands.

Additional taxi-in times in Brazil varied across the airports. Traffic at Rio de Janeiro's Galeão (SBGL) airport deteriorated significantly. Despite lower traffic levels, the additional taxi-in time increased from around 3 minutes in 2019; to just under 4 minutes per arrival in 2020, and further increased to just under 6 minutes per arrival in 2021. Rio de Janeiro (SBRJ) observed an increase to over 3 minutes per arrival in 2020 and 2021. Arriving traffic at Porto Alegre (SBPA) experienced lower additional taxi-in times in 2021. Compared to 2019 and 2020, performance improved by over a minute per arrival. On average, additional taxi-in times decreased at the other airports across the years. Thus, showing a positive associated with decreasing traffic.

The variations across the airports suggests that local specifics contributed to the varying taxi-in performance.

Figure 6.2 compares the evolution of the additional taxi-in time at two of the study airports. A sharp increase of the average additional taxi-in time is observed at both Galeão (SBGL) and London Heathrow (EGLL) by the end of 2020, despite significantly lower daily traffic in comparison to 2019. At SBGL, the observed average monthly additional taxi-in times increased even further in the beginning of 2021. EGLL saw a drop following the Chrismas/New Year season and then experienced a strong increase of the additional taxi-in times. These patterns have to be contrasted with with the shallow increase of daily traffic.

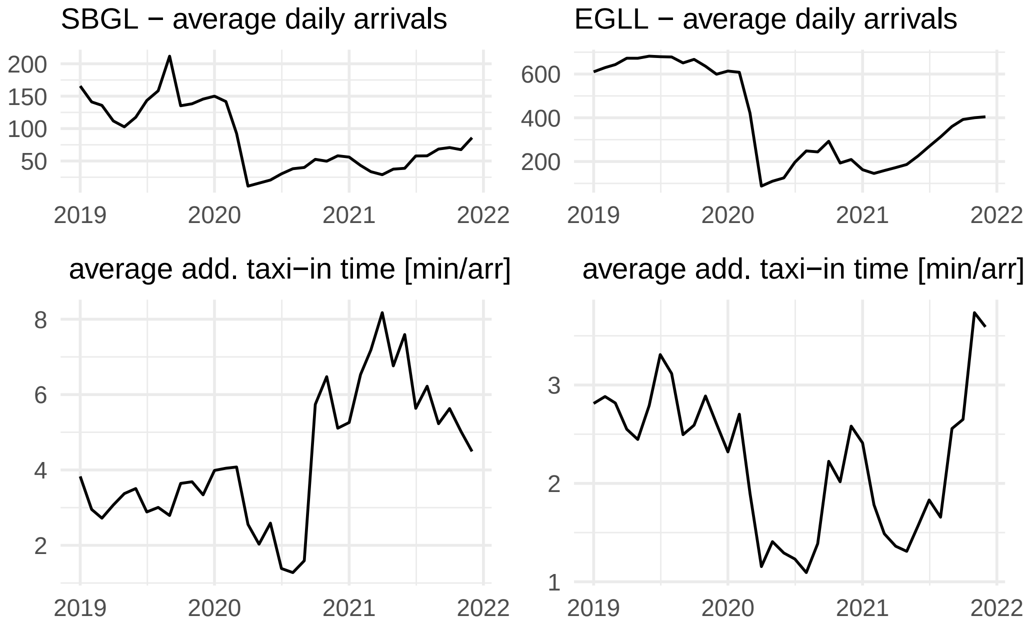


Figure 6.2: Monthly evolution of additional taxi-in time at SBGL and EGLL

6.2 Additional Taxi-Out Time

The additional taxi-out time addresses the travel time of a departing aircraft from when it can move away from its stand/gate position (i.e. actual off-block time [AOBT]) until the aircraft takes off (i.e. actual take-off time [ATOT]). This travel time is compared to an associated reference time.

As mentioned above, the taxi-times at Brazilian airports are determined on the airport level and the observed additional taxi-out times may be influenced by the predominant runway system - stand combinations for departure traffic. The inclusion of stand/gate positions is foreseen for future iterations.

San Salvador (SBSV) in Brazil and Europe's Rome Fiumicino (LIRF) and London Heathrow (EGLL) observed high average additional taxi-out times in 2019. For the majority of the airports, average additional taxi-out times are at or below 4 minutes per departure. In both regions, taxi-out performance was affected by the lower level of air traffic and typically resulted in a reduction of the average additional taxi-out time. In Brazil however, SBGL and SBBR showed increased additional taxi-out times in 2020 compared to 2019. This signals a substantial change of the taxi-operations based on the predominant usage of stands. Interestingly, additional taxi-out times varied differently across airports when comparing 2020 vs 2021. While in many instances the change is neglible (smaller than 30 sec per departure), Munich (EDDM) and Amsterdam (EHAM) showed a discernible increase in the observed additional taxi-out times. This was related to the re-opening of closed parts of the terminal in line with the general increase in air traffic.

In both regions, flights observed a higher additional taxi-out time than taxi-in time. Thus, air traffic services in both regions manage departure queues more actively by separating

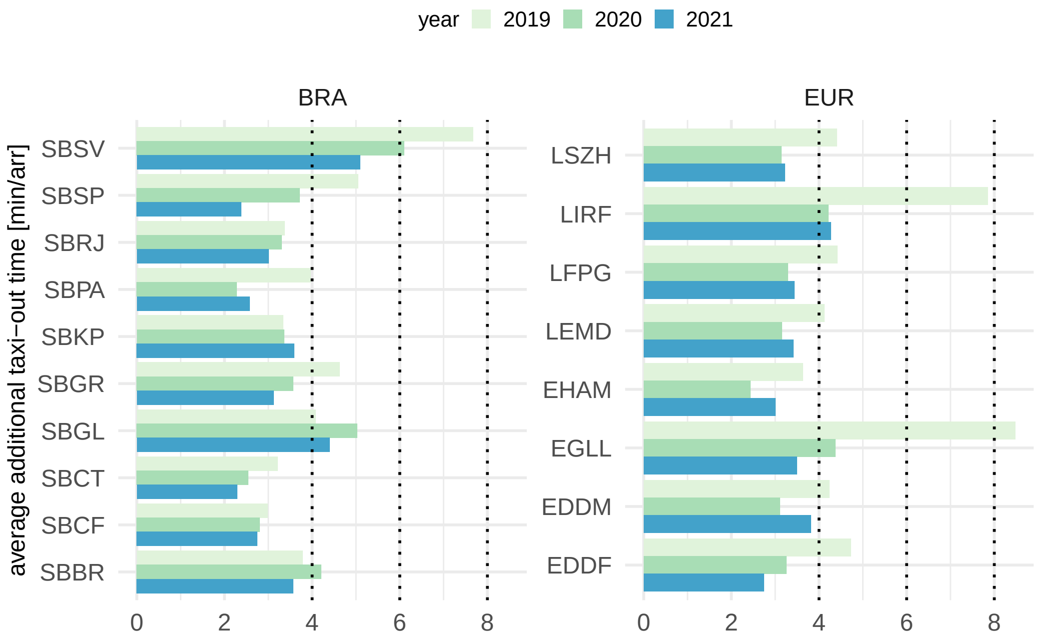


Figure 6.3: Additional taxi-out time

and sequencing traffic within the maneuver area. This may be linked to higher interactions between departing traffic, or departing and arriving traffic.

6.3 Mapping of Taxi-out and Taxi-in

The following analysis builds on the observations of the previous sections. Figure Figure 6.4 reveals different patterns in Brazil and Europe. In general surface movement operations see a higher variation in Brazil than in Europe. Within the European region London Heathrow (EGLL) and Rome Fiumicino (LIRF) experienced a strong reduction of the additional taxi-out time due to the reduced traffic in 2020. On average the returning traffic did not impact the additional taxi-in and taxi-out times observed in 2020 and 2021.

With the exception of Rome Fiumicino (LIRF) and London Heathrow (EGLL) and the observed high additional taxi-out times at these airports, the spread between additional taxi-in and taxi-out time is smaller in Europe than in Brazil. This suggests that operational constraints are of systemic nature and less dependent on the level of traffic. This may reveal differences in the management of arriving and departing traffic in both regions. All European airports of this study operate ACDM [1] processes. ACDM aims to optimise the use of resources and improving the predictability of air traffic, in particular departing traffic. Further research is needed to analyse the impact of ACDM on the departure process with the average additional taxi-out times typically 2-3 minutes higher than the additional taxi-in times.

[1] ACDM implementation at EGKK is on-going, c.f. https://www.eurocontrol.int/concept/airport-collaborative-decision-making.

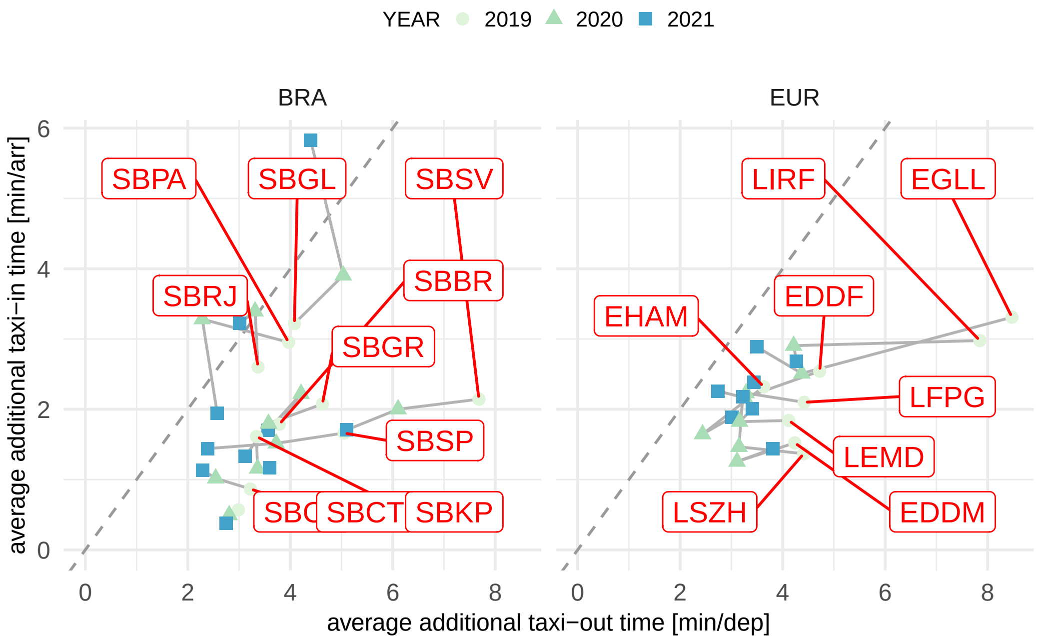


Figure 6.4: Comparison and evolution of additional taxi-in and taxi-out times

6.4 Evolution of Additional Taxi-Times in early 2022

This section highlights and compares the performance observed in the first part of 2022, i.e. January through June. Typically, taxi-in operations are less constrained than taxi-out operations. However, flights taxiing in may be subject to interaction with other surface movements when approaching the apron or need to hold until a parking position is vacated.

Figure 6.5 shows the monthly evolution of the average additional taxi-in times in Brazil. On average, monthly additional taxi-in times showed a smoother behaviour in 2020, 2021, and the first half of 2022 than in comparison to 2019. In particular, a higher level of variation and share of additional taxi-in times were observed in 2019 at Galeão (SBGL), São Paulo/Guarulhos (SBGR), São Paulo (SBSP), and for the first part of the year in Salvador (SBSV). For the beginning of 2022 arriving flights in Brazil accrued additional taxi-in times of 2 minutes or less. This evidences that incoming flights are not subject to higher constraints while taxiing in.

Figure 6.6 shows the taxi-out performance observed at Brazilian study airports. The monthly taxi-out performance, on average, improved in comparison to 2019 at all airports. Brazilia is the only airport that showed a higher level of variability in 2020 during the first month of COVID. With the exception of Rio de Janeiro (SBRJ) and Sao Paulo (SBSP), observed additional taxi-out times follow the pattern of 2020 and 2021. This suggests that taxi-out procedures were adapted during COVID and taxi-out performance was stabilised on similar levels. SBRJ showed a step increase in taxi-put time in April 2022. Additional taxi-out times before and after the step were constant. This suggests a procedural change at the airfield. SBSP showed an increase in accrued additional taxi-out times as of February 2022 and reached levels of taxi-out performance simlar to pre-COVID levels (2019).

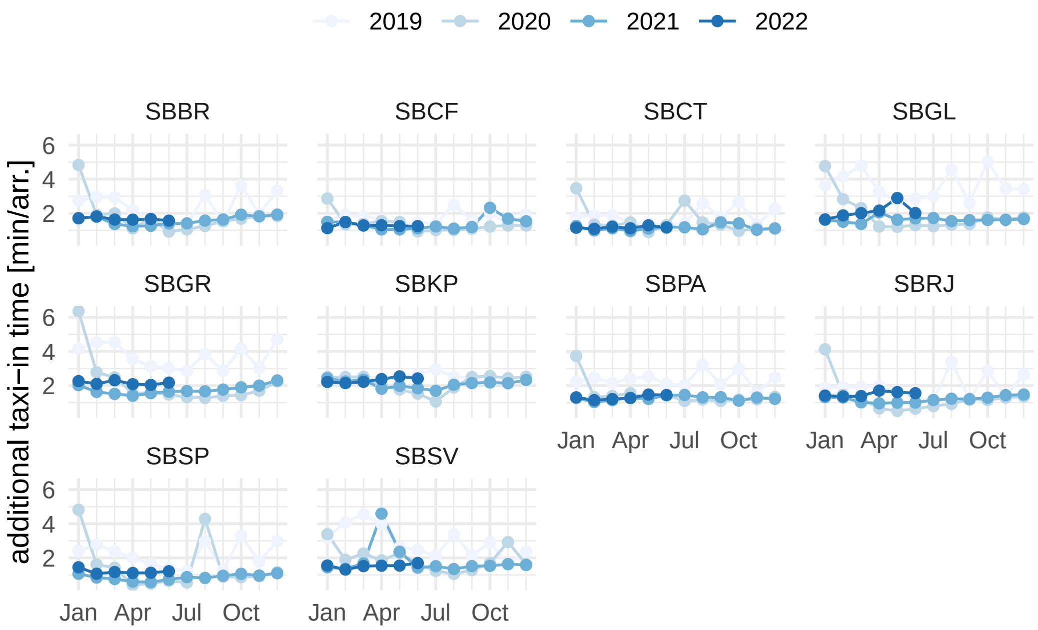


Figure 6.5: Evolution of monthly average additional taxi-in times at Brazilian study airports

6.5 Additional Time in Terminal Airspace

The additional time in terminal airspace is calculated as the difference between the actual travel time from entering the sequencing area (100NM radius around the airport) to the landing time and an associated reference time for the entry sector, aircraft class, and landing runway. The reference times are established based on 2019.

Figure 6.7 shows the observed annual average additional time in terminal airspace for all airports. The additional time in terminal airspace followed different patterns in Brazil and Europe. Generally, additional ASMA times are higher in Brazil than in Europe [2], although, arrival sequencing in 2019 (pre-COVID) shows some airports in Europe with extremely high additional times, e.g. Zurich (LSZH), London Heathrow (EGLL), and London Gatwick (EGKK).

The approach concept for London arrivals differs from other airports. To achieve maxium runway utilization, aircraft are held close to the airport. This resulted in higher ASMA times in 2019. The observed additional ASMA times for EGLL and EGKK in 2021 need to be interpreted based on the GANP algorithm chosen for this report. Reference times are determined based on the actual travel times in 2019. Thus, the negative annual average ASMA time for Heathrow (EGLL) and the extremely low result for Gatwick (EGKK) in 2021 demonstrate that at both airports the lower traffic levels in the following years are served differently. Obviously, the 2019 reference times comprise procedural elements, i.e. include sequencing induced additional time, and are too high for the observed traffic in 2021. For future studies it will be interesting to enhance the metric to account for

[2] The assessment of additional ASMA time for Brazil is based on a dataset that spans several months and partial years. For this study, data for 2018 is attributed to 2019. The data set will be complemented in future updates of this comparison. The overall behaviour of arrival times is assumed to not be affected across the years.

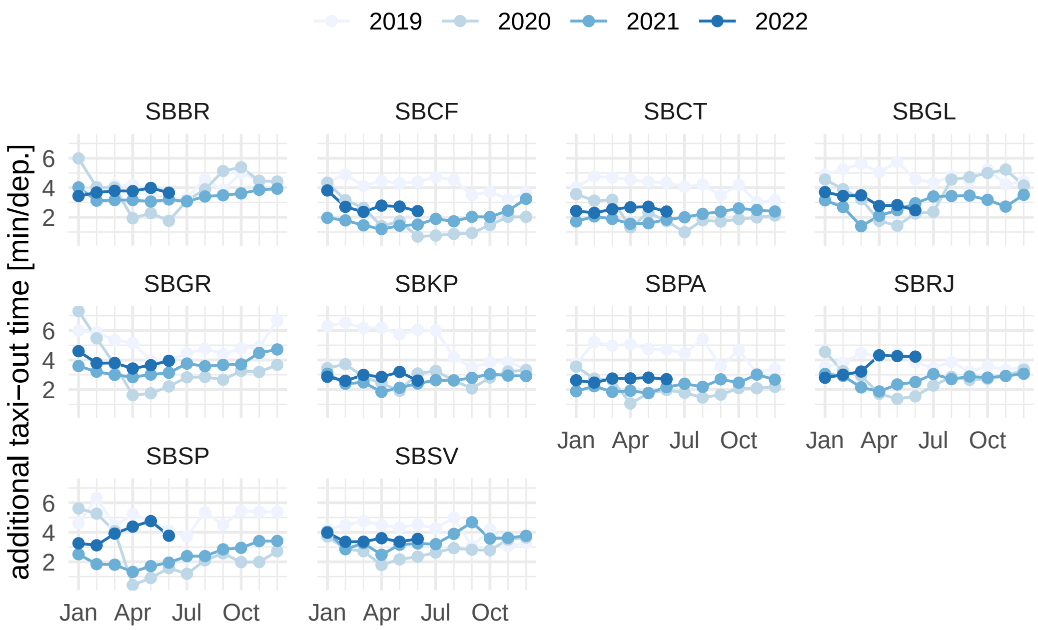


Figure 6.6: Evolution of monthly average additional taxi-out times at Brazilian study airports

substantial changes of the prevailing traffic. This also highlights that the London arrival and procedures benefitted significantly from the lower air traffic and yielded less holding and sequencing constraints on airspace users. Across the other European airports the change between the pre-COVID year 2019 and the observed performance in 2020 and 2021 is clearly visible. However, the overall change between 2020 and 2021 is - on average - negligible. This suggests that the metric measures procedural aspects in the arrival management at these airports offering room for improvement as these accrued additional times are independent of the traffic. Traffic at São Paulo Guarulhos (SBGR) observed additional times in 2019 and 2020 above four minutes per arrival. Its reduction in 2021 may be related to the new airspace design for São Paulo TMA and correlated airways changes, the TMA SP Neo Project implemented in May/2021. Higher additional times are observed in 2021 at Campinas (SBKP), Curitiba (SBCT), and Brasilia (SBBR), which also can derive from airways modification. DECEA keeps this assessment ongoing, as the demand returns to 2019 levels. For the majority of Brazilian airports, arrival traffic in 2021 experienced higher additional times than in the previous years, while the observed additional times for 2019 and 2020 ranged in the same order of magnitude. The average additional times at Brazilian airports ranged typically between two and four minutes per arrival. Traffic at São Paulo Guarulhos (SBGR) observed additional times in 2019 and 2020 above four minutes per arrival.

For future reports the data for the assessment of the additional terminal time will be complemented for Brazil. This will allow to better investigate the changes observed across the years [3]. This edition of the comparison suggests that there were changes to the en-route

[3] The assessment of additional ASMA time for Brazil is based on a dataset that spans several months and partial years. For this study, data for 2018 is attributed to 2019. The data set will be complemented in future updates of this comparison. The overall behaviour of arrival times is assumed to not be affected across the years.

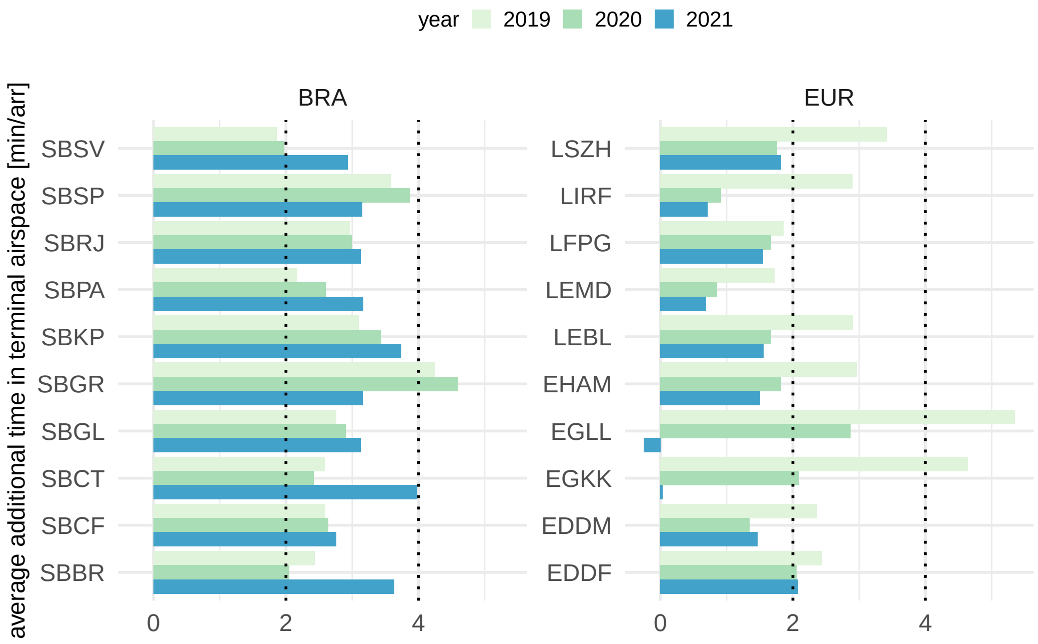


Figure 6.7: Additional time in terminal airspace

/ arrival interface across the majority of Brazilian airports.

Figure 6.8 shows the change of average additional time in terminal airspace in both regions comparing 2019 to 2021 [4].

This comparison shows the effect of the decline of air traffic in the European region on arriving traffic. For all airports, the lower traffic levels resulted in a reduction of the additional time accrued by the arrivals. However it is also noteworthy to stress that in several cases, procedures have a prevalent role on arrival sequencing. This can be observed for airports that show a relatively low change of the observed additional time while the number of arrivals significantly declined.

Overall, the change in terms of observed average additional time in the terminal airspace is characterised by a rearrangement of the airports. The overall trend of an increase in sequencing times for arrivals was shown already in Figure 6.7. Based on the available data for this assessment (c.f. number of valid flights), the change in operational procedures might be masked. This will require further investigations in future editions of this bi-regional comparison. However, it is evident that the Brazilian system showed a lower level of change in the management of arrival traffic when comparing 2019 and 2021, recalling that the comparison kept the unimpeded reference time from 2019 for all years. This suggests that the observed performance is representative of the region, i.e. applied operational procedures, and less dependent on the volume of air traffic.

[4] The additional time in terminal airspace is calculated for arrival flights for which the required data was available. Accordingly, the number of "valid" flights might differ from the overall number of arrivals reported for the airports.

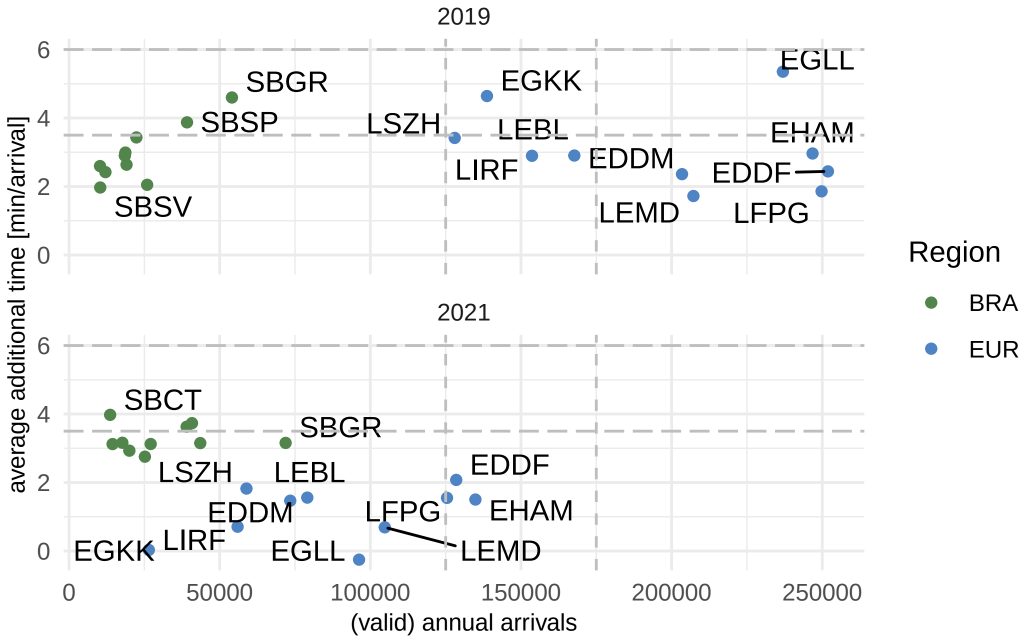


Figure 6.8: Comparison of additional time in terminal airspace

6.6 Flight Time Variability

Flight time variability determines the level of predictability for airspace users and hence has an impact on airline scheduling. It focuses on the variance associated with the individual phases of flight as experienced by airspace users. This provides an integrated gate-to-gate view, as flight time is determined by the taxi-out, en-route, and taxi-in durations. Although the measure (i.e. flight time) may also be impacted by weather influences, runway system orientation of departure and arrival aerodrome, and prevailing en-route weather conditions, the variability of the flight time comprises also synchronisation and sequencing measures of air navigation services, including airspace constraints.

For this report, flight time variability is calculated for the top 5 connections between the study airports. This serves as a proxy for the regional networks. Variability is determined as the half of the spread between the 85th and 15th percentile for flights on these connections.

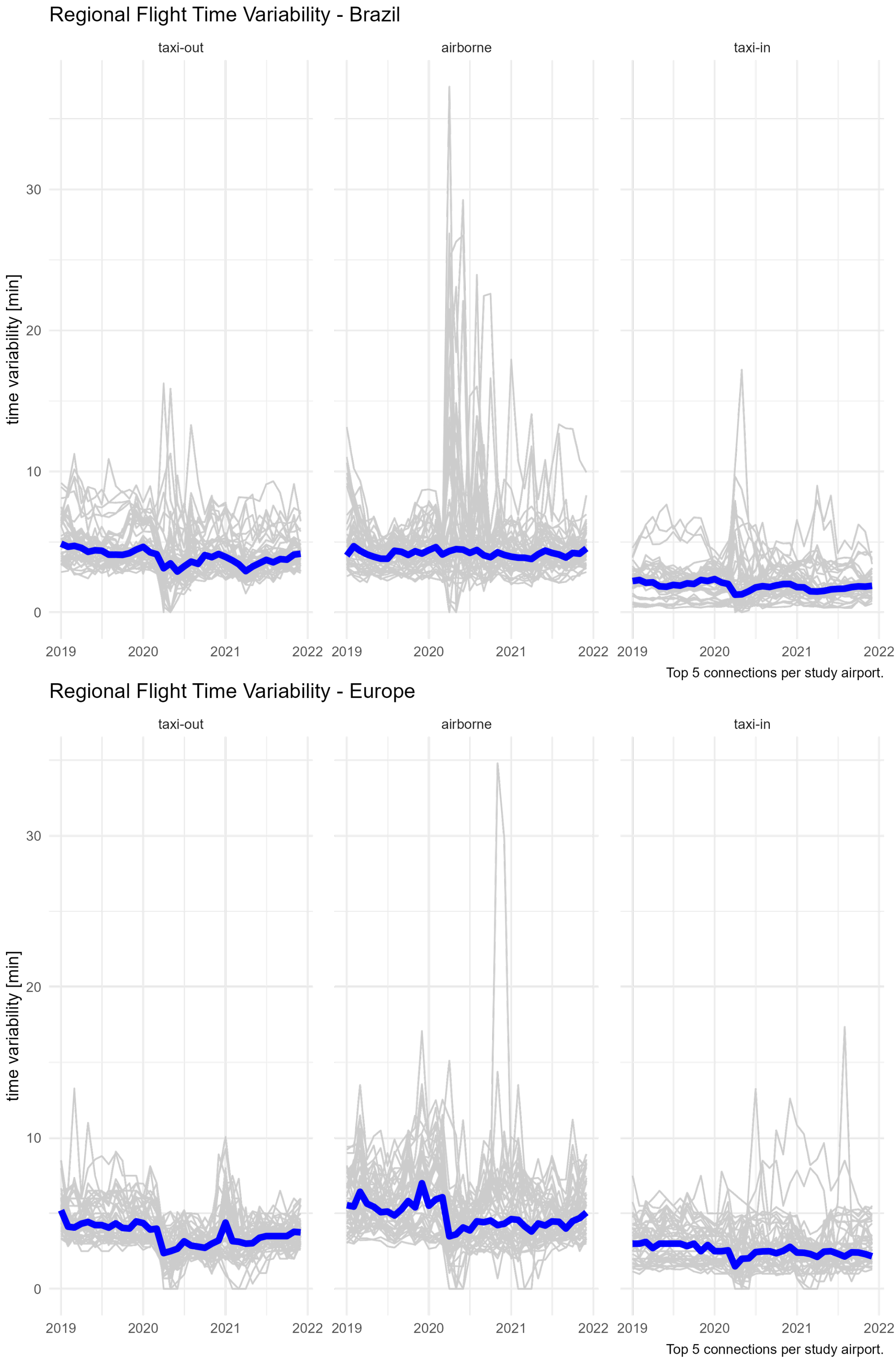


Figure 6.9: Monthly flight time variability between study airports in Brazil and Europe

Figure 6.9 shows the flight time variability for the top 5 connections among study airports in each phase of flight in both regions. Median flight time variability is less pronouced in Brazil than in Europe (depicted by the blue line). On average, both regions showed for the selected connections and flight phases different levels of monthly variability. The observed median pattern is smoother in Brazil than in Europe with a lower level of seasonality. In Brazil, lower traffic levels as part of the observed COVID waves were discernible for the surface operations only. The airborne phase - while showing high variations for certain periods - appeared to be independent on the traffic load in the system across the period from 2019 through 2021 for its median. A clear seasonal pattern was observed for taxi-out phase in Europe. Furthermore, median flight time variability in each phase reflected the overall traffic development in the region. Despite lower traffic levels, departing traffic experienced higher variability in the winter season 2020/2021. A similar pattern was observed for the en-route/airborne portion of flight. The median variability of taxi-in times were less dependent on the traffic levels, however followed the overall reduction of air transport following the pandemic declaration by WHO in March 2020. The change in terms of air transport in Europe was clearly visible in the median variation of the airborne flight time variability.There is a discernible drop by about 2 minutes for the period March 2020 through autumn 2021.

6.7 Summary

Operational efficiency provides an insight in benefit pools to be exploited. Improvements in terms of operational efficiency can be directly linked to aircraft flying time and fuel burn. In that respect, efficiency constraints impact the cost base of airspace user operations. While high performant operations will still yield a certain level of inefficiency (and associated additional times or variability), the identification of potential areas of improvement can help to enhance overall air navigation system performance and airspace user experience.

Surface movement performance in Brazil and Europe showed similarities and indicated that same operational concepts and practices are applied. On average, departing traffic in both regions observed a higher level of additional taxi-out time than compared to the observed additional taxi-in times across the years 2019 through 2021. Surface movement operations showed a higher variability in Brazil than in Europe. It will be interesting to study the respective drivers for this wider spread in future reports.

The analysis of sequencing and the management of arriving flights showed certain differences. Although trends might be masked and impacted by the available data for this comparison for Brazil, the sequencing of arrival flights appeared to be independent of the traffic volume. The increase in additional times in 2021 appeared to be linked to a change in terms of en-route / terminal airspace interface. For the European context, the overall reduction in air traffic resulted in lower pressure on the sequencing of arrivals. On average, arriving traffic at all airports observed a lower additional times. This provides a pointer to a potential benefit pool in Europe as the success of arrival management (in particular arrival sequencing) varies with traffic levels. This report also showed the stark drop of accrued additional times at London airports, i.e. London Heathrow (EGLL) and Gatwick (EGKK). As additional times are calculated based on the performance observed in a reference year (in this report 2019), it is evident that these reference times already comprise a high level of congestion. It seems to be the opposite case for Brazil, where reduced demand did not necessarily reflect lower additional times. This suggests that the measured level of inefficiency - in this report - changed significantly across the period 2019 through 2021 and may be higher than reported if the reference time varies yearly.

Overall, flight time variability showed similar extreme variations in both regions. However, on average, the Brazilian system is less impacted by seasonal variation and network operations showed a lower change in light of the varying traffic situations across the years. With both systems returning to 85-90% of pre-COVID traffic levels, it will be interesting to observe how each system will react to returning traffic load.

7 Environment

7.1 Overview and Motivation

At ICAO Assembly 40 in 2019 two global aspirational goals for curbing the impact of the international aviation sector were agreed. This includes an annual fuel efficiency improvement of 2% through 2050 and carbon neutral growth from 2020 onwards (c.f. ICAO (2019b)). Across the globe, states have defined ambitious political goals to address the impact of climate change. For example, the European Union launched its Green Deal (European Commission (2019)) and Fit-for-55 initiative. The latter strives strives towards cutting the net greenhouse gas emissions by at least 55% by 2030, compared to 1990 levels (European Commission (2021)).

In general terms, air navigation shall contribute to the protection of the environment by considering noise, gaseous emissions and other environmental issues in the implementation and operation (KPA Environment, c.f. Appendix D ICAO (2005). Accordingly, there is a higher interest in monitoring/estimating the impact of operational (in)efficiency. Operational inefficiencies typically increase the aircraft flying time (i.e. airborne and surface movement times) and , thus, engine running time. Engine time is directly linked to fuel burn and associated emissions and pollutants. In that respect, inefficiencies contribute to the ditremental effect of excessive emissions to climate change.

The Global Air Navigation Plan (GANP) proposes indicators for regional benchmarking (ICAO 2019a). However, there is no detailed guidance on how to measure *additional fuel burn*. Fuel burn per se is known to the aircraft operator. While the actual fuel burn and fuel flow during the flight is recorded (e.g. flight data recorder), these data are not commonly shared. It is noteworthy that aircraft operators have to report their fuel burn per flight in Brazil (c.f. ANAC reporting files). This level of data is not available in Europe (or generally across the globe).

For this report, both groups tapped into openly available data sources and developed an initial approach to quantifying operational inefficiencies with respect to fuel burn. It is planned to refine this approach in consultation with the international operational performance benchmarking community.

7.2 Fuel Burn Estimation

The appendix presents an initial approach to estimating fuel burn during taxi operations as part of a comparison report. Figure 7.1 depicts the monthly estimated fuel burn at a European hub for the taxi-in and taxi-out phase. It must be noted that the metric uses parameters of the ICAO landing and take-off cycle (LTO). The LTO estimates represent upper bounds for the fuel estimation and overestimates the actual fuel burn.

Figure 7.1 highlights that there is a higher fuel burn during the departure phase. This phase entails the take-off roll with a thrust setting at or close to 100%. This adds a substantial component to the fuel burn during take-off in comparison to the taxi-in phase. As mentioned above, the quantities shown reflect upper bounds based on the LTO assumptions and do not account for operational reduction measures such as single-engine taxi or reduced thrust take-offs. It is planned to refine the approach with the international benchmarking community and account for such operational measures.

7.3 Environmental Benefit Pool - Taxi

Earlier work has introduced the concept of an environmental benefit pool, c.f. EUROCONTROL Performance Review Unit and FAA Air Traffic Organization (2019).

Figure 7.2 shows the fuel benefit pool for the taxi-in phase per arrival. The benefit pool is influenced by the fleet mix and the overall taxi-in performance. Thus, it varies significantly across the airports.

With the exception of Rome Fiumicino (LIRF), there is an increase in the benefit pool when comparing 2020 and 2021 within the European region.

Comparing Figure 7.3 with Figure 7.2 shows the overall impact of higher observed taxi-out times and the high-thrust take-off run. For the major hubs in Europe the traffic decline during the COVID phase culminated in sharp decline of the average additional fuel burn per departure when comparing 2019 levels to 2020 or 2021. The impact of congestions on the taxi-operations and the associated refernce times was highlighted already in the efficiency chapter. In light of this, the results for London Heathrow (EGLL) and London Gatwick (EGKK) need to be interpreted comparing the absolute different between the different years. The decline in traffic allowed to operate without constraints which resulted in a - numerical - gain.
However, this showcases that the determined reference times internalised inefficiencies. The values for these airports range higher than presented. Future research will address how such variations in terms of traffic load can be better captured as part of the benefit pool approach.

7.4 Mapping of Benefit Pools

The following Figures depicts the observed shares of additional fuel burn for taxi-out and taxi-in. It must be noted that the totals are based on the assumptions of the ICAO LTO cycle. As such the estimates present an ***upper bound*** and do not take into consideration single-engine taxi-operations, reduced taxi-thrust, etc.

7.5 Summary

This chapter is a first attempt to estimate the environmental impact of operational inefficiencies at airports. The determined benefit pools for taxi-in and taxi-out vary significantly between airports. While operational inefficiencies, e.g. higher sequencing and holding times, impact on the overall taxi-phase duration - and ultimately - the total fuel burnt during these phases, the metric is also dependent on the different fleet mix observed at these airports. The impact of wide-bodies (and primarily international traffic) can be readily observed for the major hubs during 2019. The COVID related decline of operations of these types and connections, resulted in a sharp drop of the measured benefit pool in 2020 and 2021.

Based on the underlying databank of aircraft types and associated fuel burn indices, more detailed analyses will be feasible in future reports.

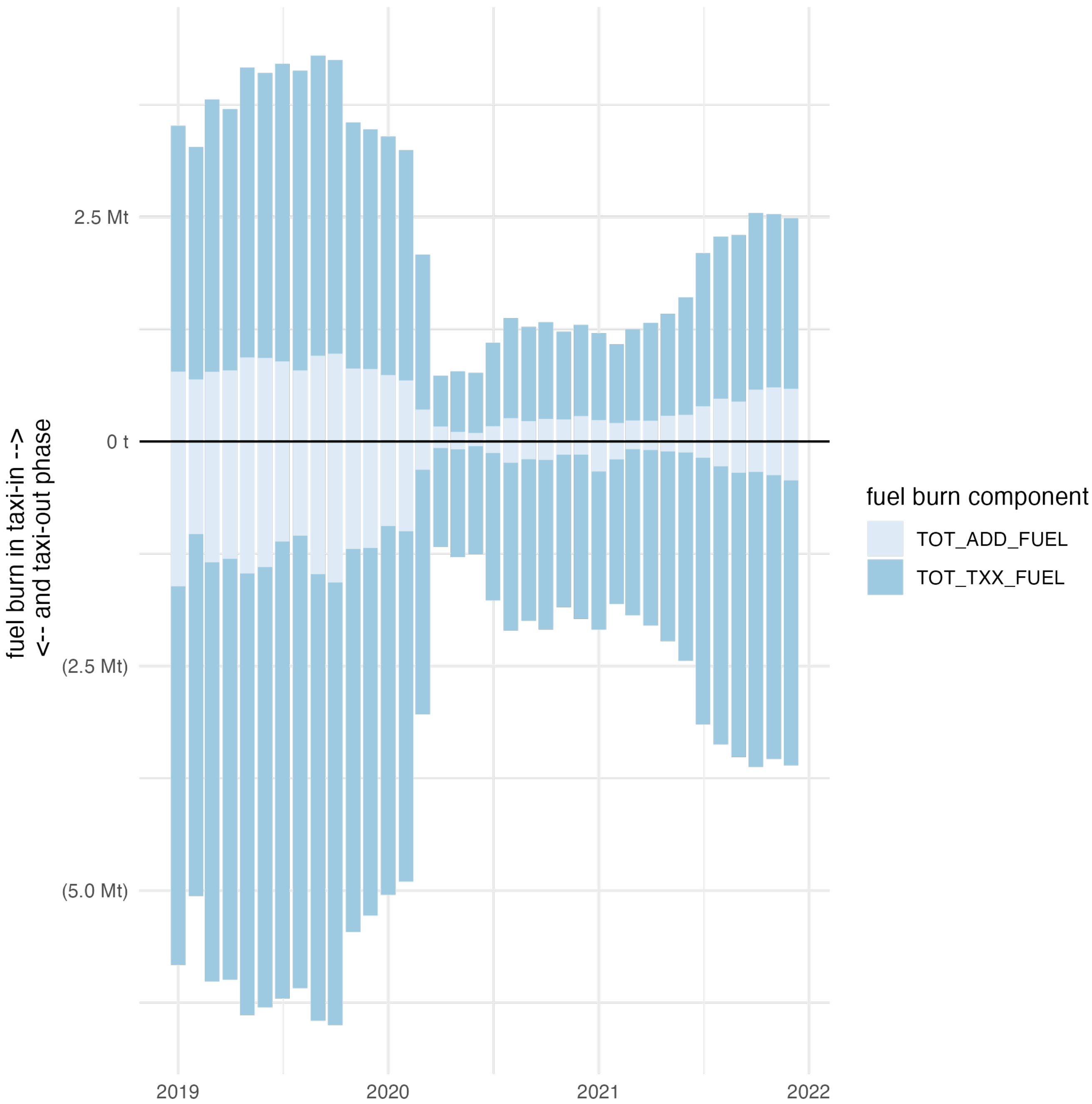


Figure 7.1: Example fuel burn estimation at a European hub airport

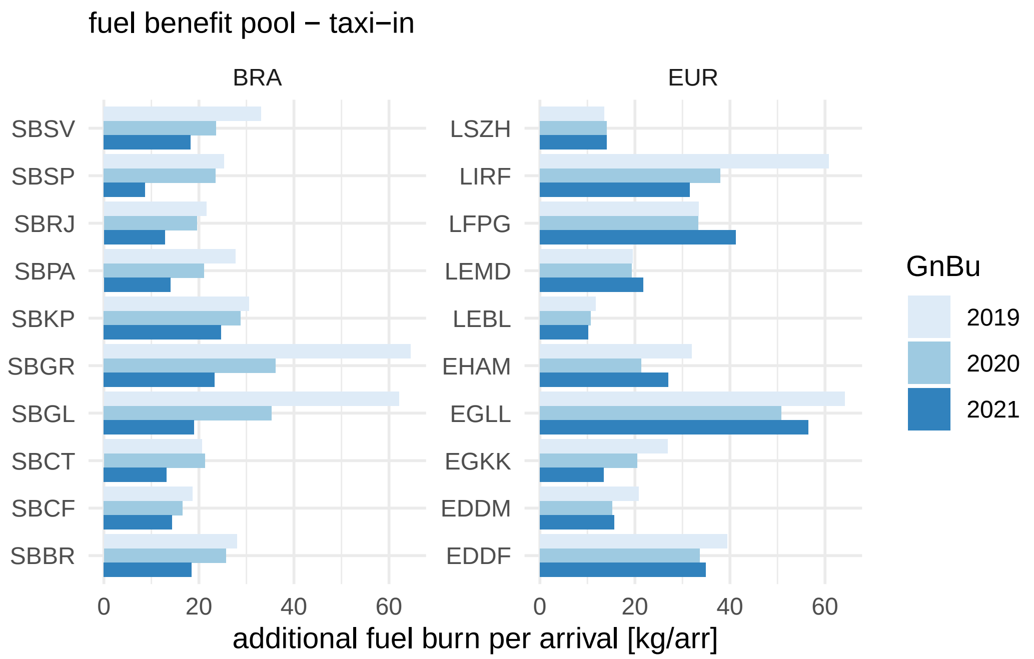


Figure 7.2: Benefit pool in terms of additional fuel burn during taxi-in phase

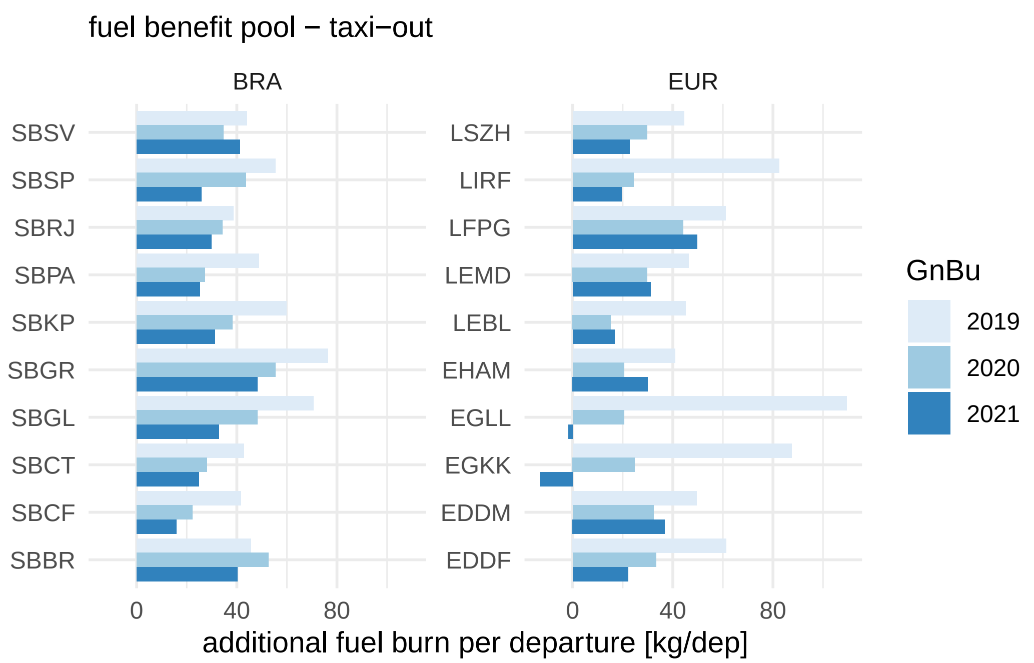


Figure 7.3: Benefit pool in terms of additional fuel burn during taxi-out

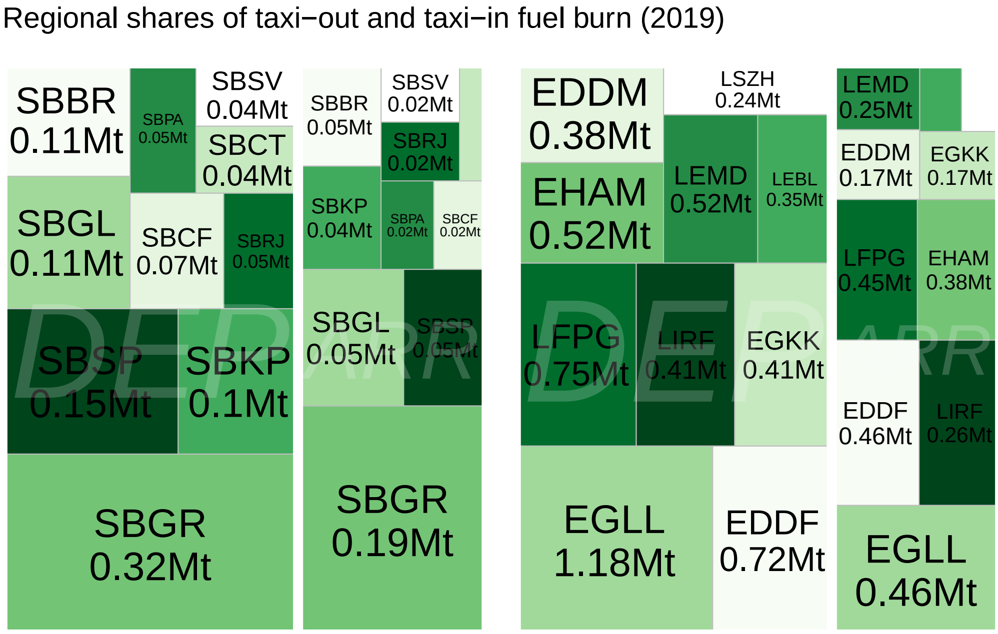


Figure 7.4: Regional shares of additional fuel burn during ground movement phase

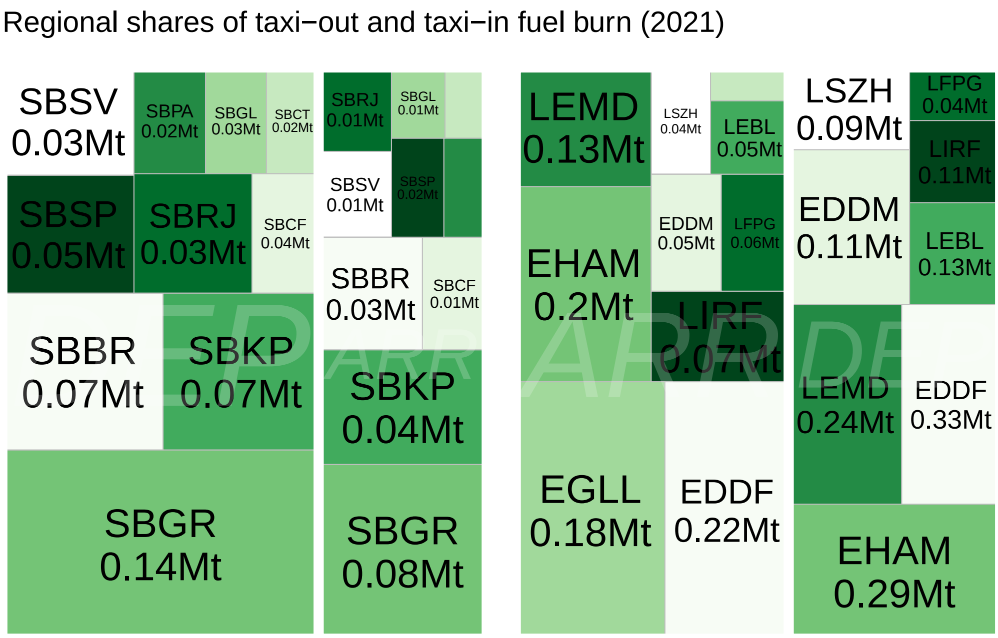


Figure 7.5: Regional shares of additional fuel burn during ground movement phase

8 Conclusions

This second iteration of the Brazil-Europe operational ANS performance comparison report builds on the joint project between the DECEA Performance Section and the Performance Review Unit of EUROCONTROL.

The collaboration project aims at the development of a joint and common understanding of agreed metrics and definitions to compare, understand, and improve operational air navigation system performance. This report uses a subset of the key performance indicators established by ICAO's GANP. The work is also used as a show-case for applying the GANP indicators within a bi-regional project, to augment the associated guidance material, and inform further multi-regional comparison efforts. The comparison shows similarities and differences in the observed performance in both regions. Throughout the report several observations and ideas for future research have been identified. This will allow to further develop and complement the performance framework.

The first part of this report examined commonalities and differences in terms of air traffic management organisation and performance influencing factors, such as air traffic demand and fleet composition. These factors can have a large influence on the observed performance. Overall, air navigation service provision is more fragmented in Europe with local/national ANSPs and their respective control units. The integrated civil/military service provision is inherent to the organisation of DECEA and the Brazilian system. Irrespective of the airspace volume, the large difference in numbers of control units in Europe and Brazil demonstrates this. Both systems operate a central flow management center to ensure network wide flow management processes and functions.

Both regions encountered an unprecedented decline of air traffic in response to COVID-19. Regional and global traffic restrictions resulted however in different patterns regarding the initial and continued recovery. European traffic levels showed several waves in light of the variety of national and pan-European measures. The Brazilian evolution of traffic showed a delayed wave pattern in comparison with Europe, however, showed a more steady recovery overall.
Additional diversity in terms of air traffic was observed across the Brazilian airports as there was a significant share of light types serviced. Within the European context, the share of light types was mostly negligible. A higher share of wide-body (heavy) aircraft operated from the European airports including a higher level of international connectivity. This is more nuanced in Brazil where the level of international connections is more centralised.

In terms of predictability and puncutality, the results were strongly influenced by the prevailing COVID-19 traffic evolution. Both systems suffered from the disruption of schedules and cancellations of flight connections. Europe showed a higher number of aircraft arriving more than 15 minutes ahead of schedule (early arrivals) and flights departing later than 15 minutes after their scheduled time). In Brazil, this behaviour was only observed for arriving traffic. Returning traffic levels drove a gradual move towards punctuality levels comparable to 2019 levels. However, there is a higher level of uncertainty in terms of movements in both regions.

Runway system capacities in Brazil were adapted over the past years to accommodate the projected growth. Respective capacities at European airports were constant over the horizon of this report as part of the local/national declaration process and operated traffic levels. Despite the COVID-related change in traffic, accomplished peak throughput levels ranged at the level of earlier years. This suggests that airport runway system capacities are commensurate with the observed (and expected) traffic levels and represent not a primary driver for operational inefficiencies during the arrival phase.

Operational efficiency in this report is measured for the taxi-in and taxi-out phase, and additional time in terminal airspace. Similar patterns were observed at the different airports in both regions. On average, arriving traffic was observing little additional taxi-in times in both regions. However, the variation across airports suggests that local specifics (traffic levels, used combinations of runway system / parking positions) contributed the varying taxi-in performance. It will be interesting to study the associated drivers in the future. The levels of additional taxi-out times is generally higher for departing flights in comparison to arrivals. The additional taxi-out times for the study airports showed a clear association with the traffic levels during and post COVID-19 in Brazil. This behaviour is less prominent for the European airports and may be linked to the partail use of runway system, terminals, and parking positions. In general surface movement operations see a higher variation in Brazil than in Europe. Although trends might be masked and impacted by the available data for this comparison for Brazil, the sequencing of arrival flights appeared to be independent of the traffic volume. The increase in additional times in 2021 appeared to be linked to a change in terms of en-route / terminal airspace interface. For the European context, the overall reduction in air traffic resulted in lower pressure on the sequencing of arrivals. On average, arriving traffic at all airports observed a lower additional times. Flight time variability was obviously affected by the varying traffic levels. However, the Brazilian system is less impacted by seasonal variation than the European system.

Political priorities require to address the impact of air transportation on climate change. There is a growing interest in both regions to better quantify the potential benefit pool actionable by air navigation. This report develped a first approach to better quantify inefficiencies observed in the taxi-in and taxi-out phase. Higher operational performance will ultimately lead to higher levels of fuel efficiency and lower fuel burn. Absolute numbers in terms of fuel burn / CO_2 emissions are linked to the volume of air traffic and aircraft types in service. The latter impacts a direct comparison and require more research for future editions. This comparison shows the potential benefit pool at the different airports. This pool provides a higher margin of improvement at airports with higher levels of air traffic and large (heavy) aircraft. As such, the role of the airport within the system - heavy aircraft & international connectivity - is a fundamental aspect in terms of addressing the contribution of air navigation.

This second edition of the operational comparison between Brazil and Europe allowed to further harmonise the application of GANP performance measures and identified areas for further research and joint developments. Both groups, Performance Section of DECEA and Performance Review Unit of EUROCONTROL, plan to continue the close collaboration and expand on the analyses of this report. This report will be updated throughout the coming years under the umbrella of the DECEA-EUROCONTROL memorandum of cooperation. Building on this collaboration, the idea is to establish a web-based rolling monitoring complementing this and future editions. A web-based monitoring will enable updates on a regular basis. Future editions will also enable to complement data time series and support the development of further use-case analyses. The lessons learnt of this joint project will also be coordinated with the multi-national PBWG and ICAO GANP Study sub-group concerned with the further development of the GANP KPIs.

A Fuel Burn Methodology

A.1 Fuel Flow Estimation - Look-Up Table Approach

At the time of writing no consolidated fuel burn methodology for operational performance benchmarking existed. The guidance material for the application of the GANP KPI16 suggests to apply **average fuel burn estimates**. To advance the state-of-the-art, PS and PRU established a look-up table on the basis of openly available mappings of aircraft type and (representative) engine.

With the ICAO Aircraft Engine Emissions Databank certification data for registered engines allowed for the identification of associated fuel flow indices for specific thrust levels per engine during the landing and take-off cycle (LTO). Further engine specific consumption data - primarily piston engines - were obtained from the database of the Federal Office for Civil Aviation of Switzerland. This dataset will be made available and further augmented with the help of the international benchmarking community. While the approach supported a good coverage of current aircraft types (about 90%), there was a need to make fuel burn assumptions for the remaining fleet.

Earlier work, c.f. EUROCONTROL Performance Review Unit and FAA Air Traffic Organization (2019), defined a benefit pool on the basis of a generic **"average flight"** (i.e. A320, 450NM leg). These values were taken as defaults for aircraft types not yet accounted for in the established data set.

For the estimation of the fuel burn in the en-route portion (climb-cruise-descent := CCD) it is proposed to apply an heuristic approach in future reports. This however requires for research and validation. The principles are laid out as follows:

- ICAO's Carbon Emission Calculator Methodology supports the identification of **average fuel burn** on a per aerodrome pair.
- The calculator methodology estimates the fuel burn on the basis of pre-dominantly flown aircraft types, i.e. it can be assumed to be a fleet mix representative sample estimate.
- This estimate can be scaled for each arrival and compared to the additional time in terminal airspace.

An improvement to these estimates, i.e. estimating the fuel burn during surface operations and during the arrival phase, will be subject to further research.

A.2 Assumptions for Estimation of Taxi-in and Taxi-Out Fuel Burn

For this report, the operational LTO Cycle is defined as follows:

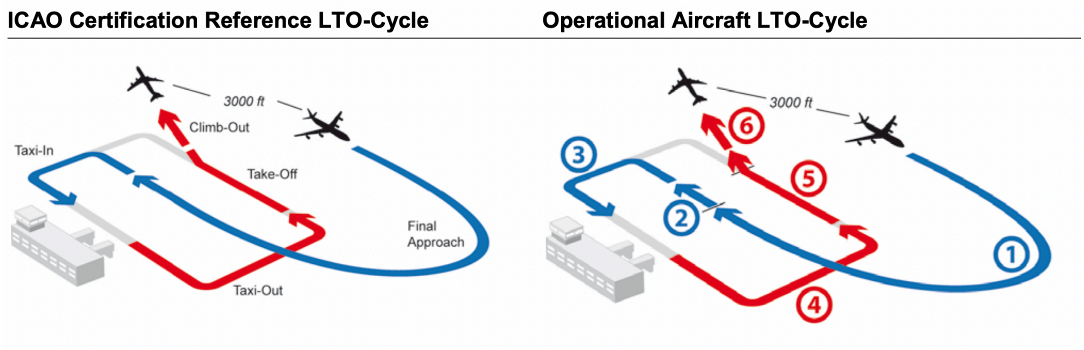


Figure A.1: Operational LTO cycle based on Fleuti, Maraini, and Janicke (2012).

# Phase	Comment
1 approach	3000ft GND to actual landing
2 landing roll	touchdown to end rollout
3 taxi-in	taxi from end rollout/runway to stand
4 taxi-out	taxi from stand to runway/line-up position
5 take-off roll & initial climb	take-off roll to lift-off, including initial climb to 'throttle back'
6 climb-out	climb-out to 3000ft GND'

Taxi-in is defined as the difference between the actual landing time (ALDT) and the actual in-block time (AIBT), i.e. $TXIT = AIBT - ALDT$.

Conversely, taxi-out is defined as $TXOT = ATOT - AOBT$.

Based on the LTO assumptions, TXIT comprises phases 2 and 3. For TXOT, phases 4 and 5 apply until the actual take-off/lift-off - strictly speaking without the initial climb to 'throttle back'.

By convention, the standard ICAO LTO cycle assumes a specific *"time-in-mode" (TIM)* for each phase. Research has shown that the TIMs are not representative for many airports and operations. This report, thus, replaces the TIMs with the observed ground movement times, i.e. ALDT, AIBT, AOBT, ATOT.

The standard LTO cycle uses 0.7 min (42 sec) for the take-off roll and lift-off. From an operational perspective, this value is realistic for large (and heavy) aircraft or reduced thrust take-off (resulting in lower acceleration and longer take-off roll).
No provisions are made for decelaration during the landing roll (e.g. reverse thrust).

Per definition, the taxi-in and taxi-out indicator includes the landing roll or take-off roll. This report applies the following assumptions:

- taxi-in:
  - inefficiencies during the taxi-in phase are primarily encountered following the landing roll;

  - the landing roll is a systemic duration and can be broadly assumed to be constant per aircraft type, variations in terms of landing roll (shorter & longer durations) are equally distributed; and
  - measured additional taxi-in times are therefore encountered after vacating the runway and during taxi to the stand/gate.

- taxi-out:
  - inefficiencies during the taxiout phase are primarily encountered during taxi from the stand/gate to the holding point at the runway;
  - line-up and take-off roll are a systemic duration and do not vary significantly per aircraft type, thus, can be considered equally distributed; and
  - measured additional taxi-in times represent therefore the inefficiency during taxi-out.

While the additional time approach and assumptions eliminate the need to consider the landing-roll or take-off roll for the calculation of the additional fuel burn during these modes, the absolute fuel burn needs to considers the associated time-in-mode.

- For the landing, ICAO LTO assumes a 7% idle thrust and taxi setting.
  Thus, the overall measured taxi-in time, i.e. $TXIT = AIBT - ALDT$ is performed under the continuous 7% thrust setting.
- For take-off operations, the take-off roll / lift-off is performed under 100% thrust setting.
  Accordingly, the take-off roll duration needs to be deducted from the total observed taxi-out time.
  Total taxi-out fuel is then calculated based on the reduced taxi-out phase at 7% thrust setting and the take-off roll at 100% thrust setting.

To account for missing data regarding aircraft types and/or respective reference engines, an estimate for the fuel burn for “similar” flights is calculated on the basis of complete data records. This similarity is based on aircraft wake turbulence category and engine type (e.g. light jet, medium jet, heavy/medium/light turboprop). This ensures that nuances of the fleet mix are captured and reduces the further overestimation by using general averages, etc.

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