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Air Navigation and COVID-19: ATM Efficiency in Pandemic Crisis

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by

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Abstract

The coronavirus crisis effects on aviation in 2020 are currently well-documented. Nonetheless, the widely registered low traffic due to the crisis does not necessarily lead to increased air navigation efficiency. Thus, the present work, developed to fulfill the program outcomes for the Master of Science in Aeronautics, Air Traffic Management (ATM) specialization, aimed to investigate what was the impact of the COVID-19 crisis on air navigation efficiency in Brazil. This research question was addressed through a quantitative, nonexperimental, observational approach with two parallel branches, designed to answer two sub-questions. For the first, regarding what was the impact of the crisis on arrival delays in Brazil, a posttest, one group design found no evidence of significant differences in mean arrival delays between 2019 and 2020. For the second, regarding flight times between city pairs, there was no strong correlation between the number of flights in a given route and their respective flight durations. Together, both branches suggested no overall efficiency improvements. In other words, the COVID-19 crisis did not have a significant impact on the air navigation system efficiency, within the Brazilian context. The work was relevant for the ATM industry due to the contrasting findings in other parts of the world and also for helping to develop alternative air navigation efficiency evaluations. Due to the nonexperimental nature of the research design, further investigations are recommended to support a better comprehension of global ATM.

Keywords: air navigation, air traffic management, ATM, aviation, COVID-19, efficiency

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Chapter I

Introduction

The coronavirus crisis effects on aviation in 2020 are currently well-documented from many standpoints. According to the International Civil Aviation Organization (ICAO, 2021), airlines' passenger traffic decreased by around 60% compared to 2019, and airports revenues were down by approximately $112 billion. However, studies of the pandemic effects on air navigation services performance are less frequent and relatively scarce.

Arguably, the relatively low commercial traffic intuitively favored fewer delays, for overall system capacity is more likely to accommodate the low demand readily. At least, those were the findings by EUROCONTROL (2021), after analyzing the impacts of COVID-19 on European Air Navigation Services Providers (ANSP). For the agency, "fewer flights meant there was little to no congestion throughout Europe over 2020, permitting more direct flight profiles" (EUROCONTROL, 2021, p. 9).

However, there might be alternative factors influencing efficiency, such as seasonal extreme weather events, ANSP-related constraints, and poor airspace design. For instance, causes related to the National Aviation System in the U.S. represented only 21% to 25% of total flight delays in recent years, while air carrier and extreme weather together were present in around 35% to 47% (Bureau of Transportation Statistics, 2021). So, the relationship between capacity and efficiency is not always linear. Other factors play relevant roles, and low traffic may not lead to increased efficiency *per se*. Besides, one particular trend in the U.S. might not be found in other parts of the world.

Hence, the doubt remains valid whether COVID-19 air traffic decreases actually led to more efficient air navigation systems in every scenario. As a result, the present research aimed to investigate further the crisis effects on air navigation performance, from a system-wide efficiency perspective, in the Brazilian context.

Significance of the Study

The study was relevant to provide additional insights on the impacts of the coronavirus crisis on aviation from an alternative perspective. First, it helped to understand how air navigation efficiency evolved with the pandemic. Second, it proposed to put light on additional geographic regions, which, in turn, might support the comprehension of global air traffic management. Finally, there are confounding factors that may result in flight delays, which usually are difficult to isolate. Thus, the current low traffic scenario offered a unique opportunity to investigate air navigation efficiency in the context of fewer capacity imbalance constraints.

Statement of the Problem

The problem is that the low traffic due to the COVID-19 crisis does not necessarily lead to increased air navigation efficiency. As shown in the previous section, flight delays in the U.S. are related to factors other than capacity imbalances – such as weather or air carriers' mismanagement. Also, EUROCONTROL (2021) reported that the crisis favored more direct routes. However, it is still unclear if that happened in all contexts. As a result, inefficiencies might still be present, even with reduced air traffic demand.

Purpose Statement

The purpose of this research was to provide a better comprehension of the Brazilian air navigation system in a low-traffic scenario. As a result, the research aimed to create conditions to improve efficiency. Besides, the study proposed to deliver additional insights about the Brazilian air traffic to the country's ANSP, Department of Airspace Control (DECEA), through the investigation of efficiency parameters still not explored by its current publications. For now, DECEA (2020) only addressed arrivals punctuality, but not arrivals delays.

Research Question and Hypothesis

The low traffic may not lead to increased efficiency, for factors other than capacity imbalances might be present. Although some evidence suggested that was the case in Europe, it is helpful to investigate further the problem in different scenarios. In that context, the present work aimed to answer the following research question:

RQ: What was the impact of the COVID-19 crisis on air navigation efficiency in Brazil?

However, efficiency is a conceptual construct that may be measured in many different ways. A preliminary literature review suggested that, in the air navigation field, this concept could be measured through flight delays and average flight time between city pairs (Civil Air Navigation Services Organisation, 2015). So, it is not only helpful but also more complete to interpret efficiency under the light of both indicators.

Considering that delays may be measured on departure and arrival phases, the author opted for measuring the latter, for it might have encapsulated better any inefficiency during the en-route phase of the flight. As a result, the following sub-questions, with their correspondent hypotheses, allowed a more precise answer for the primary inquiry.

RQ1: What was the impact of the crisis on arrival delays in Brazil?

H_0: There was no significant difference in mean arrival delays before and after the COVID-19 crisis.

H_a: There was a significant difference in mean arrival delays after the COVID-19 crisis.

RQ2: Is there a correlation between the number of flights and the average flight times?

H_0: There is no strong correlation between traffic counts variation and average flight times variation between city pairs.

H_a: There is a strong correlation between traffic counts variation and average flight times variation between city pairs.

Delimitations

The investigation was delimited by both geographical and temporal constraints. Geographically, the research investigated the problem in Brazil for three reasons. First, Brazil offers an excellent sample of aerodromes: With 2,717 airports, the country is second only after the U.S. in the number of registered airports worldwide (Ahlgren, 2021). Next, the last report published by the Department of Airspace Control (DECEA, 2020), the Brazilian ANSP, addressed efficiency only through punctuality indicators but did not consider delays individually. Although this choice is still a proper approach, adding alternative perspectives may contribute to its air navigation network's comprehension. Finally, the Brazilian National Civil Aviation Agency (ANAC) keeps a public record for all national and international commercial flights, thus offering a suitable and reliable data collection process. Therefore, the author gathered a representative sample of all Brazilian airports to broaden as wide as possible the air navigation routes under study.

For the temporal aspect, it seemed reasonable to assume that examining air traffic data from January 1, 2019, to December 31, 2020, is sufficient to start drawing some conclusions. The period has likely encapsulated most of the crisis effects on air traffic while still offered potential comparisons to similar previous periods. Besides, as stated in the previous section, the research was limited to arrival delays only.

Limitations and Assumptions

The ANAC database is comprised of a list of flights sent by the airlines to the agency, which then compiles the information. Therefore, the primary assumption was that the registers, particularly dates and times, represented an accurate picture of how the flights actually occurred, mostly free of errors. Also, some flights, such as general and military aviation, are not in the database. Thus, the analysis of commercial flights performance was assumed as a reasonable representation of aviation in Brazil, in most of the country's busiest airports.

In addition, the database provided in and out block times rather than departure and landing times. As a result, all information referred to a gate-to-gate perspective. In other words, if any inefficiency exists, the research would not be able to precisely identify whether it occurred during taxi in, taxi out, or en-route phases. Also, the database did not provide the type of aircraft for each flight, which might imply larger dispersions in flight times. Nonetheless, rather than measures of dispersion, only measures of center were under the concern of the study, e.g., average flight time, average arrivals delay. Therefore, this limitation did not have a significant impact on the overall results.

Finally, the arrival delays indicator was an author's adaptation of the original ANSP-Attributable Delay indicator, as originally proposed by the Civil Air Navigation Services Organisation (CANSO, 2015) as "one of the most visible measures available to the public on aviation performance" (p. 33). As the Brazilian database did not disclose the particular, individual cause of delays, it was only possible to calculate the raw delay, but without precisely specifying if it was actually attributable to the ANSP.

List of Acronyms

ANAC: National Civil Aviation Agency

ANSP: Air Navigation Services Provider

CANSO: Civil Air Navigation Services Organisation

DECEA: Department of Airspace Control

EUROCONTROL: European Organisation for the Safety of Air Navigation

ICAO: International Civil Aviation Organization

Chapter II

Review of Relevant Literature

The comprehension of the terms efficiency, air traffic management, and air navigation services are fundamental to the reader's understanding, so are the different methods to measuring the first in the context of the others. First, Arblaster (2018) explained that air traffic management (ATM) is, in fact, one of the services within the air navigation system. Other services include search and rescue, meteorological, and aeronautical information. The author argued that air traffic flow management has evolved "to achieve overall system efficiency" (p. 19), making evident the high relevance of this concept nowadays. However, efficiency is still a broad concept, often used to describe some output level or results relative to a given input or best practice reference. The concept can also be applied in different performance dimensions.

For example, in the airport industry, Oum et al. (2008) investigated different forms of airport ownership and their effects on cost efficiency. The research used several operational and monetary inputs to build a stochastic cost frontier model as a reference and compared the diverse airport outputs to confirm, among other remarks, that privatization could help airport efficiency in the financial domain. More recently, Kim and Son (2021) analyzed 31 global airlines to evaluate their efficiency, this time in the environmental dimension. While the authors found that environmental efficiency was higher in European and Russian airlines, they also addressed efficiency as "the ratio of outputs to inputs" (p. 5). Yu (2016) had previously supported that notion, having added that efficiency is always relative and referred to how well a particular unit performs. Facing so many different forms, what efficiency means in the ATM field?

In the academic domain, Todorov and Petrov (2017) argued that ATM efficiency could be measured through different indicators in several sub-domains. Those categories included cost-efficiency and environment, as previously seen, but also safety and capacity. For the professional sector, however, efficiency is one of those particular domains. For example, the Global Air Navigation Plan (ICAO, 2016) identified efficiency as one of the ICAO's key performance areas. For the agency, the concept could be measured by additional times in taxi-in, taxi-out, or times in terminal airspace performance indicators. Nonetheless, those indicators vary from region to region worldwide.

In Europe, EUROCONTROL (2020) monitored ANS-related efficiency both en-route and around airports. For the first, the agency used en-route flight delays; for the latter, arrival delays and additional time in arrival sequencing. Jointly with the European agency, the Federal Aviation Administration (EUROCONTROL & FAA, 2016) stated that "efficiency generally relates to fuel efficiency or reductions in flight times of a given flight" (p. 52). The American agency oversaw delays segmented in the different phases of flight. And in Brazil, the Department of Airspace Control (DECEA, 2020) monitored airport punctuality and additional taxi-in and taxi-out times as efficiency measurements while making no mention of indicators such as arrival delays or additional times in terminal airspace.

As a result, some notions are reasonably accepted, despite some local variations. First and foremost, for the ATM as a service, temporal measurements such as additional times and delays are well-established efficiency indicators. That makes sense, considering that, within a given air navigation system, the resulting flight times and delays (outputs) tend to improve or worsen depending on the overall airport infrastructure and air navigation services available to the users (inputs). Second, there is no single indicator capable of encapsulating the entire notion of efficiency. Specialized aviation agencies worldwide use more than one measurement to address the same dimension. Finally, those multiple indicators are often used in complementary ways. Individually, they might provide an incomplete view of such a broad and relative concept.

For those reasons, the present work opted for an adapted methodology based on the theory proposed by Civil Air Navigation Services Organisation (CANSO). CANSO (2015) explained that, in addition to the efficiency as measured per phase of flight, other values are reliable indicators of system efficiency. For the agency, "delay is one of the most visible measures available to the public on aviation performance" (p. 33). Hence, ANSP-attributable delays could be used as an efficiency indicator, despite some remarks regarding potential airlines' scheduled buffer times and weather considerations. Besides, ATM efficiency could be measured through average flight times between city pairs.

Summary

Efficiency is a broad concept used by academic researchers in many ways (Kim & Son, 2021; Oum et al., 2008; Todorov & Petrov, 2017; Yu, 2016). However, for the ATM domain, defined as an air navigation service (Arblaster, 2018), efficiency is often measured by temporal values. Based on some common understandings, ATM efficiency can be reasonably measured through multiple, complementary indicators, such as flight delays, additional taxi and terminal times, flight times, or punctuality (DECEA, 2020; EUROCONTROL, 2020; EUROCONTROL & FAA, 2016; ICAO, 2016). For this work, in particular, the theoretical framework proposed by CANSO (2015), comprised of average delays and average flight times between city pairs, seems, therefore, as a good starting point to address efficiency within the ATM field.

Chapter III

Methodology

The research followed the classification proposed by Edmonds and Kennedy (2017). According to the authors, “nonexperimental research is conducted when the researcher does not have direct control of the independent variables simply because their manifestations have already occurred” (p. 117), which seems to be the case with the COVID-19 crisis in aviation. However, in nonexperimental research, causal relationships are difficult to establish, and control is not possible through variable manipulations or group assignments. Instead, control is applied through statistical procedures. Therefore, to overcome those inherent limitations, a quantitative, nonexperimental, observational approach with two parallel designs was performed.

Research Approach

The research proposed an observational approach comprised of both a posttest (one group) design and an explanatory design in parallel branches. Each design was aimed to investigate one of the research sub-questions, hence providing a complementary view on different efficiency measures and a more comprehensive answer to the main question.

Design and procedures

The posttest (one group) design aimed to answer the RQ1: What was the impact of the crisis on arrival delays in Brazil? The rationale behind it consisted of gathering the group of airports in a classic before/after approach to verify if there is a significant change in mean arrivals delays, between 2019 and 2020, through a paired t-test. According to Weiss (2017), “a paired sample may be appropriate when the members of the two populations have a natural pairing” (p. 507). Here, there were two samples (2019 and 2020) of the same airports, thus forming a natural pairing. The test verified the difference in mean arrival delays, measured in minutes per flight, at a 5% significance level ($\alpha = 0.05$). An overall scheme is provided in table 1 below:

Table 1

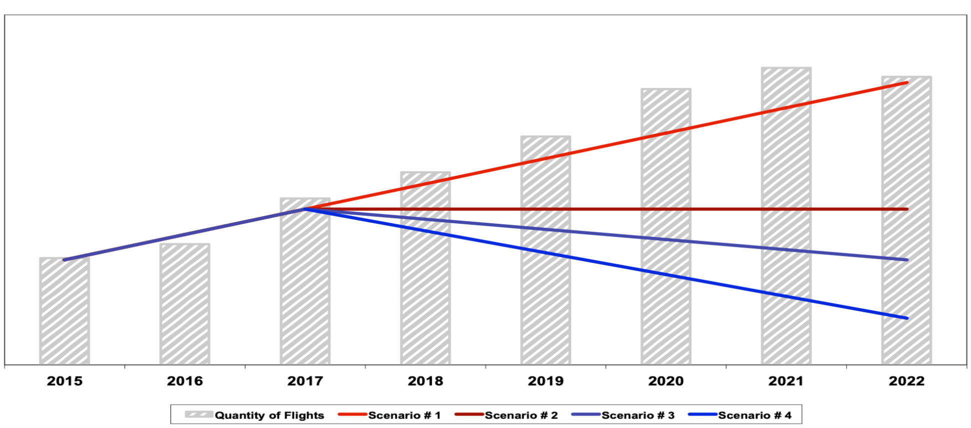
Airports Mean Arrival Delays Example

Airport	Average arrival delay in 2019 (minutes/flight)	Average arrival delay in 2020 (minutes/flight)
SBAA	0.2	0.4
SBAB	3	1.5
…	…	…
SBZZ	0.5	0

In parallel, the explanatory design aimed to answer the RQ2: Is there a correlation between the number of flights and the average flight times? According to Edmonds and Kennedy (2017), this design was intended to establish potential associations between two variables. CANSO (2015) argued that a positive correlation between the number of flights and the average flight time for a given city pair is evidence for less efficient air navigation systems, as shown in Figure 1 below:

Figure 1

Average Flight Time Between City Pairs as a Measure of Efficiency



Note. As published by CANSO (2015, p. 35), scenario 1 is less efficient (higher flight times), while scenarios 2, 3, and 4 are more efficient (equal or lower flight times).

However, when analyzing multiple city pairs – which is the research intention – those values must be normalized against a standard value to eliminate distance as a confounding variable – shorter city pairs will evidently have shorter flight times, despite the number of flights over time. Therefore, instead of measuring flight times and number of flights in integer minutes and counts, respectively, the research measured those variables in relation to 2019 values.

As a result, the data processing formed a table, as provided in Table 2 below, to check a potential correlation between the two variables. As explained by Weiss (2017), the expected value should be between -1 and 1. Values close to 0 denote a weak association, whilst values close to 1 (-1) indicate a stronger positive (negative) correlation.

Table 2

Average Flight Times and Number of Flights Example

City pair	Number of flights (relative to 2019)	Average Flight Time (relative to 2019)
SBAA-SBXY	0.55	1.001
SBAA-SBYY	0.45	0.999
…	…	…
SBXY-SBZZ	0.70	1.023

Note. The values are the result of the number of flights 2020 divided by 2019, and average flight times 2020 divided by 2019.

Apparatus and materials

Data collection and processing were performed with RStudio software, open-source, desktop edition. RStudio has many crowd-sourced packages available, supporting data manipulation and statistical analysis. The final research report was written in Microsoft Word software, using the regular ERAU license to students.

Sample

The sample was formed by the maximum number of airports available in the database after the cleaning process. There was no preliminary need to obtain a reduced randomized subset of the airports, as RStudio was able to process all airports in the database, resulting in a comprehensive analysis.

Sources of Data

Data was collected from the public ANAC database available at *https://www.gov.br/anac/pt-br/assuntos/dados-e-estatisticas/historico-de-voos*. The database is a historical repository of all commercial flights in Brazil, including scheduled, charter, cargo, and passenger segments, for all national and international flights with a Brazilian origin or destination.

Validity

The research used two different designs in parallel to mitigate the threats to external, construction, and, particularly, statistical validity. In addition, including all possible airports in the sample may have reduced any sampling bias: Some airports may be more prone to delays than others, so picking only a part could lead to wrong conclusions. Finally, the normalization of the average flight time and the number of flights to 2019 values will allow a comparison of multiple city pairs, despite the different distances among them: Distance, in this case, would be an evident confounding variable. Based on those measures, the research created reasonable conditions to answer the research question with valid conclusions.

Treatment of Data

The data were treated in the following step-by-step procedures:

1. Data collection with RStudio, using - mostly - *read_csv()* function on the ANAC database.
2. Data preparation to remove any potential data errors, such as empty spaces or obvious impossibilities, e.g., inexistent airport codes, typos, N/As, etc.

3. Data processing to produce two full tables of flights, realized in 2019 and 2020, including each scheduled and actual off-block and in-block times.
4. Treatment of outliers and filtering of Brazilian airports only.
5. Data transformation to produce the airport average delays table, as previously detailed in Table 1.
6. Data transformation to produce the average flight times table, as previously detailed in Table 2.
7. Perform the respective statistical tests: Paired t-test with the *t.test()* function, and correlation analysis with *cor.test()* function.
8. Describe the results and start writing the research report.
9. Infer potential conclusions and finalize writing the research report.

Chapter IV

Results

Preliminarily, the ANAC database provided a sample of 1,468,157 flights, being 982,991 in 2019, and 485,166 in 2020. However, during the data collection process, it became more apparent that many flights were actually not executed, i.e., canceled. Also, several entries contained some sort of error or invalid value, i.e., "NA" or flights with evidently wrong dates. Therefore, the dataset was treated to eliminate those entries, as well as to remove potential outliers. The main assumptions below briefly describe the flights that remained in the dataset:

1. Only flights without empty or invalid entries in the original dataset.
2. Only realized flights with different origins and destinations, i.e., no local or canceled flights.
3. Regarding arrival delays, only flights with delays between -6 and 6 hours.
4. Regarding arrival delays analysis, only airports with 10 or more arrivals in 2019.
5. Regarding average flight times, only flights with a duration between 15 minutes and 12 hours.
6. Regarding average flight times analysis, only routes with 730 or more flights in 2019 (around two flights per day on average).

As a result, the final data pool was comprised of 1,302,346 flights (89% of the complete database) for the arrival delays analysis, and 1,390,208 (95% of the complete database) flights for the flight time analysis.

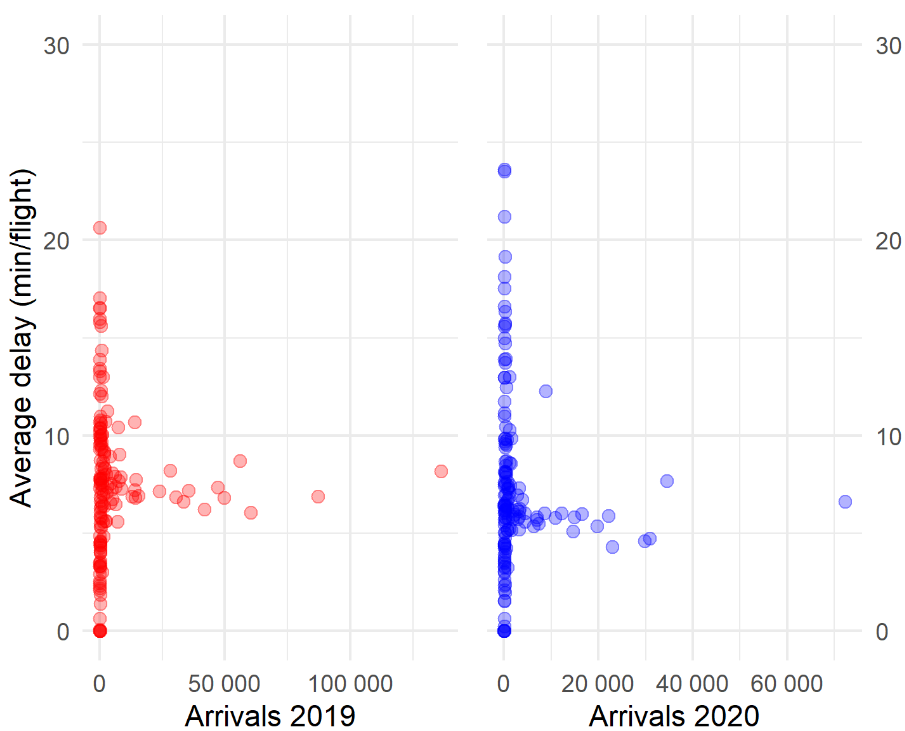
Arrival Delays

Within only Brazilian airports, a sample of n = 146 airports registered more than 10 arrivals in 2019. Table 3 in the Appendix shows the first entries of the sample, as proposed in the methodology. The number of arrivals at a particular airport ranged from 18 to 136,214 in 2019, and from 1 to 72,336 in 2020. In total, 126 airports (86%) registered decreases in the number of arrivals in 2020, compared to 2019.

The number of arrivals related to average delays in two distinct forms. A small group of airports, with higher arrival counts, concentrates delay performance between 5 and 8 minutes per flight, approximately, with little dispersion. In contrast, numerous smaller airports – with fewer arrivals – have widely dispersed delay values. This creates two distinct groups of airports that, together, form a t-shaped dispersion pattern, which can be better identified in Figure 2. However, this pattern did not change relevantly from 2019 to 2020, except for a slight decrease in average delays for the busiest airports group.

Figure 2

Relationship of Arrivals and Arrival Delays in Brazilian Airports

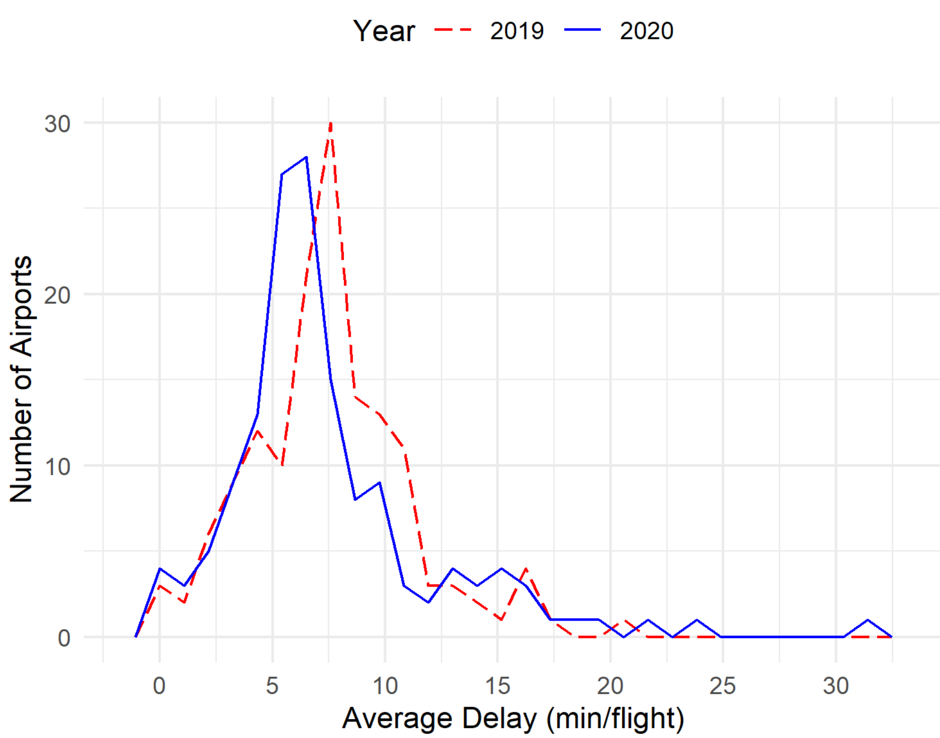


Note. Each point corresponds to an airport. Some airports with very high average delays, i.e., above 30 min/flight, were omitted for better visualization.

Finally, regarding solely average arrival delays, 2019 values ranged from 0 to 20.6 minutes in 2019, and from 0 to 31.4 minutes in 2020. The mean arrival delays decreased slightly from 7.59 minutes in 2019 (*SD* = 3.55) to 7.46 minutes in 2020 (*SD* = 4.62). In total, 94 airports (64%) registered decreases in average arrival delay. Figure 3 assists in verifying the distribution of arrival delays.

Figure 3

Frequencies of Average Delays per Year



A paired t-test was performed to check if there is a difference between the arrival delay means and address the first research question. The test result ($t = 0.38222$, $p = .7029$) indicates that, as $p > 0.05$, the null hypothesis could not be dismissed. Therefore, at a 5% significance level, there was no significant difference in mean arrival delays between 2019 and 2020.

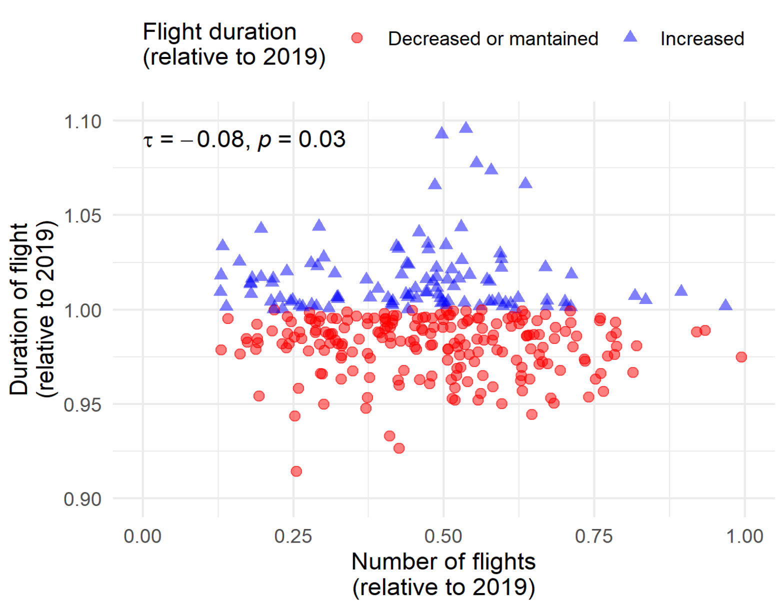
Average Flight Times Between City Pairs

A sample of n = 327 different routes containing at least one Brazilian airport as origin or destination was formed from the data pool. Table 4 in the Appendix shows the first entries of the sample, as proposed in the methodology. The number of flights in each route ranged from 738 to 17,671 in 2019, and from 114 to 7,316 in 2020. In total, 326 (99%) routes registered a decrease in the number of flights. As for the flight durations, 214 routes (65%) registered flight times in 2020 equal to or shorter than in 2019.

Figure 4 shows the association between the two variables: the number of flights in 2020 (normalized to 2019 values) and average flight time in 2020 (normalized to 2019 values). The graph shows that most of the routes registered decreases in the number of flights by around 25-75% of 2019 reference. However, it does not appear to have influenced the duration of the flights. Besides, the points are well dispersed in both axes. In other words, a reduction in traffic counts did not cause an apparently proportional reduction in flight times.

Figure 4

Association Between Number and Duration of Flights



A correlation test was then performed to check any association between the two variables and address the second research question. Preliminarily, a Shapiro-Wilk test indicated that both variables are not normally distributed ($p < .001$ for both variables), reason why the RStudio *cor.test()* function was set to the non-parametric Kendall method. The correlation test ($\tau = -0.08$) confirmed the visual evaluation, in that the null hypothesis might not be dismissed, and there was no strong correlation between the two variables.

Chapter V

Discussions, Conclusions, and Recommendations

Based on the data, the researcher failed to reject the null hypothesis for both tests. For the arrival delays branch of the research, there was no difference in performance in the year before the pandemic compared to the year during the pandemic. Flight duration analysis also did not find any significant correlation between flight frequencies and flight times, as suggested by CANSO (2015). Together, both perspectives allow some remarks regarding the air navigation system in Brazil and its efficiency.

Discussions

First, it is necessary to highlight the evident reality again: The COVID-19 pandemic had a profound impact on the Brazilian air navigation system regarding traffic counts. For example, Guarulhos Airport (SBGR), the busiest in the study, registered a decrease from around 136,000 arrivals in 2019 to a few more than 72,000 in 2020. Nonetheless, this reduction did not cause substantial changes in the overall system performance.

Some of the busiest hubs indeed had a slight decrease in delays, but that trend was not enough to compensate for the regional airports' performance. Although 86% of airports registered decreases in the number of arrivals, only 64% registered decreases in average delays. The delay patterns also did not change: The t-shaped scatterplot – as displayed in Figure 2 - remained roughly the same from one year to another.

As a result, the distribution of delays throughout the system was positively affected – which can be clearly seen in Figure 3, as the curve drifted to lower values in 2020 – but not sufficiently to indicate an actual improvement. Despite the decrease in mean delays from 7.59 to 7.46 minutes per flight, respectively, before and during the pandemic, this difference was not found to be statistically significant. Even if it was, a reduction of just some seconds is arguably irrelevant in air traffic management practical terms.

The average flight times analysis seems to confirm the evidence found in the previous perspective. First, a similar grouped behavior was found: Although 99% of the routes decreased in number of flights, only 65% of them had their durations reduced. In addition, the correlation of those two variables was very weak, indicating that flight times between city pairs did not change substantially – or systematically - due to the lower traffic. Altogether, those pieces of evidence point in the same direction.

Based on CANSO (2015) assumptions, the lack of correlation between flight duration and traffic during times of increased traffic may indicate an increased system efficiency. However, the opposite interpretation is also possible: The same lack of correlation during times of decreased demand may indicate an absence of improvements in system efficiency. Besides, most of the previous technical literature (DECEA, 2020; EUROCONTROL & FAA, 2016) supports the notion that flight delays approximately indicate the efficiency levels of an air navigation system: the lower the delays, the better the system efficiency. Considering that inputs are a relevant part of the efficiency understanding (Kim & Son, 2021; Oum et al., 2008), one could argue that the changes in input, i.e., the significant drop in flight traffic, should have resulted in significantly fewer delays or shorter flight durations. However, that was not the case in the Brazilian air navigation system during the pandemic. No overall improvements were found in the efficiency indicators under this study in 2020. Nonetheless, it is not possible to affirm that there was an efficiency reduction, only that it did not increase.

Finally, it is also interesting to note the contrasting difference found in the present research, within the Brazilian context, and the findings by EUROCONTROL (2021). While in

Europe, the COVID-19 drop in traffic resulted in an undoubtful reduction of flight delays – and consequently efficiency improvement - that trend was not so apparent in Brazil. A plausible explanation is that the highly congested air traffic environment is possibly the most relevant factor for the system's efficiency in Europe, while in Brazil, other factors, such as airlines' route structures, the share of domestic flights, or passenger demand patterns, may prevail. The researcher found that, for some busy Brazilian airports, which may experience a similar context to their European counterparts, there was a slight reduction in flight delays, which supports this view. However, from an overall system's perspective, there was virtually no difference in the Brazilian efficiency performance in 2020, compared to 2019.

Conclusions

The need for ATM efficiency is constantly under the scrutiny of many specialists within the industry. During the pandemic, it remains relevant to pursue better air navigation systems, despite the current low traffic levels. As previously stated, low traffic may not lead to increased efficiency *per se*. In that context, the present research aimed to answer what was the impact of the COVID-19 crisis on air navigation efficiency in Brazil. That question was broken into two separate but parallel analyses: arrival delays and flight times between city pairs.

Regarding the first, the researcher found evidence that arrival delay patterns in Brazil remained the same, despite the lower traffic counts. Besides, there was no significant difference between mean arrival delays in 2019 and 2020 from an overall system's standpoint. Therefore, air navigation efficiency, as measured by arrival delays, did not improve, despite the lower demand. As for flight durations, almost all analyzed routes had fewer flights in 2020 compared to 2019. However, only 65% of those registered decreases in flight times. Besides, there was no significant correlation between the number of flights and flight times. Hence, air navigation efficiency could not be deemed improved, as measured by this indicator either.

As a result, the main answer sought by this work is that, despite the lower number of flights, efficiency levels remained the same, at best. In other words, the COVID-19 crisis did not have a significant impact on the air navigation system efficiency, within the Brazilian context. Those outcomes are relevant and potentially valuable for the ATM industry in several manners.

First, the present findings were different from similar investigations in other parts of the world, namely Europe, which means that some factors affecting air navigation efficiency are not equally relevant, or perhaps not even the same, depending on the geographical context. Second, some aspects, such as system flexibility, scalability, or resilience, may be fundamental to better efficiency. Air navigation systems should be able to adapt to the changing environment – not only due to increases in traffic but also for decreases as well, as was the current case. Finally, the work can help to develop alternative or broader air navigation efficiency evaluations – an approach particularly valuable for the Brazilian ATM sector, but that could also be replicated in other regions worldwide.

Recommendations

First, the nonexperimental nature of the research design implies that causal relationships could not be uncovered by the present work. It was possible to draw some conclusions regarding the system's efficiency in two different moments, based on two different indicators, but it is not possible to explain the precise reasons behind them. Naturally, the sharp decrease in traffic was likely the most relevant aviation factor during 2020, and could have significantly explained the behavior of the curves. Nevertheless, other confounding variables may still play a role, so further research with different designs is encouraged.

In addition, the work was geographically limited to Brazil. Results found in the present research may not appear, or occur with some variations, in other regions worldwide. That was the case, for example, with the European case study, as explained in previous sections. Therefore, expanding the air navigation efficiency study to other countries may provide additional comprehension on the subject.

Furthermore, the ANAC database is comprised of date-time entries at the airport gates. Any differences in delays or flight times could only be viewed from a gate-to-gate perspective. As a result, it is not possible to differentiate if there is any performance change during the flight phase or the taxi phase for any given flight. Hence, the researcher also recommends further investigation considering take-off and landing times instead, so that those details could be captured.

Finally, all data used herein is public. The data collection, preparation, and analysis processes were made in open-source software (RStudio) and are fully reproducible. Therefore, further research in similar methods, but from different researchers, could confirm or reject the findings, or even expand the theme, aiming to support a better comprehension of global ATM, from both academic and professional perspectives.

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Appendix

Table 3

Airports Mean Arrival Delays

Airport	Average arrival delay in 2019 (minutes/flight)	Average arrival delay in 2020 (minutes/flight)
SBGR	8.18	6.61
SBSP	6.90	4.61
SBBR	6.08	4.75
SBKP	8.72	7.69
SBCF	6.82	5.89
SBGL	7.34	5.98
SBRJ	6.24	4.31
SBRF	7.19	5.38
SBPA	6.64	5.11
SBCT	6.85	6.04

Note. Table showing only the first 10 entries of 146 airports, ordered by number of arrivals in 2019.

Table 4

Average Flight Times and Number of Flights

City pair	Number of flights (relative to 2019)	Average Flight Time (relative to 2019)
SBKP-SCEL	1.06	0.988
SBEG-SBKP	0.994	0.975
SBKP-SBVT	0.968	1.000
SBKP-SBEG	0.934	0.989
KMIA-SBKP	0.920	0.988
SBVT-SBKP	0.894	1.010
SBGR-SBSL	0.835	1.010
SBRF-SBKP	0.820	0.981
SBSL-SBGR	0.817	1.010
SBKP-SBRF	0.814	0.967

Note. Table showing only the first 10 entries of 327 routes, ordered by relative number of flights in 2020.