COVID 19 Impact on Aircraft Ground Time at Congonhas Airport (CGH)

Embry-Riddle Aeronautical University

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by

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A Capstone Project Submitted to Embry-Riddle Aeronautical University in Partial Fulfillment of the Requirements for the Aviation Management Certificate Program

Embry-Riddle Aeronautical University
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This Capstone Project was prepared and approved under the direction of the Group's Capstone Project Chair, Dr. Leila Halawi
It was submitted to Embry-Riddle Aeronautical University in partial fulfillment of the requirements for the Aviation Management Certificate Program

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Abstract

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Title: The Impact of Aircraft Ground Time Increase due to COVID-19 at Congonhas Airport

Institution: Embry-Riddle Aeronautical University

Year: 2020

This project aims to research and analyze the impact of the increase of ground time at Congonhas Airport caused by the new safety procedures in aviation to avoid the spread of the COVID-19 virus.

Aviation is a highly regulated industry, with the high cost and tiny margins. It focuses on optimizing one of the most expensive assets, the aircraft. To keep aircraft flying is one of the airline's primary goals as aircraft on the ground means no revenue generation and cost increase.

Congonhas Airport is one of the busiest airports in Brazil and already operated on its limited capacity before the crisis; higher ground time will bring operational and financial impact to the airlines, airport administrators, and suppliers.

We selected the public database from ANAC and ABEAR that contains detailed data about arrivals and departures at Congonhas Airport to analyze the impact. We also used

available data from INFRAERO about the capacity and operational restrictions of the airport.

In the first phase of the analysis, we worked with Python to measure the ground time duration before and after implementing the new procedures and validating the ground time increase hypothesis. The second phase was performed using Arena Software to simulate the airport's movements, considering airlines' ground time before and after implementing the new procedures. The results from both analyzes were complementary and allowed to confirm the hypothesis and identify the impact of the increase in the ground time due to the new cleaning and social distancing measures adopted during the COVID-19 pandemic.

Resumo

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Título: The Impact of Aircraft Ground Time Increase due to COVID-19 at Congonhas Airport

Instituição: Embry-Riddle Aeronautical University

Ano: 2020

O objetivo deste projeto é a pesquisa e a análise do impacto do aumento do tempo de solo no Aeroporto de Congonhas devido aos novos procedimentos adotados para evitar a contaminação pelo vírus do COVID-19.

A aviação é uma indústria muito regulamentada, com altos custos e margens pequenas. Ela foca em otimizar um dos ativos mais caros, as aeronaves. Manter as aeronaves voando é um dos principais objetivos de uma empresa aérea, uma vez que uma aeronave em solo significa não gerar receita e aumentar custos.

O Aeroporto de Congonhas é um dos aeroportos mais movimentados no Brasil e operava no limite da capacidade operacional antes da crise. Maior tempo de solo traz impactos operacional e financeiro para as empresas aéreas, administrador aeroportuário e fornecedores.

Para analisar o impacto desse aumento utilizamos bases de dados públicas da ANAC e ABEAR, contendo dados detalhados de pousos e decolagens do Aeroporto de

Congonhas. Também utilizamos dados públicos da INFRAERO referente a capacidade e restrições operacionais do aeroporto.

A primeira fase da análise dos dados foi executada em Python com o objetivo de identificar a duração do tempo de solo antes e após a implementação dos novos procedimentos e validar a hipótese do aumento desse tempo. A segunda fase da análise foi executada no software Arena com o objetivo de simular os movimentos no aeroporto considerando o tempo de solo realizado pelas empresas aéreas antes e após a implementação dos novos procedimentos. Os resultados das análises foram complementares e permitiram confirmar a hipótese e identificar o impacto causado pelo aumento do tempo de solo devido aos novos protocolos de limpeza e distanciamento social adotados durante o período da pandemia causada pelo COVID-19.

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Introduction

The COVID-19 brought to the airlines many operational challenges, new processes related to disinfection in the flight deck, passenger cabin, cargo compartment, air system operations, and general points to provide a safe and sanitary environment for ground personnel, aircrew, and passengers. (ICAO - International Civil Aviation Organization, 2020)

The boarding and disembarking processes were adjusted to reduce proximity among passengers due to physical distancing recommendations. As a consequence of implementing new procedures, the ground time in between the flights got longer.

The longer ground time is not an issue for the airport capacity during the pandemic because the number of daily operations decreased close to zero for most airlines. Still, as the number of flights increases, it will directly impact airports and airlines' capacity. It is particularly crucial for airports that operated at almost full capacity before the pandemic. The increase in ground time has a financial and operational impact on airlines and other stakeholders involved in the operation. The current demand for air travel is low, and airlines are operating much fewer flights than before. However, when the demand for air travel returns to the pre-pandemic levels with new airport procedures, airlines and airports will have to be even more efficient to accommodate the flights.

The purpose of this research is to primarily evaluate the impact of the increase in aircraft ground time. We will also simulate arrivals and departures with the new ground time for Congonhas Airport operations, the Brazilian busiest airport operating only domestic flights with narrow-body aircraft. This airport is located in São Paulo and is mainly used by business travelers due to the easy access to the business centers. It is also known for its frequent air shuttle services between São Paulo and Rio de Janeiro.

Project Definition

Aviation is a very regulated industry, with very high costs and tiny margins, focused on maximizing its most expensive asset, which is the aircraft. To keep aircraft flying is one of the main goals of any airline. Keeping the airplane on the ground means no revenue generation and increasing variable costs related to personal and suppliers who will need to support the operation while the aircraft is on the ground. Increasing aircraft utilization is a manner to dilute fixed costs. We can make an analogy with a factory with its machinery. If the machinery is not producing what it is supposed to do, they will represent costs without generating revenue on the other hand. Aircraft are made to fly and generate revenue, and the more an airline utilizes its airplane, the more revenue it will generate.

This research is relevant to many airline departments, airport administrators, and ground service providers due to the financial and operational impact on the aircraft ground time. Some of these effects are seen in the following areas: Network Planning must reschedule flights to accommodate the new expected ground time; the Crew Schedule Planning has to assess the flight hours limitation, as the same crew may not complete the journey they used to do due to longer time between flights; the Airport Administrator must reschedule the slots, especially during peak hours, as aircraft will be occupying the gates for a longer time; ground service providers need to adapt staff schedules, and maintenance may experience an increase in APU usage.

Project Goals and Scope

New public health and social measures for COVID-19 were created by ANVISA (Brazilian Health Regulatory Agency, 2020) and published by ANAC (National Civil Aviation Agency – Brazil) to provide more safety for passengers. The instructions addressed to airports, airlines, and passengers, divided the new procedures into before boarding, during the flight, and after deplaning procedures. The recommendations cover social distancing in the airport areas, masks by passengers and aviation professionals, and aircraft and on-board service hygiene (ANAC, *Agência Nacional de Aviação Civil*, 2020).

These new regulations created by ANVISA require more attention to aircraft hygiene, causing companies to carry out further procedures that may impact the aircraft's ground time. The definition of an aircraft's turnaround time is the period between the airplane lands until it takes off for the next flight. During this interval, airline and airport teams work together to do all the required processes to make the aircraft available for the next flight in the shortest time.

With the correct turnaround control, it is plausible to decrease this time by optimizing the aircraft's procedures on the ground. It guarantees adherence and punctuality to slots designated by the airlines (IKUSI, 2018).

This study aims to confirm, measure, and evaluate these new procedures' impact on aircraft ground time. As a result, we expect outcomes to bring valuable information to understand the possible effects on Congonhas Airport's capacity.

Definitions of Terms

COVID-19	Coronavirus disease (COVID-19) is an infectious disease caused by a newly discovered coronavirus. (WHO - World Health Organization, 2020)

List of Acronyms

ABEAR	*Associação Brasileira das Empresas Aéreas*
ANAC	*Agência Nacional de Aviação Civil*
ANVISA	*Agência Nacional de Vigilância Sanitária*
APU	Auxiliary Power Unit
IATA	International Air Transport Association
ICAO	International Civil Aviation Organization
INFRAERO	*Empresa Brasileira de Infraestrutura Aeroportuária*
OCC	Operational Control Center
WHO	World Health Organization

Chapter II

Review of the Relevant Literature

This chapter will present relevant publications about the subjects that will support the background needed to measure the impact of aircraft ground time increase in an airline activity. It will cover airline business, planning, and operational fields, linked to this project's main subject.

Turnaround Time

Short turnaround time is a target airline wants to achieve and keep; it means excellent operational efficiency and maximizes aircraft and crew utilization. According to ANAC, in 2017, the average flying hours per aircraft per day by the Brazilian airlines was 9.7 hours. The ability to turnaround planes fast allows airlines to maximize aircraft utilization and schedule more flights per day. From the Airport Administrator's perspective, longer turnaround time means slots being used for a longer time during the peak hours. Quick turnaround time is a competitive advantage and is a core of many airlines' strategies.

The turnaround time is the time spent on the ground between two flights during a flight duty period. During the turnaround time, many processes must happen to prepare for the next flight. A set of operations occurs while the aircraft is on the ground, and the tasks can be completed in parallel or sequentially (Sánchez & Eroles, 2017).

The main turnaround activities can be set in four major topics: passenger, baggage, freight, and ground services. The ground services are the operations required from when the aircraft arrives at its parking position (actual in block time) until it leaves it (real off block time). Figure 1 shows the activity required for a B737 turnaround for domestic operations where some events are conducted sequentially on the timeline. The service time of activities determines the total time needed for turning around an aircraft, meaning that the faster each function performs, the shorter the whole ground time will be (Wu, 2016).

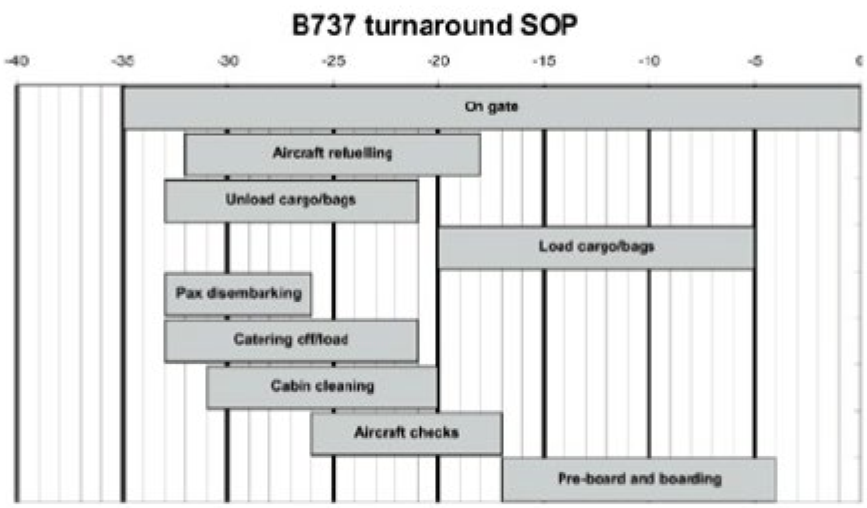


Figure 1. B737 turnaround time operations for a domestic flight (Wu, 2016)

One of the aircraft routing steps, assign an aircraft/tail to the flight leg, considers the turnaround time to validate the routing. Validating a routing means to have the aircraft/tail ready by the next departure time, considering the previous flight's arrival time plus the turnaround time (Bazargan, 2010).

Network Planning

The network planning is the beginning of the construction of the entire preparation of an airline. The initial construction starts with the objective of increasing revenue by selecting destinations according to demand. After this information, the operational areas such as airports, crew, OCC, and maintenance carry out the plan to operationalize in the best possible way. However, there is always a challenge for the planning team to define the right flight time and ground time to increase efficiency. Still, it needs to be feasible for the operational departments to carry out at the same time.

A characteristic of an airline schedule comparable to numerous complex network operations is that stochastic events influence most of the network's components. (Wu, 2016):

- An airport's operation is subject to weather circumstances, influencing the practical runway capacity and some groundworks.
- For airlines, ground services are subject to many risks such as aircraft ground process delays, staff deficiency, and lack of internal resources, such as connecting crew delays.
- The air traffic control can hold aircraft or change the flow in congested terminal areas around large airports during peak hours.

Performing a planned network that covers all possible events would be economically unfeasible for the business. It is necessary to find the best balance between network planning and operations and put in place mechanisms to recover the network in case of events causing delays.

Airport Slots

Aircraft turnaround is necessary to prepare the aircraft that arrived at the airport for the next flight. Most of these activities cannot occur in parallel, which means there is a critical path to follow. Any delay in this crucial path will result in a delay in the aircraft's departure (Makhloof, 2012).

The airport slot is permission given to the airline for a specific date and time to land or take off and use the full airport infrastructure. The IATA guideline classifies the slot requests into three principal subjects; the first is the requests based on the historical performance, the second for the new entrants, and the third for other claims. The strategic slot allocation is managed twice a year for summer and winter periods; the strategic period covers two to twelve months before the flight operation. The current slot allocation process for congested airports in Europe results in an estimated loss of 20 million Euros based on the Airport Council International due to the late reply of slots that could not be re-allocated in a brief-term (Benlic, 2016).

Any increase in time due to new measures, like the new COVID-19 procedures, will reflect each flight's turnaround time. Therefore, when the airport has already reached its maximum capacity before the pandemic and adds more processes that increase the turnaround time, we need to understand its impact on the airport's maximum capacity.

The airport has been continuously challenged by new aircraft types and equipment types in operations (Schmidt, 2017).

Beyond this, the increase of new airlines and passengers brings more pressure to the whole system to have even more available slots, which pressures each aircraft's turnaround time, as airports have runway and gate limitations. In Figure 2, it is possible to see a generic scheme of an airport with land and airside elements.

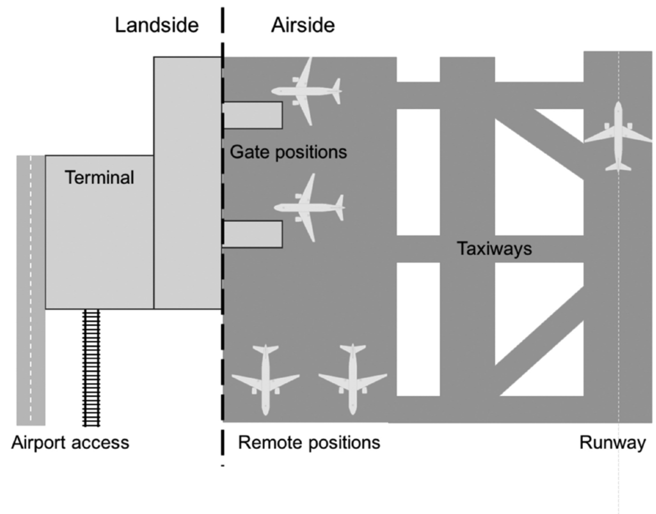


Figure 2. Generic airport with landside and airside elements - N.J. Ashford, H.P.M. Stanton, C.A. Moore, P. Coutu, J.R. Beasley - Airport Operations (3rd ed.), McGraw-Hill (2013)

Congonhas Airport

Congonhas Airport is located in Sao Paulo, Brazil. The city concentrates on the most significant number of businesses, events, and conventions in Latin America. Most of the big companies have their headquarters in the town. Beyond this, it is an important place for startups and multinational subsidiaries. It has about 12 million inhabitants.

Congonhas Airport is the primary airport for businesspeople in Brazil. It is driven by business because of its privileged location inside the city, with easy access to several important points of Sao Paulo. In September 2019, the average daily movement had 60,932 passengers, 592 flights, and 159,124 kg of cargo. The total capacity of Congonhas Airport is approximately 17,1 million passengers per year (Infraero, 2020).

On the other hand, Congonhas has significant constraints due to its location. According to ABEAR's report "Panorama 2019", Congonhas's runaway is limited by 33 operations per hour, align with other similar airports in Brazil. One restriction is that

Congonhas has a curfew from 11 p.m. until 6 a.m. because of noise restrictions. Thus, in the picture below, the airport is already close to its limits of flights.

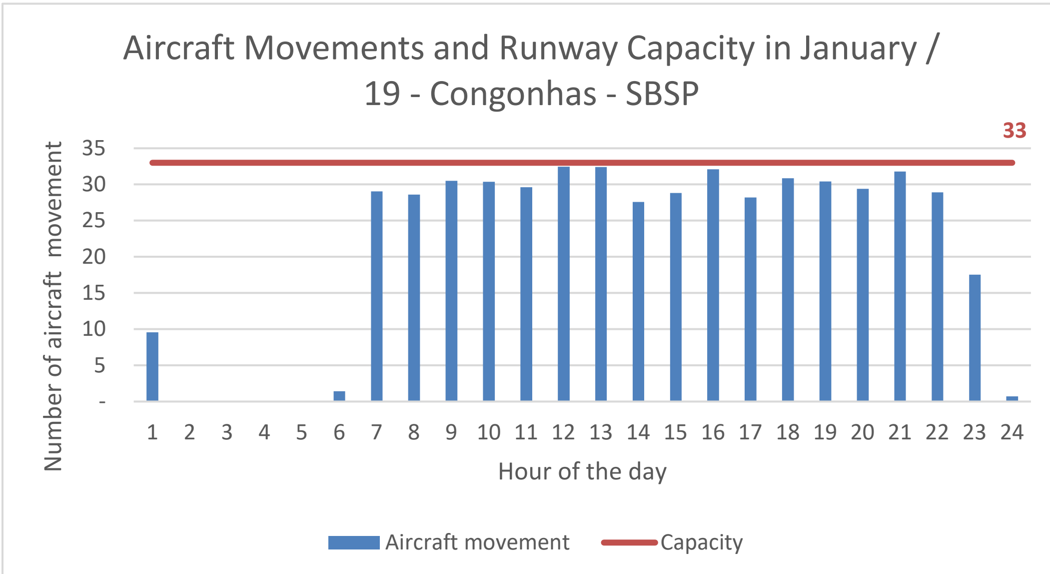


Figure 3. Aircraft Movements and Runway Capacity – Panorama Report 2019 from ABEAR

Another constraint Congonhas has is limited to maximum aircraft movements per hour, which means it is impossible to add more flights under the current rules. We can see this in the graphic below:

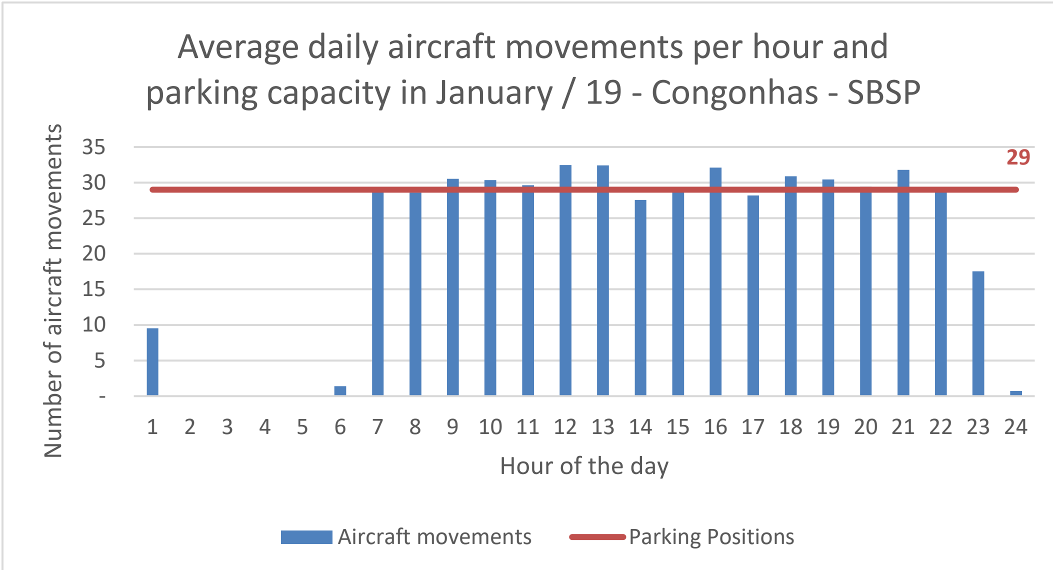


Figure 4. Aircraft Movements and Gate Capacity – Panorama Report 2019 from ABEAR

Crew Planning

Flights are carried out by specialized staff with proper training and licenses to operate the flying aircraft. For every flight, an aircrew, including pilots and flight attendants, will be assigned, and their working hours are regulated by the civil aviation authority of the country of their airline.

Total crew costs are among the most significant cost figures for airlines. The airlines have systems to conduct the crew pairing, which is, still, a sequence of flight legs that starts and ends at the same crew base. The crew pairing follows the legal requirements and airline procedures and minimizes total crew costs (Bazargan, 2010).

As the aircraft utilization indicator shows how efficient the airline is using its asset to generate revenue, airlines must plan and work towards a high crew flying time, respecting the resting time.

According to the Brazilian law LEI Nº 13.475 DE 28 DE AGOSTO DE 2017 (2017), flight time is the total time a fixed-wing aircraft starts its movement to the moment it stops at the end of the flight known as "block to block" time. Still, according to this law, a flight crew can fly up to 8 (eight) hours and 4 (four) landings within the same duty period. For domestic flights, which are the scope of this study, the duty period starts when the flight crew reports for duty and ends 30 (thirty) minutes after the engines are turned off at the destination. The duty period has a limit of 9 (nine) hours.

According to Jhunjhunwala, Haywood, Vicq, & Levine (2016), airlines can improve flight crew productivity by having a long-term strategy, crew value chain optimization, and an improvement end-to-end flight crew management. Flight crew productivity can be much more needed if the crew flight time utilization decreases due to longer ground times.

Simulation

Simulation is a technique used to create an estimated new system, recommending reconfiguration or changes in existing systems' control. Its applications have grown in all areas, assisting managers in decision-making on complex problems and enabling better knowledge of organizations' processes.

Modeling can be used to understand the company's better and uniform representation, support the design of new parts of the organization, or even support the control and monitoring of operations. Process modeling provides a systemic vision to managers; enables managers to understand how work happens and how their tasks impact the end customer. The business modeling is a prerequisite for integration, even serving for control and monitoring, and supporting projects in new areas (Vernadat, 1996).

In general, systems simulation is performed to estimate the distribution of random variables, statistical test hypotheses, compare scenarios representing different solutions to the problem under study, evaluate an analytical solution's behavior, and assess a decision-making process in real-time.

The simulation method optimizes and diagnoses the designed process by simulating to realize the correct process impact evaluation. Process simulation involves four main steps: process modeling, simulating, results analyzing, and process optimizing. Better than examines a system through experience and intuition, a simulation technology provides the possibility to evaluate with more scientific and reliability (Li & Chang, 2012).

Figure below shows the roadmap of process simulation.

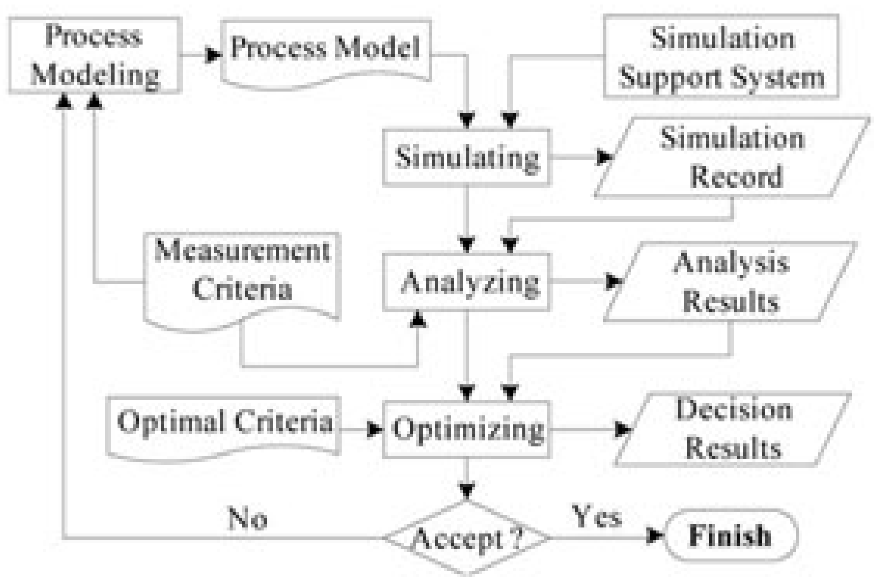


Figure 5. Process simulation roadmap

Simulation in Aviation (Turnaround)

There are many execution processes during the turnaround times; the major and longest ones are the boarding and deplaning (Bazargan & Liang, 2016).

Many studies have been conducted to reduce costs and improve performance focused on simulations using the airplane's front door to board and deplane passengers. Bazargan & Liang (2016) researched the paper's objective to compare the one-door procedure versus the two-door procedure using simulation approaches. The simulation model considered the new technological improvements adding extensions to the jet bridges, allowing both aircraft doors with the jet bridge.

The boarding simulation model considered different types of boarding methodology and compared them using one versus two-door. It was already expected that the result using two-door boarding would be faster than using only one, regardless of the methodology applied to it. The development of the simulation using two-door was around 40% faster than one-door.

There are fewer publications related to deplaning compared to the boarding process; the reason is that, in general, deplane is faster than boarding. The deplaning simulation model considered two types of methodology, by rows and by columns. The result was very similar in both cases, and the deplaning by two-door resulted in a reduction of 43% in the total time compared to one-door.

There are many studies focused on the boarding process, which has been discussed and simulated. Papers related to this subject came up with different approaches, using various computer simulation and analytical models. One point of view is using a computer simulation to run other boarding processes and compare the results; another is related to elaborate a boarding process based on analytical models, using linear or nonlinear programming. Some papers analyze the boarding process from a physical perspective or based on passenger behavior (Jahen & Neumann, 2015).

According to Bazargan (2010), a significant component of turnaround time is passenger boarding. During the process, interferences may happen when getting the designated seat because another customer delays the boarding. The study considered the linear program to minimize the number of passenger interferences. The simulation model was built to identify the most suitable boarding process.

According to Eroles & Sánchez (2018), turnaround is complicated due to the chain activities and stakeholders linked. The sequence of activities can be impacted if one of the chain players causes any delay, stop, block, or anything that could impact the next move or activities. The impact of higher turnaround time affects landside capacity and, consequently, the airside.

The purpose of the article published by Eroles & Sánchez (2018) is to generate a detailed turnaround behavior analysis and use simulation tools to improve the confidence in the impact of the increase in the time and as an indicator for evaluation, focusing on the causal methods and simulation models. The simulation included 106 turnarounds of aircraft type A320 in a European International Airport. Each process of the turnaround was measured.

The result of the simulation pointed the impact and also opportunities for potential improvements of the following tasks: deboarding, bulk unloading, bulk loading, and refueling – the results observed in the analysis showed that excluding the above four tasks, there could be more than 13% operations on time and an overall reduction of 7 minutes.

Simulation in Aviation (Slot-scheduling)

The balance of supply and demand for time slots is a problem at some airports; there are peak times and days of the week where the airport administration will not allocate the slot requested by airlines. When the airline gets a time slot different than the requested one, it generates a gap; this gap is called displacement. Slot-scheduling plays a vital role in reducing removal.

One of the criteria used to define the slot-scheduling is fairness; in this criterion, the displacement is allocated among the airlines. The research conducted by Fairbrother, Glazebrook, and Zografos (2020) proposes a model using fairness and efficiency and airline preferences. It is divided into two stages: first, building a fair reference schedule for the airlines. In the second, the airlines indicate how the displacements could be distributed among their requests. The result of their model showed an improvement in the suggestions made by the airlines without large increases in the schedule displacement.

According to Madas, Salouras, and Zografos (2011), the slot allocation methodology applied in Europe follows the International Air Transport Association (IATA), and it is complemented by the European Union (EU) rules.

The purpose of the research published by Madas, Salouras, and Zografos (2011) was to develop an optimization model using the current IATA and EU parameters, operational constraints, and airline preferences to reduce the gap between the requested to the granted slot time. The main objective of the model is minimizing the difference between the requested and allocated times. The constraints used in the model consider airport movement capacity, intervals between flights, and turnaround constraints.

For the three selected regional airports in Europe, the model improved the slot allocation results between 14% and 95%. In addition to the research, Madas, Salouras, and Zografos (2011), Benlic (2016) proposed a model that included the series of slots, with a minimum of five slots requested for some time and the en-route constraints which considered the real-time departure, flight route and real-time of arrival.

Simulation in Aviation (Arena Software)

We used Arena Simulation Software for all simulations. Rockwell Automation company is the product owner. This software's objective is to permit a simulation process that impacts business decisions before they are implemented. It is a simulation software to assist in problem-solving through simulation modeling, analysis, and research projects. (Arena Software,2020).

Summary

The turnaround time directly links to some of the airline's main business areas, like Network Planning, Crew Planning, Slots management, and the Airport. Congonhas Airport has limitations regarding the number of operations by the hour and the curfew. For this reason, it has been operating on its current limits.

Network Planning, Crew Planning, Slot management, and Airports have to plan and work based on flight time and ground time; any change must be evaluated and managed by the airlines.

We propose identifying the turnaround time at Congonhas Airport before and after implementing new procedures due to the COVID-19 by developing a method to calculate the turnaround time with public data. We also intend to verify if this new outcome impacts the Congonhas Airport capacity in terms of aircraft movements.

Chapter III

Methodology

This chapter will describe the methodology used to analyze and evaluate the impact of aircraft ground time at Congonhas Airport due to COVID-19 new procedures. The research will use public information to generate an overview of the scenario, and a specialized tool to evaluate figures will be applied to support data analysis (Python). For the process simulation, software capable of processing the airport movements and providing trustworthy information will be used (Arena).

Data Source(s), Collection, and Analysis

The raw data is public, and it is available on ANAC's website. The data is available from January 2000 until July 2020. ANAC updates the database every month, and it is usually done by the end of the subsequent month. In this database, there are two types of data: "Básica" (flight stage) and "Combinada" (On flight origin and destination – OFOD).

The "Básica" data is a set that contains statistics from the flight stage performed by an aircraft from its takeoff to the next landing, regardless of where the transported object has been loaded or unloaded. The "Básica" statistical data represents the aircraft's status at each flight stage, showing cargo and passengers' movement between the aircraft's airports of origin and destination. It is the operation of an airplane between one takeoff and the next landing.

The "Combinada" data is a set of combined pairs of origin, where the transported object embarked, and destination, where the transported object disembarked, regardless of the existence of intermediate airports served by a particular flight. The flight stage focuses on transport (people and cargo), based on embarkation and disembarkation at the related airports. The "Combinada" statistical data inform passengers and cargo's origin and destination carried on the flight, regardless of the stopovers made.

After analyzing both data sets, the one that will provide the required data to answer the research question is the "Básica". We also found similar data in CAPA (Centre for Aviation) database. However, it does not provide the aircraft registration number (tail number), limiting its usage. The data from CAPA support us better to see and compare common data from several airports with Congonhas. For example, the total seat capacity by year, any comparison between the Congonhas Airport with others, among other items.

All data were retrieved directly from the website provided by ANAC through a direct download of it.

This ANAC database has the identification of each aircraft that arrives and departs from Congonhas Airport. We calculate the turnaround time from each airplane registration (tail number) to find the average turnaround time for each type of aircraft in the period we are researching.

After this step, we found the total turnaround time from each type of aircraft. The extracted data were processed with Python Software to identify the time between aircraft landing, chocks-on, chocks-off, and takeoff.

The data analysis's first step was inferential statistics to find the relationship between turnaround time before and during the pandemic time. The null hypothesis states that there is no relationship between the groups or measured phenomena, and it will be tested statistically.

$$H0 = GT\ before\ the\ pandemic = GT\ during\ the\ pandemic$$

Where:

GT: the time between chocks-on and chocks-off

Operational Capacity for Congonhas Airport was found on INFRAERO's Transparency Portal, detailing runway, passenger terminal, apron, and parking positions capacity. The operating capacity declaration also provides a minimum and maximum ground time allowed by the airport operator, and we used it in our simulation.

Simulation Logic

After the raw data was processed in Python Software, the output was used to simulate the operational process that involves the aircraft arrival until its departure, before and after COVID-19.

We used simulation due to the high variability of parameters that involve the entire steps of the process: limited schedule per hour, the maximum number of arrivals; limited airport operation, operational separation in between flights, and operational delays.

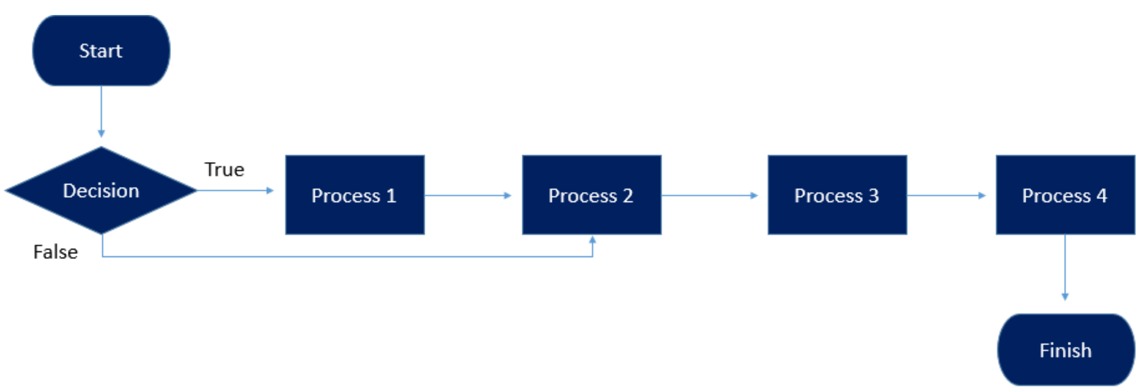


Figure 6. Flowchart

The above flow chart shows the logic used to build the Arena simulation processes. The underline terms below correspond to each box in the flow chart.

Start = The start of the simulation is considering the flights arriving at Congonhas Airport. It was limited to the maximum number of arrivals the airport was able to process due to its limitation available at INFRAERO's capacity publication, which is 269 arrival per day.

Decision = The decision process validates if a flight is delayed or not. It is the percentage of delayed flights retrieved from the "Básica" data set.

Process 1 = The Process 1 applies the delay time obtained from the "Básica" data set. It represents the delay time we found. It has a triangular distribution.

Process 2 = The Process 2 applies the constant safety separation between arrivals published by ANAC's regulation, which is the minimum time that must be followed.

Process 3 = The Process 3 considered the gate time occupation that was calculated after the raw data was processed in the Python system. It has a triangular distribution and 29 gates.

Process 4 = The Process 4 applies the constant safety separation between departures published by ANAC's regulation, which is the minimum time that must be followed.

Finish = The Finish of the simulation is a resume of output flights after the previous steps.

The Schedule parameter considered the number of aircrafts arriving per hour at Congonhas Airport.

The Resource parameter considerer one runway, which is available for commercial aviation and 29 gate positions.

Chapter IV

Outcomes

Descriptive statistics will help us understand the influence of COVID-19 in Congonhas Airport's operations and validate the turnaround time increase hypothesis due to new procedures. We used simulation concepts to check the impact in the number of flights in Congonhas, given the airport declared capacity.

Descriptive Statistics

Analyzing the flights taking off from Congonhas Airport in 2019, the total number of flights was 85,554, and it is possible to note that there is not much difference in the numbers between the months. The average number of flights per month is 7,120, and the months with fewer flights are February and June.

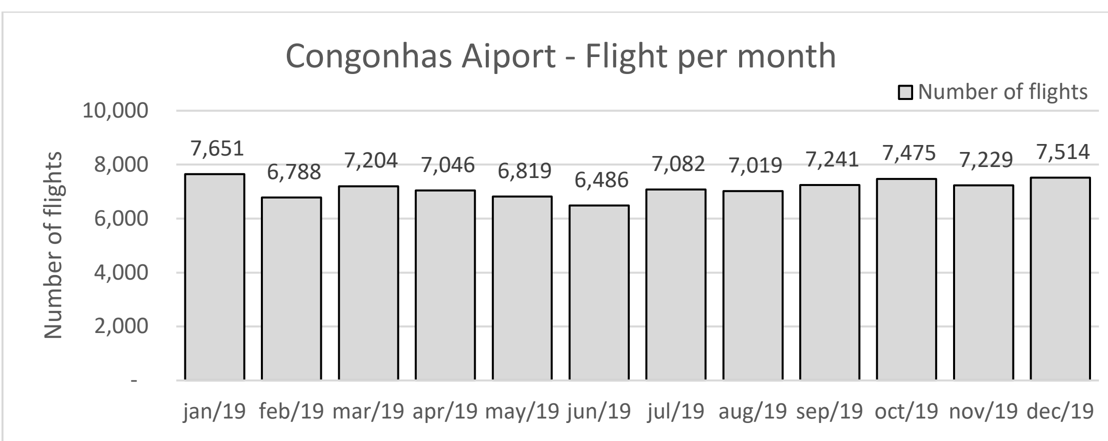


Figure 7. Number of flights from Congonhas Airport in 2019

The flights are composed of seven airlines, with LATAM and GOL representing 90% of the participation, followed by AZUL, AVIANCA, PASSAREDO, MAP, and TWO TAXI.

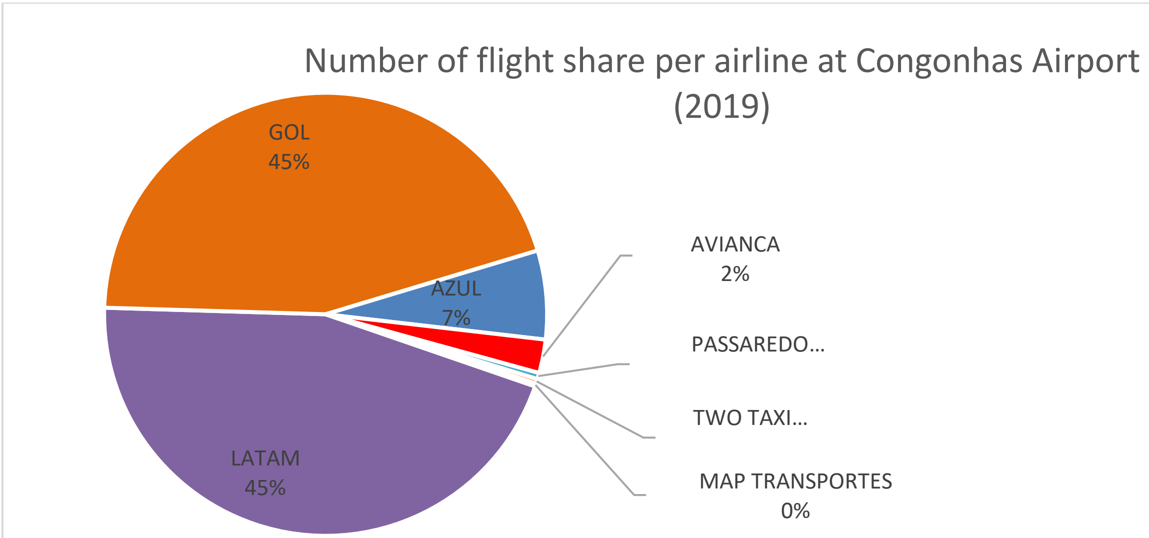


Figure 8. Flight share by airlines at Congonhas Airport

The companies fly to 45 domestic destinations from Congonhas, and the primary airports are Santos Dumont (Rio de Janeiro) with 20%, Brasilia with 9%, and Confins (Belo Horizonte) with 9% of the departures.

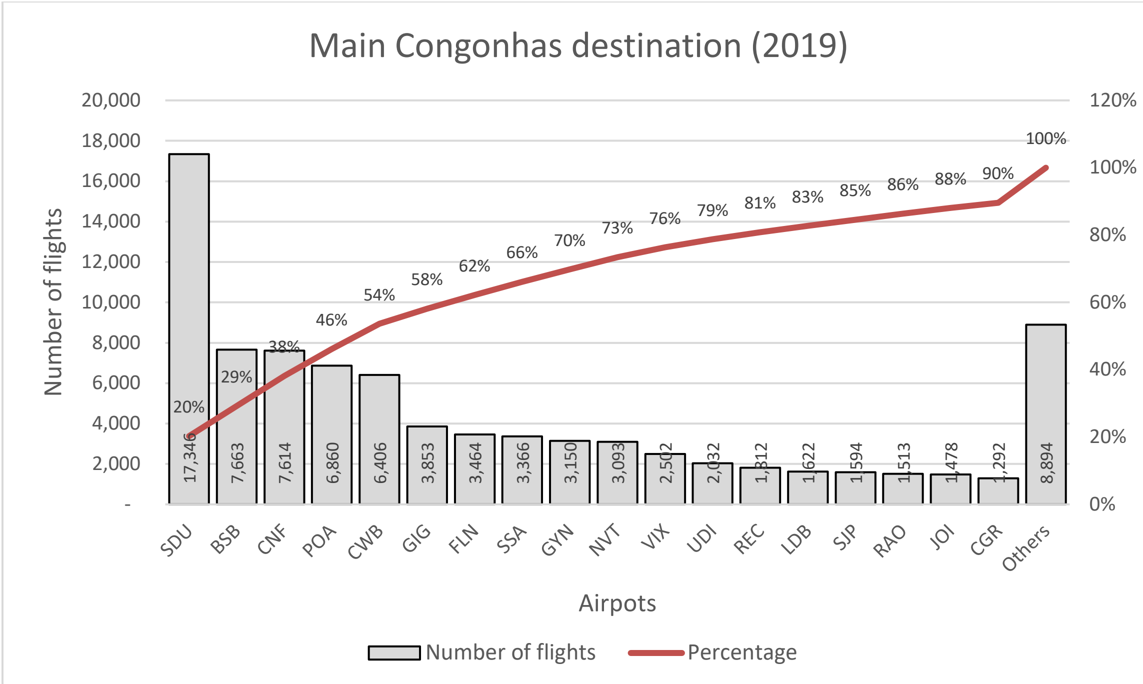


Figure 9. Main destinations from Congonhas Airport in 2019

After the announcements about COVID-19 in 2020, it is possible to notice the initial impact in March with a drastic reduction in flights in the following months compared to the same period in 2019.

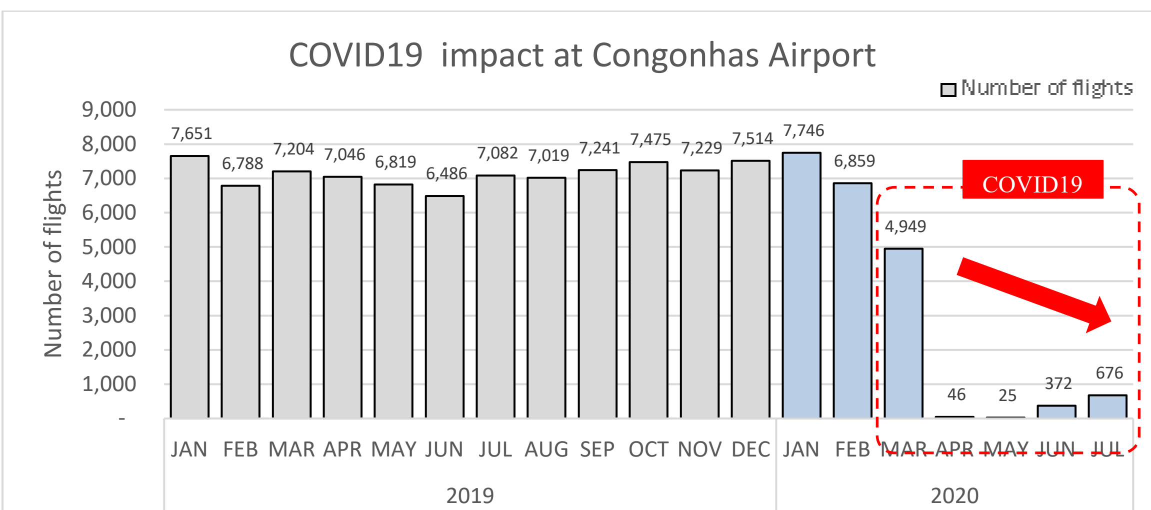


Figure 10. Impact on the number of flights due to COVID 19

Analyzing the airport's demand between 2019 and 2020 from January to July, it is possible to notice a 58% reduction in the number of flights, a 64% drop in the transported cargo, and a 63% reduction in the transported passengers.

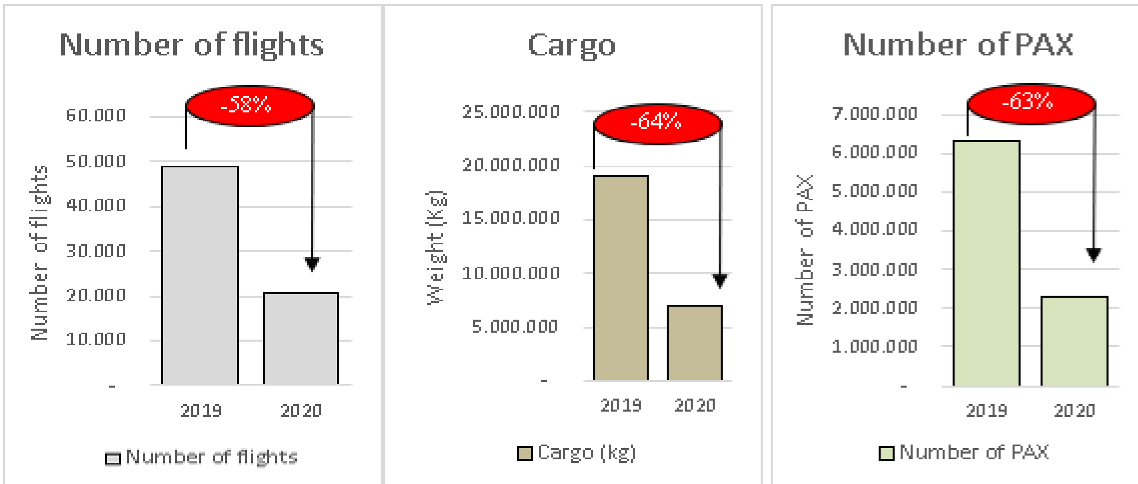


Figure 11. A scenario of reduction in the number of flights, cargo carried, and passengers

The comparison between the April-July of 2019 and April-July of 2020 shows a significant change in planned ground time distribution. In 2019, most aircraft had a planned ground time of between 30 to 40 minutes; in 2020, most aircraft's planned ground time was between 50 to 60 minutes.

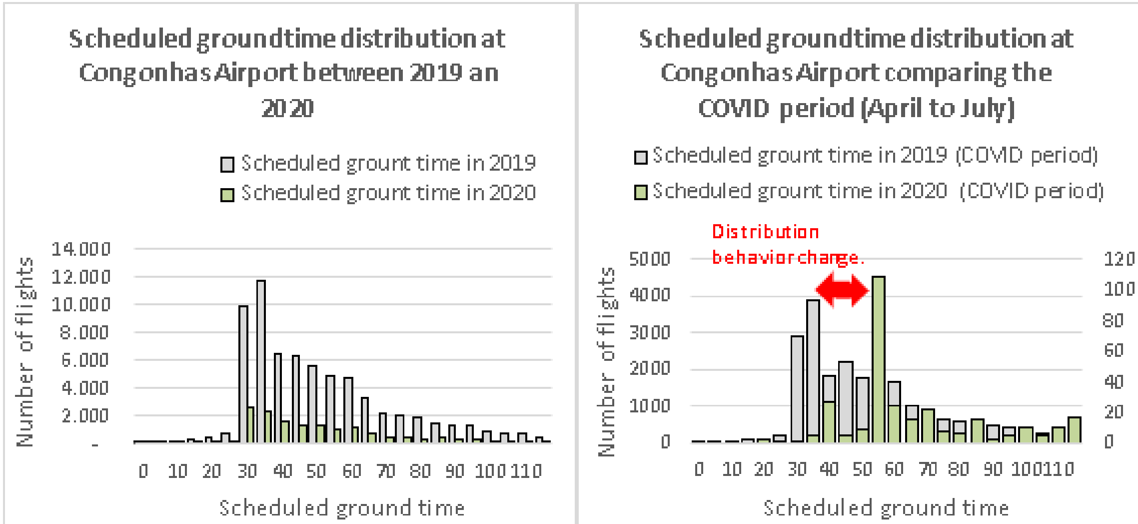


Figure 12. Comparison of planned ground time before and after the pandemic

Considering only the case where the ground time is lower than 60 minutes and removing outliers, it is possible to see the actual average time increased in the boxplot chart below (Figure 13). In 2019 most of the flights were able to perform the turnaround time on the expected time (blue color). However, 2020 average data showed that part of those flights presented expected time slightly above (yellow color).

The overall ground time distribution increased from 2019 to 2020, which can be observed by the chart's displacement upwards. The line depicted in the center of the graph shows the center of the data distribution, where 50% of ground time cases are between 46 minutes in 2019 and 56 minutes in 2020. Another observation is the main change occurred on the minimum, which can be observed on the lower limit line. The upper limit line that represents the maximum value, excluding the outliers, did not change a lot. The boxes in the middle, which represents the quartile, showed a slight increase.

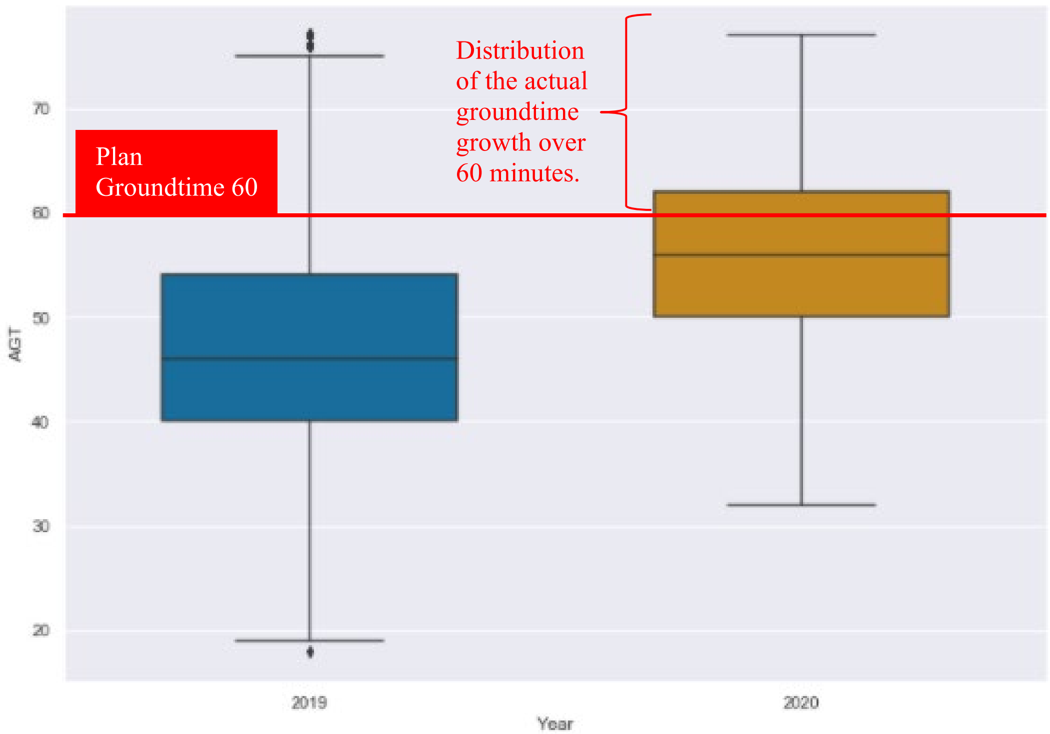
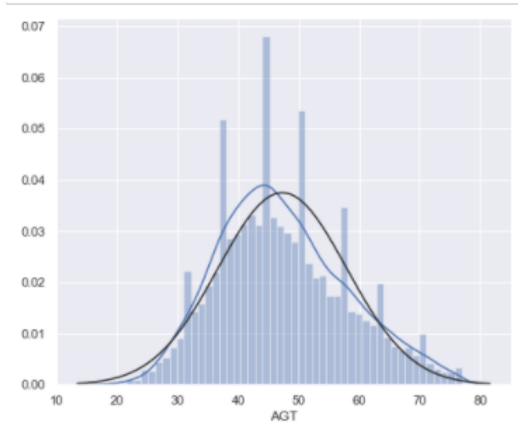


Figure 13. Boxplot with the actual ground time in cases where the planned ground time was less than 60 minutes

The graphs below demonstrate in more detail the flight groups with the ground time below 60 minutes without the outliers.

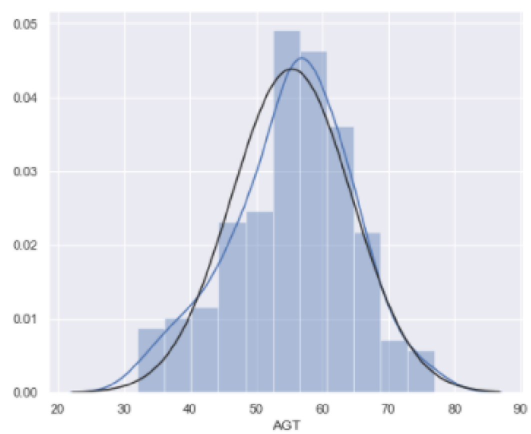
Skewness result was close to zero, which means that the data distribution looks the same to the left and right in 2019 and 2020. The kurtosis explains that both curves are a little flatter based on the normal curve.

In 2019, 16,212 cases took 47 minutes to perform the turnaround process, with a variation of 10 minutes for more and less. The mode explains that 50% of the flights were processed in 46 minutes. In 2020 despite a much smaller number of flights in the sample (169 flights), it was possible to see a significant increase in the times with 55 minutes of average process time, 9 minutes of variation, and 55 minutes in the mode indicator.




```
Skewness: 0.37888899828552636
Kurtosis: -0.26295281793942626
------------------------------------
count    16212.000000
mean        47.295830
std         10.642482
min         18.000000
25%         40.000000
50%         46.000000
75%         54.000000
max         77.000000
Name: AGT, dtype: float64
```

Figure 14. Descriptive data for flights with schedule time less than 60 minutes without outliers in 2019




```
Skewness: -0.3071613531299976
Kurtosis: -0.011410915192610283
------------------------------------
count    169.000000
mean      55.360947
std        9.130985
min       32.000000
25%       50.000000
50%       56.000000
75%       62.000000
max       77.000000
Name: AGT, dtype: float64
```

Figure 15. Descriptive data for flights with schedule time less than 60 minutes without outliers in 2020

Simulation

The increase of turnaround time was confirmed in the previous topic, descriptive statistics. In the current topic, we used Arena Software to simulate and understand the impact of the increase. The simulation was built based on the operational process that involves the aircraft arrival until its departure.

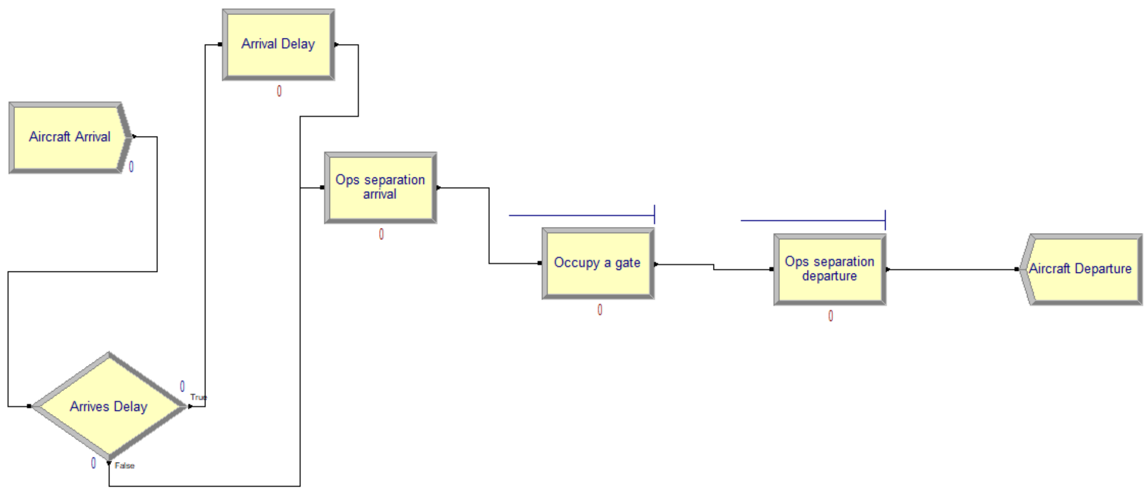


Figure 16. Workflow model used in Arena for the impact simulation

The image above shows the built-in workflow in Arena about the aircraft operation with the following parameters:

- Airport operational working hours: 17 hours/day
- Airport runway for commercial aircraft: 1 runway
- Aircraft parking positions: 29 (12 airbridges and 17 remotes)
- Number of replications: 40 replications of the simulation

The processes in the workflow represent the main steps of the aircraft during the ground time:

- Aircraft arrival (create process): process started with aircraft arrivals

- Ops separation arrival (process): minimum time (minutes) required by the air traffic control between arrivals
- Arrives delay (decision): percentage of total flights arriving with a delay found in the descriptive statistics
- Arrival delay (process): average delay time (minutes) found in the descriptive statistics
- Occupy a gate (process): duration that the aircraft is at the parking position based on the descriptive statistics of the previous topic
- Ops separation departure (process): minimum time (minutes) required by the air traffic control in between departures
- Aircraft departure (dispose of): close the process when the aircraft departures

After running the simulation using data from both scenarios, before and during COVID-19, we get the following outcome:

- Aircraft:
    - There is an increase in VA Time, which means value-added time. The average time of aircraft within the system before COVID was 59 minutes, and after COVID, it increased to 66 minutes.
    - The average waiting time of the aircraft remains the same.
    - The total average time of the aircraft within the system increased from 60 minutes to 68 minutes.
- Queue

- The maximum waiting time in the queue to occupy a gate increased from 0 to 4 minutes
- And the maximum number of aircraft waiting to occupy a gate change from 0 to 2

- Gate
    - There was an increase in the instantaneous utilization from 41% to 48%
    - And the number of gates busy increased from 12 to 14 in the average
- Runway
    - The utilization of the runway before and after is flat, 50% on average
- Outcome
    - The outcome from both reports shows that the total number of flights that could be handled on average before the crisis was 256, and after the crisis, 255

Chapter V

Conclusions and Recommendations

Overview of Research

This research was carried out during the pandemic of COVID-19, which impacted the whole world, requiring several measures to contain the virus's spread, such as wearing masks, constant hand hygiene, and several other government measures locking down cities and regions.

Aviation was one of the most impacted industries, reducing the number of flights due to lack of demand as people stayed home, and some borders between countries were closed. Gradually, the number of infection cases has decreased, and the economy started to recover, yet keeping the new health protocols to increase people's protection.

In this study, it was possible to understand the impact of the new processes established by ANVISA on the ground time at Congonhas Airport by gathering and analyzing information collected on the ANAC website. After processing the data and running descriptive analysis, the information generated allowed us to conclude that the turnaround time increased during the pandemic.

Based on the descriptive statistics methodology, data information collected was applied to the ARENA software. It was possible to simulate the impact of the new aircraft ground time at Congonhas Airport's operation.

Summary of Results

The descriptive analysis showed a behavior change in the distribution of planned ground times during the pandemic period. Comparing the period from April to July in 2019, Congonhas Airport had a high scheduled ground time between 30 and 40 minutes.

Still, in 2020 this picture changes to a scheduled ground time between 50 and 60 minutes. This time variation in the planning of airlines took place as new hygiene processes were required.

To support and verify the hypothesis of increased turnaround time due to the new processes, we selected the cases with the scheduled ground time less than or equal to 60 minutes. We compared it with the actual ground time. The data showed that in 2019 the airlines had an average real ground time of 47 minutes, and 50% of the ground times performed were below 46 minutes. In 2020, the time increased to 55 minutes, and 50% of the ground time events took place up to 56 minutes.

The Arena simulator supported us to understand the impact of this increased time on airport operation. The real aircraft's average processing time increased from 59 to 66 minutes; even so, we noticed that the Congonhas airport has a high parking capacity with 29 gates to serve the current demand, with an average usage of 12 gates before the pandemic and 14 after the pandemic. Despite the high capacity, the gate waiting time increased from 0 to 4 minutes.

Due to the increase in ground time, placing the operation rules at Congonhas airport, it was possible to verify regular operations per day before the pandemic had 256 arrivals. By applying the new aircraft ground time, the simulation brought 255 movements, proving that it is possible to maintain a similar operational routine.

Recommendations

In this study, it was possible to evaluate the impact of ground times at Congonhas airport due to the new health protocol. It was a pleasant surprise for us because we expected to see a smaller number of movements at the beginning of the study.

Still, we recommend deepening the analysis evaluating the financial impact throughout the stakeholder's chain due to the risk of reducing flights in the future if new measures are introduced.

Moreover, we recommend repeating this study in airports or situations where small variations on the turnaround time could bring other types of problems, like airports with many connections (hub airports) or a study focused on only network flights with connections.

Due to public data restriction and limitation, this study assessed the ground time from the beginning to the end of the process. An opportunity may open this total time with the help of one or more airlines to evaluate each activity individually to find improvement opportunities to adopt new procedures.

The simulation can measure the impact on the number of flights that are possible to operate due to the ground time increase and identify any other processing point impacting the operation due to the waiting time, like, gate and runway. Airlines and Airport administrators can work together to enhance the operations after identifying the operations challenges.

This simulation can also be used by Airlines and Airport administrators to analyze before and after scenarios where there will be an increase in the ground time due to any operational reason. For example, if many flights need to change the boarding and disembark process from the jet bridges to remote for any operational reason.

Lessons Learned

This capstone project allowed us to learn how to apply the simulation matter in the real world with real scenarios. It was a great opportunity to challenge ourselves to leave our comfort zone and take risks to finish it as we planned.

It took us a substantial time to understand the meaning of our first outcome. Moreover, we spent several hours identifying the better way to build the simulation. With the outstanding support from our facilitators, we were able to have all debates to focus on what we could use in our simulations.

The ability to have intense communication from the start and keep the schedule was essential for us to achieve this result.

Finally, we expected to see several issues due to the impact of this pandemic on the aircraft ground time, and the outcome was lower than we foresaw.

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Appendix A

Results of the simulation before COVID-19

10:12:03PM **Category Overview** October 28, 2020

Values Across All Replications

Unnamed Project

Replications: 40 Time Units: Minutes

Key Performance Indicators

System	Average
Number Out	256

10:12:03PM **Category Overview** October 28, 2020

Values Across All Replications

Unnamed Project

Replications: 40 Time Units: Minutes

Entity

Time

VA Time	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
aircraft	58.6321	0.30	56.8088	60.7703	23.1707	125.71

NVA Time	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
aircraft	0.00	0.00	0.00	0.00	0.00	0.00

Wait Time	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
aircraft	1.2040	0.08	0.6593	1.8252	0.00	12.8278

Transfer Time	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
aircraft	0.00	0.00	0.00	0.00	0.00	0.00

Other Time	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
aircraft	0.00	0.00	0.00	0.00	0.00	0.00

Total Time	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
aircraft	59.8361	0.33	58.1550	61.9859	23.5242	126.84

Other

Number In	Average	Half Width	Minimum Average	Maximum Average
aircraft	261.55	3.40	237.00	269.00

Number Out	Average	Half Width	Minimum Average	Maximum Average
aircraft	255.70	4.78	219.00	269.00

WIP	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
aircraft	15.2091	0.26	13.3686	16.3308	0.00	33.0000

10:12:03PM **Category Overview** October 28, 2020

Values Across All Replications

Unnamed Project

Replications: 40 Time Units: Minutes

Queue

Time

Waiting Time	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
Occupy a gate.Queue	0.00	0.00	0.00	0.00	0.00	0.00
Ops separation departure.Queue	1.2033	0.08	0.6593	1.8252	0.00	12.8278

Other

Number Waiting	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
Occupy a gate.Queue	0.00	0.00	0.00	0.00	0.00	0.00
Ops separation departure.Queue	0.3036	0.02	0.1500	0.4814	0.00	7.0000

10:12:03PM **Category Overview** October 28, 2020

Values Across All Replications

Unnamed Project

Replications: 40 Time Units: Minutes

Resource

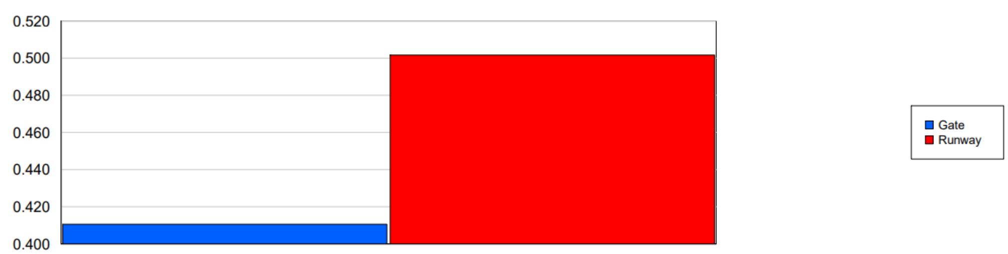
Usage

Instantaneous Utilization	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
Gate	0.4106	0.01	0.3666	0.4407	0.00	0.9655
Runway	0.5016	0.01	0.4300	0.5275	0.00	1.0000

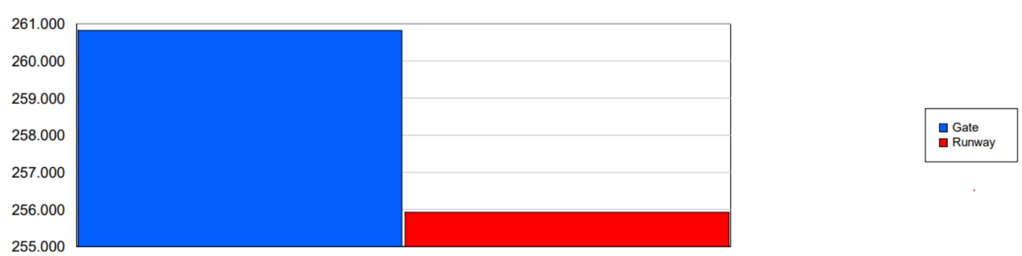
Number Busy	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
Gate	11.9070	0.18	10.6316	12.7789	0.00	28.0000
Runway	0.5016	0.01	0.4300	0.5275	0.00	1.0000

Number Scheduled	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
Gate	29.0000	0.00	29.0000	29.0000	29.0000	29.0000
Runway	1.0000	0.00	1.0000	1.0000	1.0000	1.0000

Scheduled Utilization	Average	Half Width	Minimum Average	Maximum Average
Gate	0.4106	0.01	0.3666	0.4407
Runway	0.5016	0.01	0.4300	0.5275



Total Number Seized	Average	Half Width	Minimum Average	Maximum Average
Gate	260.83	3.60	237.00	269.00
Runway	255.93	4.74	220.00	269.00



Appendix B

Results of the simulation after COVID-19

10:05:18PM **Category Overview** October 28, 2020

Values Across All Replications

Unnamed Project

Replications: 40 Time Units: Minutes

Key Performance Indicators

System	Average
Number Out	255

10:05:18PM **Category Overview** October 28, 2020

Values Across All Replications

Unnamed Project

Replications: 40 Time Units: Minutes

Entity

Time

VA Time	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
aircraft	66.3006	0.27	64.7869	68.1557	37.1351	126.19

NVA Time	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
aircraft	0.00	0.00	0.00	0.00	0.00	0.00

Wait Time	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
aircraft	1.2397	0.09	0.8431	2.1028	0.00	13.2324

Transfer Time	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
aircraft	0.00	0.00	0.00	0.00	0.00	0.00

Other Time	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
aircraft	0.00	0.00	0.00	0.00	0.00	0.00

Total Time	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
aircraft	67.5404	0.30	66.2043	69.5598	37.1351	132.57

Other

Number In	Average	Half Width	Minimum Average	Maximum Average
aircraft	261.55	3.40	237.00	269.00

Number Out	Average	Half Width	Minimum Average	Maximum Average
aircraft	254.50	4.86	218.00	269.00

WIP	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
aircraft	17.1417	0.29	15.0201	18.2870	0.00	36.0000

10:05:18PM **Category Overview** October 28, 2020

Values Across All Replications

Unnamed Project

Replications: 40 Time Units: Minutes

Queue

Time

Waiting Time	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
Occupy a gate.Queue	0.00126938	0.00	0.00	0.02505900	0.00	3.8998
Ops separation departure.Queue	1.2386	0.09	0.8431	2.0777	0.00	13.2324

Other

Number Waiting	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
Occupy a gate.Queue	0.00032723	0.00	0.00	0.00660870	0.00	2.0000
Ops separation departure.Queue	0.3116	0.02	0.1802	0.5479	0.00	7.0000

10:05:18PM **Category Overview** October 28, 2020

Values Across All Replications

Unnamed Project

Replications: 40 Time Units: Minutes

Resource

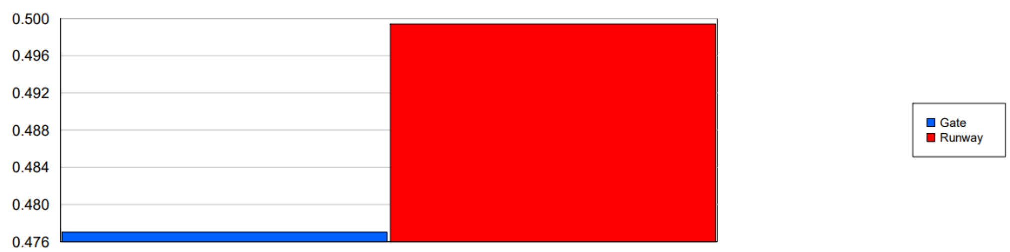
Usage

Instantaneous Utilization	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
Gate	0.4770	0.01	0.4238	0.5072	0.00	1.0000
Runway	0.4994	0.01	0.4275	0.5275	0.00	1.0000

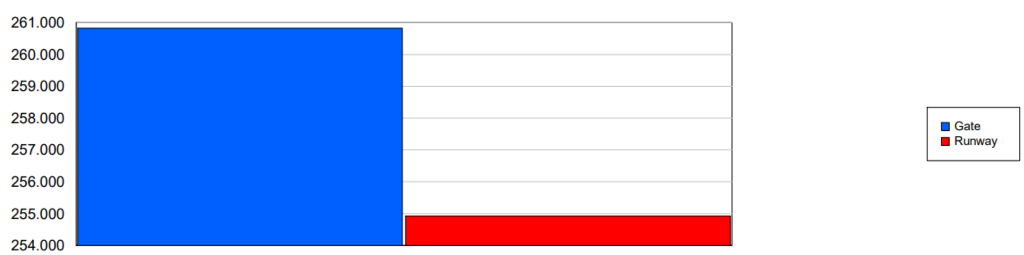
Number Busy	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
Gate	13.8337	0.22	12.2888	14.7088	0.00	29.0000
Runway	0.4994	0.01	0.4275	0.5275	0.00	1.0000

Number Scheduled	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
Gate	29.0000	0.00	29.0000	29.0000	29.0000	29.0000
Runway	1.0000	0.00	1.0000	1.0000	1.0000	1.0000

Scheduled Utilization	Average	Half Width	Minimum Average	Maximum Average
Gate	0.4770	0.01	0.4238	0.5072
Runway	0.4994	0.01	0.4275	0.5275



Total Number Seized	Average	Half Width	Minimum Average	Maximum Average
Gate	260.83	3.60	237.00	269.00
Runway	254.93	4.85	218.00	269.00



Appendix C

Python code

```
In [1]: import pandas as pd
        from pathlib import Path
```

```
In [23]: def ingest_raw_data():
             path = Path()
             df = []
             for file in path.glob('Etapa_basica/*.csv'):
                 aux = pd.read_csv(file, sep=';', encoding = "ISO-8859-1")
                 df.append(aux)
                 print(f'Loaded df{file}')
             df = pd.concat(df, axis=0, ignore_index=True)
             return df
```

```
In [24]: df = ingest_raw_data()

C:\ProgramData\Anaconda3\lib\site-packages\IPython\core\interactiveshell.py:3254: DtypeWarning: Columns (10) have mixed ty
pes.Specify dtype option on import or set low_memory=False.
  if (await self.run_code(code, result,  async_=asy)):

Loaded dfEtapa_basica\basica2019-01.txt
Loaded dfEtapa_basica\basica2019-02.txt
Loaded dfEtapa_basica\basica2019-03.txt
Loaded dfEtapa_basica\basica2019-04.txt
Loaded dfEtapa_basica\basica2019-05.txt
Loaded dfEtapa_basica\basica2019-06.txt
Loaded dfEtapa_basica\basica2019-07.txt
Loaded dfEtapa_basica\basica2019-08.txt

C:\ProgramData\Anaconda3\lib\site-packages\IPython\core\interactiveshell.py:3254: DtypeWarning: Columns (8,10) have mixed
types.Specify dtype option on import or set low_memory=False.
  if (await self.run_code(code, result,  async_=asy)):

Loaded dfEtapa_basica\basica2019-09.txt
Loaded dfEtapa_basica\basica2019-10.txt
Loaded dfEtapa_basica\basica2019-11.txt
Loaded dfEtapa_basica\basica2019-12.txt
Loaded dfEtapa_basica\basica2020-01.txt
Loaded dfEtapa_basica\basica2020-02.txt
Loaded dfEtapa_basica\basica2020-03.txt
Loaded dfEtapa_basica\basica2020-04.txt
Loaded dfEtapa_basica\basica2020-05.txt
Loaded dfEtapa_basica\basica2020-06.txt
Loaded dfEtapa_basica\basica2020-07.txt
```

```
In [30]: df.to_csv('./Etapa_basica/estapa_basica_consolidado.csv', index=False)
```

```
In [37]: df_A = df.loc[df['sg_iata_origem'] == 'CGH']
```

```
In [38]: df_B = df.loc[df['sg_iata_destino'] == 'CGH']
```

```
In [39]: df_CGH = pd.concat([df_A, df_B], axis=0, ignore_index=True)
```

```
In [41]: df_CGH.to_csv('./Etapa_basica/estapa_basica_consolidado_CGH.csv', index=False)
```

```
In [40]: df_CGH.shape
Out[40]: (215380, 110)

In [36]: df_1 = pd.read_csv('./Sirus/ANAC_VDF19092020114219.csv', sep=';')
         df_1.shape
Out[36]: (87498, 17)

In [35]: df_2 = pd.read_csv('./Sirus/ANAC_VDF19092020114426.csv', sep=';')
         df_2.shape
Out[35]: (21790, 17)

In [44]: df_3 = pd.read_csv('./Sirus/ANAC_VDF20092020065800.csv', sep=';')
         df_3.shape

         C:\ProgramData\Anaconda3\lib\site-packages\IPython\core\interactiveshell.py:3063: DtypeWarning: Columns (4,15) have mixed
         types.Specify dtype option on import or set low_memory=False.
           interactivity=interactivity, compiler=compiler, result=result)
Out[44]: (87541, 17)

In [45]: df_4 = pd.read_csv('./Sirus/ANAC_VDF20092020065932.csv', sep=';')
         df_4.shape

In [46]: df_SIRUS_CGH = pd.concat([df_1, df_2, df_3, df_4], axis=0, ignore_index=True)

In [50]: df_SIRUS_CGH.shape
Out[50]: (218660, 17)

In [54]: df_SIRUS_CGH.to_csv('./Sirus/sirus_consolidado_CGH.csv', index=False)

 In [2]: df_5 = pd.read_csv('./Sirus/ANAC_VDF27092020075613.csv', sep=';')
         df_5.shape
Out[2]: (100000, 17)

 In [3]: df_6 = pd.read_csv('./Sirus/ANAC_VDF27092020075905.csv', sep=';')
         df_6.shape
Out[3]: (100000, 17)
```

```
In [1]: import pandas as pd
        import numpy as np

In [2]: df_ANAC_1 = pd.read_csv('./Etapa_basica/estapa_basica_consolidado_CGH.csv',)
        df_SIRUS_1 = pd.read_csv('./Sirus/sirus_consolidado_CGH.csv')

        C:\ProgramData\Anaconda3\lib\site-packages\IPython\core\interactiveshell.py:3063: DtypeWarning: Columns (8) have mixed typ
        es.Specify dtype option on import or set low_memory=False.
          interactivity=interactivity, compiler=compiler, result=result)
        C:\ProgramData\Anaconda3\lib\site-packages\IPython\core\interactiveshell.py:3063: DtypeWarning: Columns (4,15) have mixed
        types.Specify dtype option on import or set low_memory=False.
          interactivity=interactivity, compiler=compiler, result=result)

In [3]: df_SIRUS_1['Início'] = pd.to_datetime(df_SIRUS_1['Início'], format='%d/%m/%Y')

In [4]: df_SIRUS_1['day'] = pd.DatetimeIndex(df_SIRUS_1['Início']).day
        df_SIRUS_1['month'] = pd.DatetimeIndex(df_SIRUS_1['Início']).month
        df_SIRUS_1['year'] = pd.DatetimeIndex(df_SIRUS_1['Início']).year

In [5]: df_SIRUS_1['key'] = df_SIRUS_1['ICAO']+'_'+df_SIRUS_1['day'].astype(str)+'_' +df_SIRUS_1['month'].astype(str)+'_'+df_SIRUS_1
```

```
In [7]: df_SIRUS_2 = df_SIRUS_1.loc[:,['key','Partida Prevista','Chegada Prevista']]
```

```
In [8]: df = pd.merge(df_ANAC_1, df_SIRUS_2, on='key')
```

```
In [9]: df['Partida Realizada'] = df['dt_partida_real']+' '+df['hr_partida_real']
```

```
In [10]: df['Chegada Realizada'] = df['dt_chegada_real']+' '+df['hr_chegada_real']
```

```
In [11]: df.columns
```

```
Out[11]: Index(['id_basica', 'id_empresa', 'sg_empresa_icao', 'sg_empresa_iata',
                'nm_empresa', 'nm_pais', 'ds_tipo_empresa', 'nr_voo', 'nr_singular',
                'id_di',
                ...
                'nr_rtk', 'id_arquivo', 'nm_arquivo', 'nr_linha', 'dt_sistema', 'key',
                'Partida Prevista', 'Chegada Prevista', 'Partida Realizada',
                'Chegada Realizada'],
               dtype='object', length=115)
```

```
In [12]: df = df.loc[:, ['sg_empresa_icao','ds_matricula', 'sg_iata_origem','sg_iata_destino',
                          'Partida Prevista', 'Chegada Prevista','Partida Realizada', 'Chegada Realizada',
                          'hr_partida_real','dt_partida_real','hr_chegada_real','dt_chegada_real',
                          'nr_voo','ds_di','ds_grupo_di','dt_referencia',
                          'nr_ano_referencia','nr_mes_referencia','nr_dia_referencia',
                        'id_equipamento','sg_equipamento_icao',
                         'ds_modelo','nr_assentos_ofertados','km_distancia','nr_passag_pagos',
                         'nr_passag_gratis','kg_bagagem_livre','kg_bagagem_excesso','kg_carga_paga','kg_carga_gratis','nr_horas_voadas
                         'kg_peso','nr_ask','nr_rpk','nr_atk','nr_rtk','key']]
```

```
In [13]: a = df['key'].value_counts().rename_axis('key').reset_index(name='Qtd')
```

```
In [14]: df_1 = pd.merge(df, a, on='key')
```

```
In [15]: df_2 = df_1.drop(df_1.index[[56116, 56197, 57497, 58412, 58534, 59107, 59355, 59683, 59944, 59999, 163768, 164863]])
```

```
In [16]: df_2['Partida Prevista'] = pd.to_datetime(df_2['Partida Prevista'], format = '%d/%m/%Y %H:%M')
         df_2['Chegada Prevista'] = pd.to_datetime(df_2['Chegada Prevista'], format = '%d/%m/%Y %H:%M')
         df_2['Partida Realizada'] = pd.to_datetime(df_2['Partida Realizada'], format = '%Y-%m-%d %H:%M')
         df_2['Chegada Realizada'] = pd.to_datetime(df_2['Chegada Realizada'], format = '%Y-%m-%d %H:%M')
```

```
In [17]: df_2 = df_2.sort_values(['sg_empresa_icao','ds_matricula','Chegada Realizada'])
```

```
In [18]: df_3 = df_2[:]
```

```
In [19]: df_3['aux_ATA'] = df_3['Chegada Realizada'].shift()
         df_3['aux_Pref'] = df_3['ds_matricula'].shift()
```

```
C:\ProgramData\Anaconda3\lib\site-packages\ipykernel_launcher.py:1: SettingWithCopyWarning:
A value is trying to be set on a copy of a slice from a DataFrame.
Try using .loc[row_indexer,col_indexer] = value instead

See the caveats in the documentation: https://pandas.pydata.org/pandas-docs/stable/user_guide/indexing.html#returning-a-vi
ew-versus-a-copy
  """Entry point for launching an IPython kernel.
C:\ProgramData\Anaconda3\lib\site-packages\ipykernel_launcher.py:2: SettingWithCopyWarning:
A value is trying to be set on a copy of a slice from a DataFrame.
Try using .loc[row_indexer,col_indexer] = value instead

See the caveats in the documentation: https://pandas.pydata.org/pandas-docs/stable/user_guide/indexing.html#returning-a-vi
ew-versus-a-copy
```

In [20]:
```
df_3['AGT'] = (df_3['Partida Realizada'] - df_3['aux_ATA']).dt.seconds/60
```

```
C:\ProgramData\Anaconda3\lib\site-packages\ipykernel_launcher.py:1: SettingWithCopyWarning:
A value is trying to be set on a copy of a slice from a DataFrame.
Try using .loc[row_indexer,col_indexer] = value instead

See the caveats in the documentation: https://pandas.pydata.org/pandas-docs/stable/user_guide/indexing.html#returning-a-vi
ew-versus-a-copy
  """Entry point for launching an IPython kernel.
```

In [21]:
```
df_3.loc[df_3['ds_matricula'] == df_3['aux_Pref'], 'cond'] = True
df_3.loc[df_3['ds_matricula'] != df_3['aux_Pref'], 'cond'] = False
```

```
C:\ProgramData\Anaconda3\lib\site-packages\pandas\core\indexing.py:844: SettingWithCopyWarning:
A value is trying to be set on a copy of a slice from a DataFrame.
Try using .loc[row_indexer,col_indexer] = value instead

See the caveats in the documentation: https://pandas.pydata.org/pandas-docs/stable/user_guide/indexing.html#returning-a-vi
ew-versus-a-copy
  self.obj[key] = _infer_fill_value(value)
C:\ProgramData\Anaconda3\lib\site-packages\pandas\core\indexing.py:965: SettingWithCopyWarning:
A value is trying to be set on a copy of a slice from a DataFrame.
Try using .loc[row_indexer,col_indexer] = value instead

See the caveats in the documentation: https://pandas.pydata.org/pandas-docs/stable/user_guide/indexing.html#returning-a-vi
ew-versus-a-copy
  self.obj[item] = s
```

In [22]:
```
df_3.loc[df_3['cond'] == False, 'AGT'] = np.nan
```

In [23]:
```
df_3 = df_3.sort_values(['sg_empresa_icao','ds_matricula','Chegada Prevista'])
```

In [24]:
```
df_3['aux_STA'] = df_3['Chegada Prevista'].shift()
```

In [25]:
```
df_3['SGT'] = (df_3['Partida Prevista'] - df_3['aux_STA']).dt.seconds/60
```

In [26]:
```
df_3.loc[df_3['ds_matricula'] == df_3['aux_Pref'], 'cond'] = True
df_3.loc[df_3['ds_matricula'] != df_3['aux_Pref'], 'cond'] = False
```

In [27]:
```
df_3.loc[df_3['cond'] == False, 'SGT'] = np.nan
```

In [28]:
```
df_3 = df_3.drop(['aux_ATA','aux_Pref','cond','aux_STA','Qtd'], axis=1)
```

In [29]:
```
df_3 = df_3.loc[:, ['key',
                     'sg_empresa_icao','ds_matricula', 'sg_iata_origem','sg_iata_destino',
                 'Partida Prevista', 'Chegada Prevista','Partida Realizada', 'Chegada Realizada',
                     'AGT','SGT',
                 'hr_partida_real','dt_partida_real','hr_chegada_real','dt_chegada_real',
                 'sg_empresa_iata','nm_empresa','nr_voo','ds_di','ds_grupo_di','dt_referencia',
                 'nr_ano_referencia','nr_mes_referencia','nr_dia_referencia',
               'id_equipamento','sg_equipamento_icao',
                'ds_modelo','nr_assentos_ofertados','km_distancia','nr_passag_pagos',
                'nr_passag_gratis','kg_bagagem_livre','kg_bagagem_excesso','kg_carga_paga','kg_carga_gratis','nr_horas_voadas
                'kg_peso','nr_ask','nr_rpk','nr_atk','nr_rtk']]
```

In [30]:
```
df_3.loc[df_3['sg_iata_origem'] != 'CGH', 'SGT'] = np.nan
```

In [31]:
```
df_3.loc[df_3['sg_iata_origem'] != 'CGH', 'AGT'] = np.nan
```

In [317]:
```
df_3.to_csv('./Consolidado/df_2.csv', index=False)
```

In [40]:
```
df_4 = df_3.loc[df_3['sg_iata_origem'] == 'CGH']
```

In [42]:
```
df_4 = df_4.rename({'sg_empresa_icao':'Company_icao',
                    'ds_matricula':'Fleet',
                    'sg_iata_origem':'Frow',
                    'sg_iata_destino':'To',
                    'Partida Prevista': 'STD',
                    'Chegada Prevista':'STA',
                    'Partida Realizada': 'ETD',
                    'Chegada Realizada': 'ATA',
                    'nm_empresa':'Company_name',
                    'nr_voo':'Flight_number',
                    'nr_ano_referencia':'Year',
                    'nr_mes_referencia':'Month',
                    'nr_dia_referencia':'Day',
                    'sg_equipamento_icao':'Aircraft_type',
                    'nr_assentos_ofertados':'Capacity',
                    'km_distancia':'Distance',
                    'nr_passag_pagos':'num_pax',
                    'nr_passag_gratis':'num_free_pax',
                    'kg_bagagem_livre':'Luggage',
                    'kg_bagagem_excesso':'Exceed_luggage',
                    'kg_carga_paga':'Cargo',
                    'kg_carga_gratis':'Free_cargo',
                    'kg_peso':'Weight'
                   }
,axis=1)
```

In [44]:
```
df_4.to_csv('./Consolidado/df_3.csv', index=False)
```

In [1]:
```
import pandas as pd
import matplotlib.pyplot as plt
%matplotlib inline
import seaborn as sns
from scipy.stats import norm
from scipy import stats
```

In [2]:
```
df_0 = pd.read_csv('./Consolidado/df_3.csv')
```

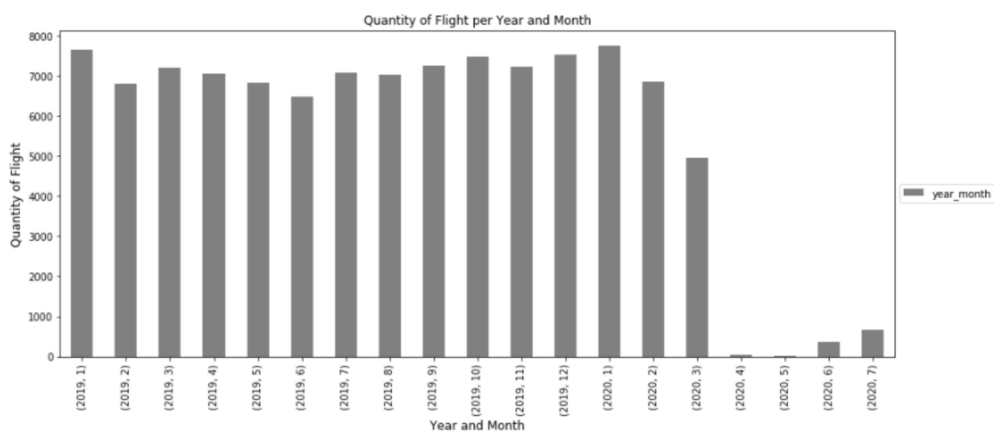
In [3]:
```
df_0.columns
```

Out[3]:
```
Index(['key', 'Company_icao', 'Fleet', 'Frow', 'To', 'STD', 'STA', 'ETD',
       'ATA', 'AGT', 'SGT', 'Company_name', 'Flight_number', 'Year', 'Month',
       'Day', 'Aircraft_type', 'Capacity', 'Distance', 'num_pax',
       'num_free_pax', 'Luggage', 'Exceed_luggage', 'Cargo', 'Free_cargo',
       'Weight', 'nr_ask', 'nr_rpk', 'nr_atk', 'nr_rtk'],
      dtype='object')
```

In [4]:
```
df_0['year_month'] = df_0['Month'].astype(str) + '.' +df_0['Year'].astype(str)
```

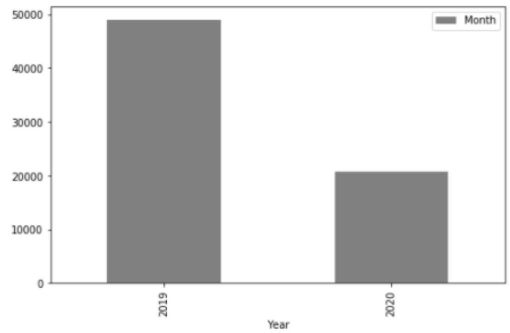
In [5]:
```
df_0[['Year','Month','year_month']].groupby(['Year','Month']).agg('count').plot(kind='bar',figsize=(15,6),  color='grey')
plt.xlabel('Year and Month', fontsize = 12)
plt.ylabel('Quantity of Flight', fontsize = 12)
plt.title('Quantity of Flight per Year and Month')
plt.legend(loc='center left', bbox_to_anchor=(1, 0.5))
```

Out[5]: <matplotlib.legend.Legend at 0x2021f92af88>



In [6]:
```
aux = df_0.loc[df_0['Month'] <= 7]
aux[['Year','Month']].groupby('Year').agg('count').plot(kind='bar', figsize=(8,5), color='grey')
```

Out[6]: <matplotlib.axes._subplots.AxesSubplot at 0x2021fa594c8>



```
In [7]: aux[['Year','Month','year_month']].groupby(['Year','Month']).agg('count')
```

Out[7]:

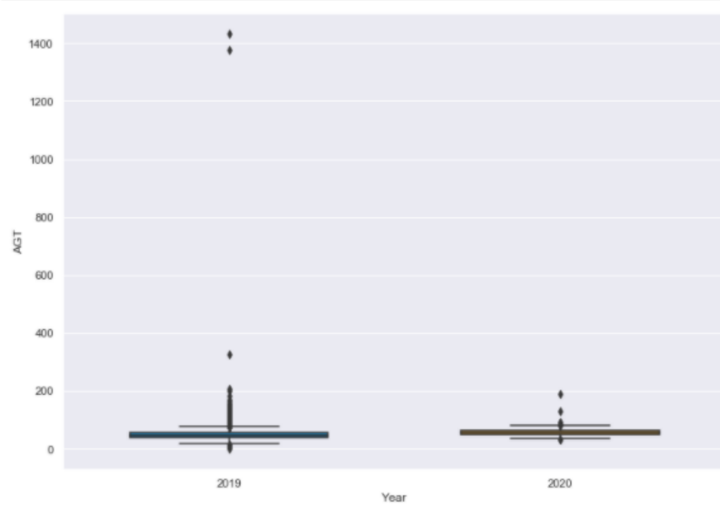
Year	Month	year_month
2019	1	7651
	2	6788
	3	7204
	4	7046
	5	6819
	6	6486
	7	7082
2020	1	7746
	2	6859
	3	4949
	4	46
	5	25
	6	372
	7	676

```
In [8]: # Gráfico boxplot da quantidade de voos por semana (2017 a 2019)
sns.set(rc={'figure.figsize':(11.7,8.27)})
boxplot = df_0[(df_0['Month'] == 4)|(df_0['Month'] == 5)|(df_0['Month'] == 6)|(df_0['Month'] == 7)]
boxplot = boxplot[(boxplot['SGT'] <= 60)]
```

```
In [9]: boxplot['Month'].value_counts()
```

```
Out[9]: 7    4772
4    4168
6    3923
5    3845
Name: Month, dtype: int64
```

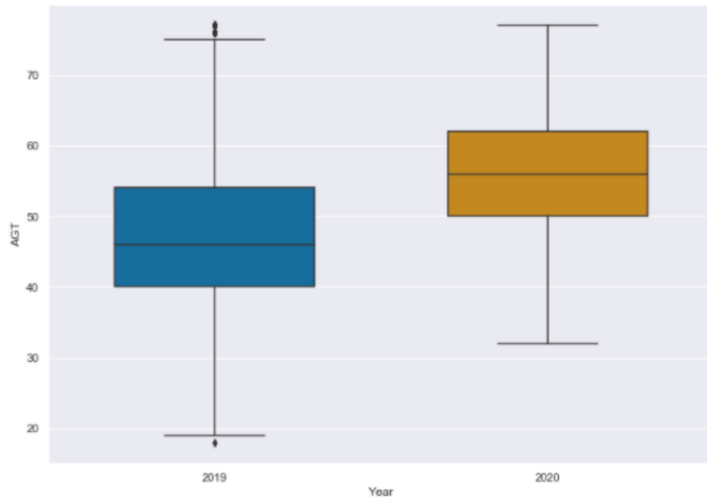
```
In [10]: boxplot = boxplot[["Year", "AGT"]]
bplot = sns.boxplot(y='AGT', x='Year',
                 data=boxplot,
                 width=0.6,
                 palette="colorblind")
```



In [11]:
```
# Função remove outliear
def remove_outlier(df_in, col_name):
    q1 = df_in[col_name].quantile(0.25)
    q3 = df_in[col_name].quantile(0.75)
    iqr = q3-q1
    fence_low  = q1-1.5*iqr
    fence_high = q3+1.5*iqr
    df_out = df_in.loc[(df_in[col_name] > fence_low) & (df_in[col_name] < fence_high)]
    return df_out

boxplot_outliear = remove_outlier(boxplot, 'AGT')
```

In [12]:
```
boxplot_outliear.to_csv('boxplot_outliear.csv', index=False)
```

In [13]:
```
bplot = sns.boxplot(y='AGT', x='Year',
                 data=boxplot_outliear,
                 width=0.6,
                 palette="colorblind")
```



In [16]:
```
boxplot_outliear.loc[boxplot_outliear['Year'] == 2019].describe()
```

Out[16]:

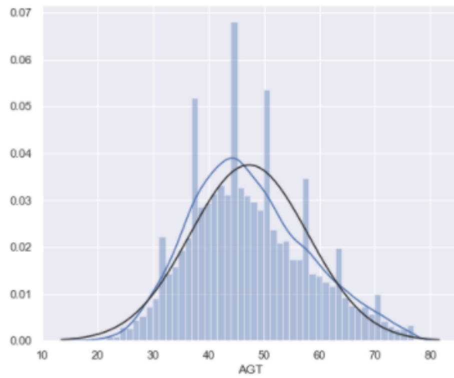
	Year	AGT
count	16212.0	16212.000000
mean	2019.0	47.295830
std	0.0	10.642482
min	2019.0	18.000000
25%	2019.0	40.000000
50%	2019.0	46.000000
75%	2019.0	54.000000
max	2019.0	77.000000

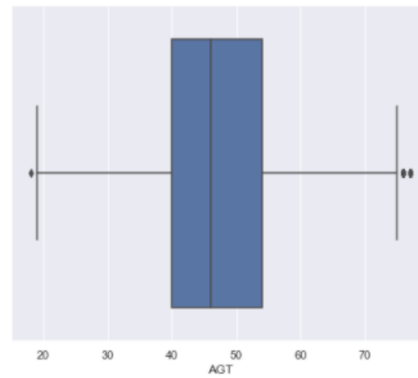
In [17]:
```
boxplot_outliear.loc[boxplot_outliear['Year'] == 2020].describe()
```

Out[17]:

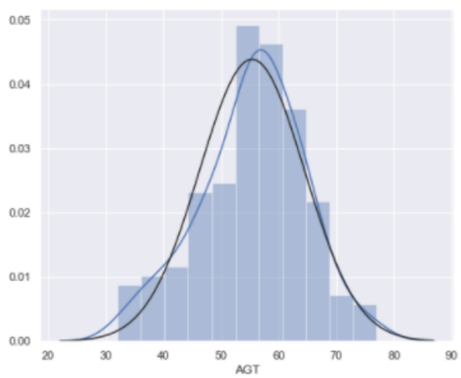
	Year	AGT
count	169.0	169.000000
mean	2020.0	55.360947
std	0.0	9.130985
min	2020.0	32.000000
25%	2020.0	50.000000
50%	2020.0	56.000000
75%	2020.0	62.000000
max	2020.0	77.000000

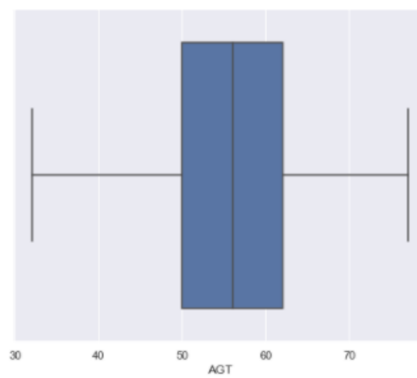
```
In [13]: f,ax = plt.subplots(1,2,figsize=(16,6))
         aux = boxplot_outliear.loc[boxplot_outliear['Year'] == 2019]
         sns.distplot(aux['AGT'],fit=norm,ax=ax[0])
         sns.boxplot(aux['AGT'])
         plt.show()

         #skewness and kurtosis
         print("Skewness: {}".format(aux['AGT'].skew()))
         print("Kurtosis: {}".format(aux['AGT'].kurt()))
         print("-------------------------------------")
         print(aux['AGT'].describe())
```






```
In [14]: f,ax = plt.subplots(1,2,figsize=(16,6))
         aux = boxplot_outliear.loc[boxplot_outliear['Year'] == 2020]
         sns.distplot(aux['AGT'],fit=norm,ax=ax[0])
         sns.boxplot(aux['AGT'])
         plt.show()

         #skewness and kurtosis
         print("Skewness: {}".format(aux['AGT'].skew()))
         print("Kurtosis: {}".format(aux['AGT'].kurt()))
         print("-------------------------------------")
         print(aux['AGT'].describe())
```





In [15]:
```
df_0.columns
```

Out[15]:
```
Index(['key', 'Company_icao', 'Fleet', 'Frow', 'To', 'STD', 'STA', 'ETD',
       'ATA', 'AGT', 'SGT', 'Company_name', 'Flight_number', 'Year', 'Month',
       'Day', 'Aircraft_type', 'Capacity', 'Distance', 'num_pax',
       'num_free_pax', 'Luggage', 'Exceed_luggage', 'Cargo', 'Free_cargo',
       'Weight', 'nr_ask', 'nr_rpk', 'nr_atk', 'nr_rtk', 'year_month'],
      dtype='object')
```

In [16]:
```
df_0
```

Out[16]:

	key	Company_icao	Fleet	Frow	To	STD	STA	ETD	ATA	AGT	...	Luggage	Exceed_l
0	AZU_19_1_2019_5163_SBSP_SBCT	AZU	AQR	CGH	CWB	2019-01-19 07:30:00	2019-01-19 08:30:00	2019-01-19 08:43:00	2019-01-19 09:55:00	27.0	...	49.0	
1	AZU_7_1_2019_2843_SBSP_SBCT	AZU	AUA	CGH	CWB	2019-01-07 07:30:00	2019-01-07 08:35:00	2019-01-07 07:18:00	2019-01-07 08:27:00	36.0	...	184.0	
2	AZU_26_1_2019_2696_SBSP_SBCF	AZU	AUA	CGH	CNF	2019-01-26 09:55:00	2019-01-26 11:10:00	2019-01-26 10:08:00	2019-01-26 11:27:00	37.0	...	526.0	
3	AZU_28_1_2019_2876_SBSP_SBCT	AZU	AUA	CGH	CWB	2019-01-28 19:30:00	2019-01-28 20:35:00	2019-01-28 20:18:00	2019-01-28 21:09:00	32.0	...	164.0	
4	AZU_31_1_2019_2876_SBSP_SBCT	AZU	AUA	CGH	CWB	2019-01-31 19:30:00	2019-01-31 20:35:00	2019-01-31 19:29:00	2019-01-31 20:32:00	30.0	...	438.0	
...	...	...	...	...	...	...	...	...	...	...	...	...	

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