v. 4, n. 4, 2024

Journal of
Engineering Research

ANALYSIS OF CONGONHAS-SP AIRPORT ACTIVITIES USING COMPUTATIONAL SIMULATION

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DOI https://doi.org/10.22533/at.ed.317442425016

Abstract: Congonhas Airport, located in São Paulo/SP, is the second busiest airport in Brazil, with an average of approximately 1000 movements/day, and an allocation capacity of more than 3000 passengers (passenger/hour). This high flow was triggered by globalization which, in turn, increased the need for more effective control and planning with air traffic. Therefore, with this context highlighted, the behavior of the aircraft in their activities was analyzed, checking average time for each of them, possible bottlenecks and resource allocation. This study considers the variations and particularities of the panorama presented through the use of the computer simulation tool, Simul8, in order to illustrate and, possibly, predict the routine involving the behavior of planes during their stay at the airport. Furthermore, different scenarios were created in order to analyze the influence of some resources that could interfere with the macroscopic situation of the case.

Keywords: Congonhas Airport, Air Traffic, Simulation, Simul8.

INTRODUCTION

Globalization has transfigured the modus operandi of existing relationships on the planet, altering not only the economy, but also completely modifying the transport sector [KHERBASH; MOCAN, 2015]. In this context, economic growth directly impacts the development of air transport [MATERA, 2012], since there is an increase in investments aimed at construction and improvements in the transport sector in order to foster competitiveness in the market in which they operate [ABREU, 2008]. These aspects result in an increase in the flow of air traffic for both commercial flights and cargo flights.

The growth of this type of service is evident mainly in large airports, which are mostly located in state capitals. According to Azul (2021), in 2017 passenger traffic increased by 15.4% compared to the same period of the previous year. Furthermore, the occupational rate on domestic flights grew by 2.4 percentage points, while international flights grew by 9.2% [AZUL, 2021]. The increase in the flow of passengers linked to poor infrastructure causes air traffic congestion problems which, consequently, generate cancellations, delays and diversion of flights.

From there, flight simulation helps solve these problems. Pinto (2008) states that operational research is made up of several techniques, one of which is simulation. This technique consists of simulating reality through a computational model that predicts events in a way that respects a series of restrictions or variables present in the problem. Thus, it is possible to find solutions that help in decision making, with the purpose of optimizing air traffic processes, as well as reducing operational costs.

Therefore, the objective of this study is to demonstrate, through modeling approaches, convenient ways to resolve airport congestion at Congonhas - SP airport using modular simulation software, Simul8. Then, after decomposing the airport's operation, a system of discrete events is modulated which, consequently, allows predictions of its behavior. Therefore, it becomes possible to observe the evolution of conditions and parameters of different opportune scenarios.

Therefore, the present work is organized as follows: until now the reader has been presented with the introduction, then it contains two topics contextualizing the topics covered, namely "Congonhas Airport" and "Simulation and Activities at Airports". Subsequently, the methodology explains the methods used in the study. Finally, the results and discussions, conclusion and references will be included.

CONGONHAS AIRPORT

One of the main gateways to São Paulo, Congonhas is the first large urban airport in São Paulo, capable of receiving international flights [FAY, 1996]. Located in the south of the city of São Paulo, Congonhas airport opened on April 12, 1936, with a vast area for aircraft operations and runway construction [GARCIA, 2015]. The chosen airport site was quite far from the urban center of the capital, there was no population concentration that the airport subsequently attracted and which later became the main obstacle to the expansion and operation of the space [GIMENEZ, 2020].

As one of the busiest airports in Latin America, Congonhas airport connects several cities in Brazil and around the world, both due to its strategic location and the socioeconomic characteristics of the region in which it is located [GIMENEZ, 2020]. Thus, it is today the second largest national airport in terms of passengers boarding and disembarking on domestic flights, with a growth of approximately 10.4% between 2010 and 2019 according to ANAC - ``*Agência Nacional de Aviação Civil*`` - National Civil Aviation Agency (2022), as shown in Figure 1.

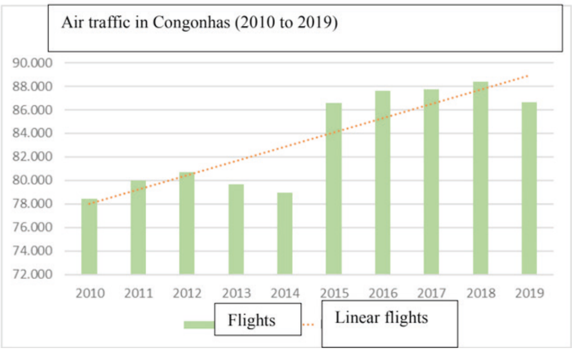


Figure 1 - Air Traffic Chart in Congonhas between 2010 and 2019

Source: Graph plotted from ANAC data (2022)

Congonhas airport is part of the administration of INFRAERO - Brazilian Airport Infrastructure Company, and today has a main runway and an auxiliary runway and two wings for boarding and disembarking passengers, totaling 22 access gates. Aircraft parking has allocation positions divided by fingers (12 spaces) and remote positions (17 spaces). The control center has 4 flight controllers and the airport is closed to civil aircraft between 02:00 and 09:00 [DECEA, 2022].

The aforementioned increase in air traffic demand leads airports around the world to make large investments aimed at modernizing and maximizing capacity and efficiency. As an alternative, tools have been used to support the decision-making process [CONFESSORE; LIOTTA; GRECCO, 2005]. Poor management of the airport site can lead to the impression of operation at maximum capacity and a feeling of congestion, leading to delays and bottlenecks that impact the entire flight system [BASTOS; BAUM et al., 2008].

SIMULATION AND ACTIVITIES AT AIRPORTS

Simulation is an analysis or experimentation of the interactivities of a system, without the need to modify reality and without the presence of costs [BANKS et al., 2009]. Hillier and Lieberman (2006) state that a simulation model records the operational performance of the system, in order to understand alternative designs or procedures, enabling evaluation and comparison before their implementation. This way, it becomes viable to identify bottlenecks, queue sizes, determine the level of use and observe the system's performance [SILVA, SILVA et al., 2018].

The biggest advantage and main property of simulation models is their flexibility [PORTUGAL, 1983]. Ashford, Mumayiz and Wright (2011) also state that it is more practical to set up, understand the results and cheaper to develop a program than to build a real system. Furthermore, a model can be used continuously for the analysis of numerous projects. However, simulation models tend to consume significant amounts of data, depend on tools such as advanced hardware and software, and have inaccuracies compared to analytical models [CHWIF, 1999].

Simulation models can be classified as static or dynamic, discrete or continuous and deterministic or stochastic. Static models (Monte Carlo simulation) present only one moment of the system, whereas dynamic models represent the entire set as they change over time [BANKS et al., 2009]. Deterministic ones have a set of previously determined inputs that will result in a single output, while stochastic ones have a grouping of random variables which generate random outputs considered estimates of the real outputs of the model [SILVA, 2022]. In turn, static models are those in which variables are changed at defined times and dynamic models vary continuously over time [ANGELINI, 1995].

The analysis of a simulation problem involves the creation of modeling and among the various methodologies there is the Activity Cycle Diagram (DCA). It stands out for its simplicity of understanding, for using simple elements (entities, queues and activities) and for its versatility in symbolizing different situations [SALIBY, MERHI et al., 2002]. Its final result expresses the behavior of the system, presenting the cycles of interconnected activities. This way, it facilitates the creation and development of simulation programs, better highlighting the events, which are key parts to describe the behavior of the model [SALIBY, MERHI et al., 2002].

The complexity of the growing demand for flights at airports, such as Congonhas - SP, prevents simple solutions from being found. Given this, it is necessary to apply alternative methodologies that allow finding quick and efficient solutions for processing these flights, highlighting simulation as a tool to achieve such objectives [GANTT, 1992; RIBEIRO, 2003]. Furthermore, simulation adds greater objectivity to the analyzes carried out, through the use of statistics and modeling, contributing to more assertive decision-making [MANATAKI; ZOGRAFOS, 2009; MANATAKI; ZOGRAFOS, 2010].

That said, simulation is a useful tool for planning and controlling airport infrastructures, especially when there is significant growth in air traffic in Congonhas, as previously mentioned and demonstrated by Figure 1. This growth has resulted in numerous problems for the responsible organizations, since the risks of accidents involving aircraft on the ground or in the air, delays and the deterioration of users' perception of the quality of services provided increase [RIBEIRO, 2003], especially in the context of Congonhas, which has just one main landing and takeoff runway.

METHODOLOGY

DATA COLLECT

Congonhas airport, in São Paulo, was the object of study for the development of the case, considering its infrastructure, information regarding its flight traffic and services in general. The data was made available by INFRAERO and ANAC, in addition to information provided by the Operational Coordinator of ``Gol Linhas Aéreas`` and secondary data obtained through on-site observation. The base had the flight identification, landing, takeoff, entry and exit times from the box, as well as the respective origins and destination. To analyze the airport's behavior, the events of 11/02/2022 from 9:00 am to 11:59 pm were considered.

To model the simulation program, the interval times between the arrivals and departures of planes on the airport runway, the landing and takeoff times, the aircraft's stay times in the pits, and the waiting time for aircraft that cannot land immediately, this time being estimated at 30 minutes by INFRAERO (2021) and ANAC (2022). In addition, the resources of flight controllers who work directly in managing the flow of planes that transit Congonhas airport and its surroundings.

SIMULATION MODEL

The present study is characterized from a quantitative approach, once the analysis of numerical variables has been adopted under the perception of statistical and simulation methods. Furthermore, there is the analytical nature of the case, based on an objective analysis of the data collected and the direct and indirect relationship with the simulated scenarios. Finally, it is based on a case study, with a view to analyzing in detail an individual case that can explain the dynamics of a given event.

This way, an Activity Cycle Diagram (DCA) was developed for the visualized scenario based on one of the three categories of airport analysis models defined by Manataki and Zografos (2009), namely: macroscopic, mesoscopic and microscopic. The category used in the present work consists of the macroscopic, that is, they have a lower level of detail, while the microscopic encompasses the greatest amount of detail possible and the mesoscopic is something between the two previous ones. Therefore, the macroscopic model adopted only considers general activities at the airport: landing, takeoff, waiting and stall time. Subsequently, this DCA was modeled in the Simul8 software and experimentation was carried out.

In view of this, simulations were carried out for other scenarios, varying aspects related to the number of resources available. By changing such variables, it is possible to predict different perspectives and their results, therefore, this data was tabulated for a later analysis of possibilities. Thus, at the end of the simulation process, the results obtained in each scenario were examined in order to find a solution with improvements for the situation presented. Therefore, based on quantitative and efficient information obtained through the software, more assertive decision-making becomes viable.

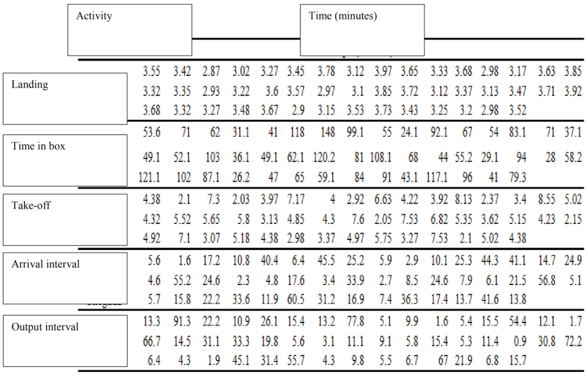
RESULTS AND DISCUSSIONS

The present work studied the process of landing and taking off flights at Congonhas Airport, located in São Paulo/SP. Landing begins with the arrival of planes in the airport's airspace. Once on the airport territory, the pilot waits for landing authorization, which is given by one of the flight controllers 1, since there are two individuals for this role. If the runway is not clear, it will fly over the region until clearance is received, not exceeding 30 minutes of waiting in the air. If the runway is not cleared during this period, the plane is directed to another airport.

Once landed, it goes to the box, where it is parked and remains for a period of time (shown in Table 1 below). The aircraft's stay in the box is monitored by flight controller 2 (this position is held by just one individual), so the plane is only released to leave with the approval of this controller. Takeoff begins with the plane leaving the pit towards the runway. This procedure also only occurs when there is approval from flight controller 1. Then, it takes off and the studied process is completed.

After a detailed study of the entire process, it was possible to identify the entities, activities and queues that made up the process. Next, it was necessary to understand the distributions of activities, which were designed through the analysis of the information collected. For this analysis, the Simul8 software was used. The studied scenario covers a busiest day as it is a national holiday, in addition to not having been influenced by meteorological factors, so the situation presented may not represent the real capacity of the yard on routine days or under the effect of adverse weather conditions.

Furthermore, the times in minutes of landing, time in the pit, takeoff, arrival and departure intervals were collected. Below is Table 1 with data referring to 11/02/2022.



Activity	Time (minutes)															
Landing	3.55	3.42	2.87	3.02	3.27	3.45	3.78	3.12	3.97	3.65	3.33	3.68	2.98	3.17	3.63	3.85
	3.32	3.35	2.93	3.22	3.6	3.57	2.97	3.1	3.85	3.72	3.12	3.37	3.13	3.47	3.71	3.92
	3.68	3.32	3.27	3.48	3.67	2.9	3.15	3.53	3.73	3.43	3.25	3.2	2.98	3.52		
Time in box	53.6	71	62	31.1	41	118	148	99.1	55	24.1	92.1	67	54	83.1	71	37.1
	49.1	52.1	103	36.1	49.1	62.1	120.2	81	108.1	68	44	55.2	29.1	94	28	58.2
	121.1	102	87.1	26.2	47	65	59.1	84	91	43.1	117.1	96	41	79.3		
Take-off	4.38	2.1	7.3	2.03	3.97	7.17	4	2.92	6.63	4.22	3.92	8.13	2.37	3.4	8.55	5.02
	4.32	5.52	5.65	5.8	3.13	4.85	4.3	7.6	2.05	7.53	6.82	5.35	3.62	5.15	4.23	2.15
	4.92	7.1	3.07	5.18	4.38	2.98	3.37	4.97	5.75	3.27	7.53	2.1	5.02	4.38		
Arrival interval	5.6	1.6	17.2	10.8	40.4	6.4	45.5	25.2	5.9	2.9	10.1	25.3	44.3	41.1	14.7	24.9
	4.6	55.2	24.6	2.3	4.8	17.6	3.4	33.9	2.7	8.5	24.6	7.9	6.1	21.5	56.8	5.1
	5.7	15.8	22.2	33.6	11.9	60.5	31.2	16.9	7.4	36.3	17.4	13.7	41.6	13.8		
Output interval	13.3	91.3	22.2	10.9	26.1	15.4	13.2	77.8	5.1	9.9	1.6	5.4	15.5	54.4	12.1	1.7
	66.7	14.5	31.1	33.3	19.8	5.6	3.1	11.1	9.1	5.8	15.4	5.3	11.4	0.9	30.8	72.2
	6.4	4.3	1.9	45.1	31.4	55.7	4.3	9.8	5.5	6.7	67	21.9	6.8	15.7		

Table 1 – Operating times for activities on 11/02/2022

Source: Collected by authors

With the data in hand, activity distributions were established using Simul8's Stat Fit tool. Continuous distributions were used, since we worked with fractional units of minutes. For each activity, the distributions shown in Table 2 are:

Activity	Distribution
Landing	Weibull (2., 5.38, 1.51)
Time in the Box	Beta (24., 160, 1.07, 2.18)
Take-off	Beta (0., 12.1, 4.19, 6.44)
Arrival Interval	Exponencial (1., 5.5)
Output Interval	Lognormal (0., 2.53, 1.1)

Tabela 2 – Adopted distributions

Fonte: Autores

It is worth mentioning that Stat Fit presents several distributions for each activity positioned in a rank, as well as informing whether or not they are rejected. Therefore, for the activities, the first position in the rank was chosen with no rejection, except for the take-off and arrival activities. For these activities, the second position in the rank was chosen, since modeling with the distribution of their first position resulted in the generation of unrealistic bottlenecks. Once the distributions were found, a DCA was structured to better visualize the activities and their behavior in relation to the airport's operation and, subsequently, modeled in the Simul8 software, as shown in Figure 2.

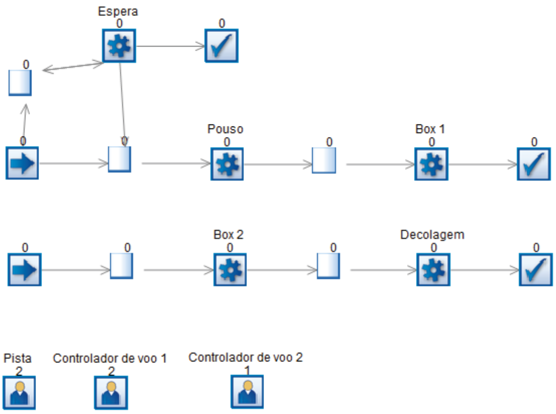


Figure 2 – Activity Cycle Diagram (DCA) – Congonhas Airport - SP

Source: Authors using Simul8 software

It is possible to observe that there are two entries referring to the arrival time, one for planes that are going to take off and another for those that are going to land. Note that for both tasks there is the Box route, which indicates the aircraft's movement interval from its allocation position to the flight runway and vice versa. In addition, there are the entities Landing and Takeoff which refer to the time taken for the planes to complete the landing or departure, respectively. Lastly, there is Waiting, relating to the period in which each aircraft must comply in situations where the runway is unavailable.

After preparing the DCA, the resources (Track, Controller 1 and 2) were allocated to their respective activities. The flight runway and Controller 1 were designated for the Landing, Takeoff and Waiting entities (only the controller), while Controller 2 is responsible for releasing the aircraft in Box 1 and 2. It is worth mentioning that there are two runways (main and auxiliary), two type 1 controllers and one type 2 controller. With the diagram finalized, the group adjusted its simulation for a day of work at the airport, thus obtaining the results presented in Figure 3.

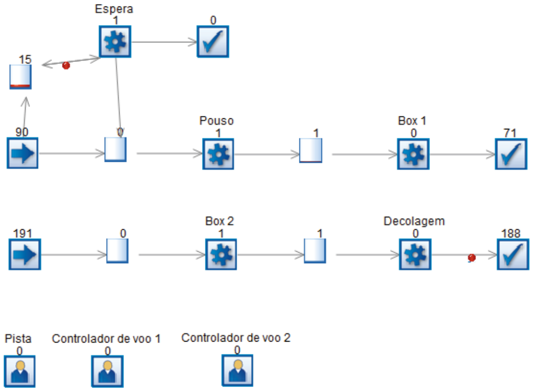
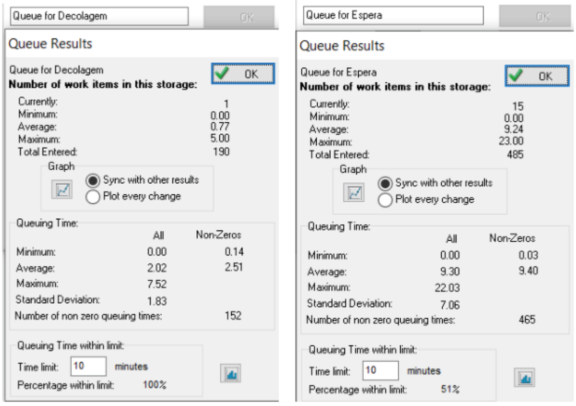


Figure 3 – Final Result – Congonhas Airport – SP

Source: Authors using Simul8 software

With the projection of the results obtained, it was observed that 188 aircraft take off, 71 land and none are released to another airport throughout the simulated day. Furthermore, it was possible to understand which activities generate bottlenecks, that is, the tasks that have the longest queues throughout the working day. At this juncture, the queues before take-off and the waiting queue present greater traffic, with 5 and 23 planes respectively, generating congestion on the runway and in the airspace, as illustrated in Figure 4.



Queue for Decolagem

Queue Results

Queue for Decolagem
Number of work items in this storage:

Currently: 1
Minimum: 0.00
Average: 0.77
Maximum: 5.00
Total Entered: 190

Graph
● Sync with other results
○ Plot every change

Queuing Time:

	All	Non-Zeros
Minimum:	0.00	0.14
Average:	2.02	2.51
Maximum:	7.52	
Standard Deviation:	1.83	
Number of non zero queuing times:		152

Queuing Time within limit:
Time limit: 10 minutes
Percentage within limit: 100%

Queue for Espera

Queue Results

Queue for Espera
Number of work items in this storage:

Currently: 15
Minimum: 0.00
Average: 9.24
Maximum: 23.00
Total Entered: 485

Graph
● Sync with other results
○ Plot every change

Queuing Time:

	All	Non-Zeros
Minimum:	0.00	0.03
Average:	9.30	9.40
Maximum:	22.03	
Standard Deviation:	7.06	
Number of non zero queuing times:		465

Queuing Time within limit:
Time limit: 10 minutes
Percentage within limit: 51%

Figure 4 – Result of the number of planes per row – Takeoff and Waiting - Congonhas-SP Airport.

Source: Authors using Simul8 software

It is worth noting that data such as altitude, load and/or speed that could interfere with the results obtained were not considered. On the other hand, such variables are empirically of great relevance and have a direct relationship with the airport's air flow. Such information is of interest to flight controllers, in order to devise a logistical plan for the best route for the planes, freeing up queues and reducing obstructions along the way.

PROJECT SCENARIOS

Once the standard model for the macroscopic simulation of the Congonhas aerodrome was created, two different scenarios were designed in order to analyze what changes they would bring to the system. The idea behind these scenarios is to find possibilities for improving the airport's performance by changing resources, mainly in terms of reducing queues. Therefore, two fictitious situations were designed: one in which there is the addition of a runway for landings and takeoffs; and another in which the number of controllers is increased.

a) Increase of a lane

This first scenario is evidenced by Figures 5 and 6.

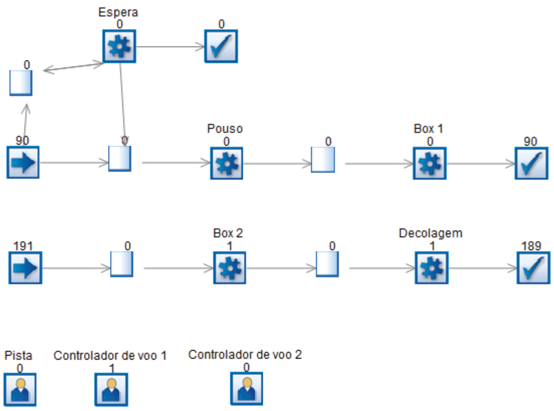
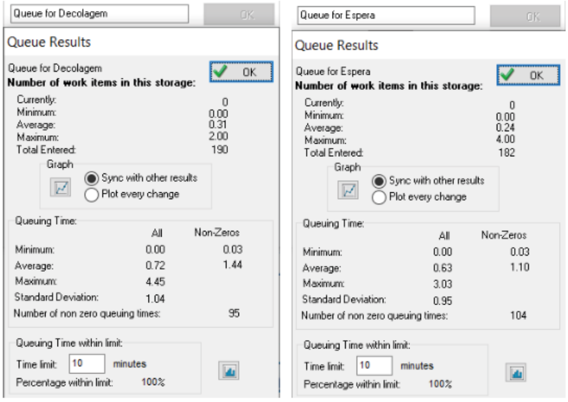


Figure 5 – Final result scenario A - Congonhas-SP Airport

Source: Authors using Simul8 software



Queue for Decolagem

Queue Results

Queue for Decolagem
Number of work items in this storage:
Currently: 0
Minimum: 0.00
Average: 0.31
Maximum: 2.00
Total Entered: 190

Graph
● Sync with other results
○ Plot every change

Queuing Time:

	All	Non-Zeros
Minimum:	0.00	0.03
Average:	0.72	1.44
Maximum:	4.45	
Standard Deviation:	1.04	
Number of non zero queuing times:		95

Queuing Time within limit:
Time limit: 10 minutes
Percentage within limit: 100%

Queue for Espera

Queue Results

Queue for Espera
Number of work items in this storage:
Currently: 0
Minimum: 0.00
Average: 0.24
Maximum: 4.00
Total Entered: 182

Graph
● Sync with other results
○ Plot every change

Queuing Time:

	All	Non-Zeros
Minimum:	0.00	0.03
Average:	0.63	1.10
Maximum:	3.03	
Standard Deviation:	0.95	
Number of non zero queuing times:		104

Queuing Time within limit:
Time limit: 10 minutes
Percentage within limit: 100%

Figure 6 – Result of the number of planes per row in scenario A - Takeoff and Waiting - Congonhas-SP Airport.

Source: Authors using Simul8 software

In this context, the final numbers point to the occurrence of 189 takeoffs and 90 landings, providing space for all planes arriving at the airport, curbing previously existing bottlenecks. Furthermore, this improvement would reduce the number of planes waiting in the takeoff queue from 5 to 2 as well as the number of aircraft waiting to land, this reducing from 23 planes to 4.

b) Increase of one flight controller 1

This second scenario is evidenced by Figures 7 and 8 below

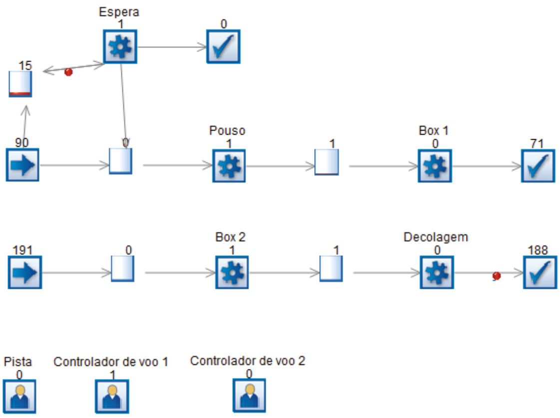
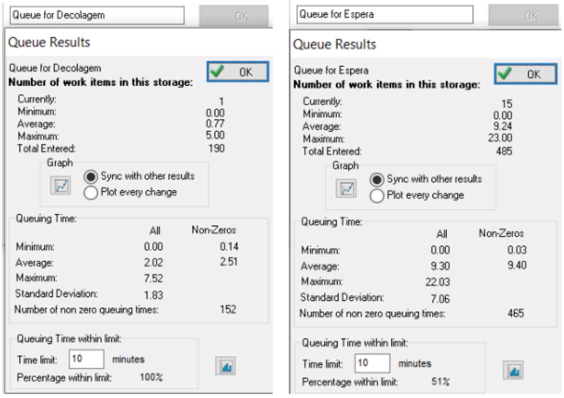


Figure 7 – Final result scenario B - Congonhas-SP Airport

Source: Authors using Simul8 software



Queue for Decolagem

Queue Results

Queue for Decolagem
Number of work items in this storage:
Currently: 1
Minimum: 0.00
Average: 0.77
Maximum: 5.00
Total Entered: 190

Graph
● Sync with other results
○ Plot every change

Queuing Time:

	All	Non-Zeros
Minimum:	0.00	0.14
Average:	2.02	2.51
Maximum:	7.52	
Standard Deviation:	1.83	
Number of non zero queuing times:		152

Queuing Time within limit:
Time limit: 10 minutes
Percentage within limit: 100%

Queue for Espera

Queue Results

Queue for Espera
Number of work items in this storage:
Currently: 15
Minimum: 0.00
Average: 9.24
Maximum: 23.00
Total Entered: 485

Graph
● Sync with other results
○ Plot every change

Queuing Time:

	All	Non-Zeros
Minimum:	0.00	0.03
Average:	9.30	9.40
Maximum:	22.03	
Standard Deviation:	7.06	
Number of non zero queuing times:		465

Queuing Time within limit:
Time limit: 10 minutes
Percentage within limit: 51%

Figure 8 – Result of the number of planes per queue in scenario B - Takeoff and Waiting - Airport Congonhas-SP.

Source: Authors via software Simul8

From the second scenario highlighted, it was noted that the addition of a type 1 flight controller does not interfere with the flow of aircraft, that is, it does not bring significant improvements or worsening. We can observe from this that this is not a performance-detracting resource, not being the main responsible for the bottlenecks witnessed in the simulation, however, it is not a continuous improvement resource for the process in question. Its variation does not directly impact the results obtained.

CONCLUSIONS

The simulation model structured in this work illustrates, in a macroscopic way, the behavior of air flow and activities at Congonhas Airport. In practical terms, the management of such scenarios deals with even more complex situations, taking into consideration, variables that are sometimes beyond the operator's control. That said, the assistance of computational tools such as Simul8 is essential in order to support INFRAERO operators in making decisions and controlling and planning activities.

In view of this, and based on the situations projected in the airport scenario, it can be concluded that the addition of a runway would be quite advantageous for Congonhas airport, as the queue for Waiting activities is considerably reduced. However, considering that the airport is located in the middle of Greater São Paulo, a project of such proportion is not a feasible alternative. The addition of a flight controller for landing and takeoff does not make any significant differences; on the contrary, this employee's idleness can be seen, which is therefore unfavorable to the airport.

Given this, an alternative to congestion at the airport is to reduce the flow of aircraft passing through Congonhas airport, reducing the number of stopovers, that is, flights that do not necessarily need to land specifically at this airport. Alternative routes can be suggested to other airports in the region, such as Guarulhos and Viracopos airports.

Despite the reliability of the information obtained, relative errors and uncertainties to which data collection is subject must be taken into consideration. Furthermore, the fact that it is a macroscopic model implies the application of several variables, just like a microscopic model, which has greater detail.

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