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Security screening capacity during COVID-19 recovery: simulation study of a domestic airport in Brazil

Capacidade da inspeção de segurança durante a recuperação da COVID-19: estudo de simulação de um aeroporto doméstico no Brasil

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ABSTRACT

With the recent COVID-19 pandemic, air travel has suffered a dramatic financial and operational crisis, in which quarantine and social distancing have suddenly become habitual and almost ubiquitous. When such measures are taken, the airport throughput capacity is reduced, something that is missed in the current design guidelines. This capacity temporary shortage can undermine system recovery, demanding proper treatment in the post-pandemic world. However, the capacity loss is offset by demand shortage: the relationship between both will tell if a given infrastructure fits the actual needs. This research acknowledges that social distancing might be an important factor for the planning and operation of airports in the foreseeable future and presents a methodological contribution based on simulation. The security screening queueing area of a busy Brazilian domestic airport was assessed under different combinations of %PHP (i.e., the percentage of peak hour passengers) and social distancing. The results indicate that the existing queueing area cannot withstand pre-pandemic passenger traffic under COVID-19 social distancing procedures. However, the recovery rate was found to be low enough to allow social distancing for the most critical time window. The proposed methodology, discussions, and recommendations can be valuable for a more resilient approach to airport design regarding eventual disruptive events in the future.

RESUMO

Com a recente pandemia de COVID-19, o setor aéreo sofreu uma dramática crise operacional, na qual a quarentena e o distanciamento social repentinamente se tornaram habituais. Quando tais medidas são tomadas, a capacidade do aeroporto é reduzida, algo não previsto nas diretrizes de projeto. Esta pesquisa reconhece que o distanciamento social pode ser um fator importante no futuro dos terminais e apresenta uma contribuição metodológica baseada em simulação. A área de filas da inspeção de segurança foi avaliada sob diferentes combinações de %PHP (% de passageiros no horário de pico). Os resultados indicam que a área de filas existente não pode suprir o volume de passageiros pré-pandemia sob os procedimentos de distanciamento, mas a taxa de recuperação foi baixa o suficiente para permitir o distanciamento social na janela de tempo mais crítica. A metodologia contribui para uma abordagem mais resiliente em relação a potenciais eventos disruptivos no futuro.

1. INTRODUCTION

The air transport industry is susceptible to a myriad of disruptive events, such as terrorist attacks, financial crises, and sanitary crises. One possible short-term effect of such events is demand shrinkage. The 9/11 terrorist attacks caused a 20% decrease in domestic ATV (Air Travel Volume) between September and December 2001, when compared to the same period in 2000 (Blunk et al., 2006). The outbreak of SARS (Severe Acute Respiratory Syndrome) reported by the World Health Organization (WHO) in March 2003 reached 29 countries and accumulated 916 deaths in 5 months. Consequently, Hong Kong recorded a 77% decrease in ATV between March and April 2003 (Siu and Wong, 2004). Following the 2008/09 financial crisis, the Asia-Pacific region recorded a decline (Year-Over-Year) of more than 15% in passenger numbers (Pearce, 2012). COVID-19 has led to a shocking decrease of 92% in international seat capacity during the 2nd quarter of 2020 (ICAO, 2020a).

The demand retraction triggered by the aforementioned events cannot be solely explained by economic variables, as security and sanitary restrictions, along with traveler confidence and willingness to travel are important drivers for the fall and rebound of demand for a specific transport mode (Shakibaei et al., 2020; Shamshiripour et al., 2020). Lasting impacts on demand can be expected from disruptive events, as concluded by Blunk et al. (2006), based on analyzes of the impact of the 9/11 terrorist attacks on US air travel. Considering the communicable diseases scenarios, the provision of additional space can be an appealing strategy to recuperate consumer confidence.

On the supply side, companies struggle to rescale operations and keep costs in acceptable levels after a significant demand shrinkage is felt, sometimes leading to modifications in the industry structure, as found by Franke and John (2011), when examining the 2008 financial crisis effects over airlines. Regulators are concerned to preserve fares and public air service throughout the crisis, as the CARE (Coronavirus Aid, Relief, and Economic Security) Act in the US (Hotle and Mumbower, 2020). If a given demand crisis is strong and lasting enough, carriers can go bankrupt and entire markets can disappear, augmenting the supplier's timespan to recover if they are able to. This requires governments and companies' proper coordination towards safeguarding the air transport industry, possibly by means of loans, tax incentives, and other financial (Abate et al., 2020) and operational measures.

Considering specifically the COVID-19 sanitary crisis, the strict observation of sanitary protocols can be argued as a safeguarding measure because it protects the demand and supply. From the demand perspective, Pan et al. (2021) study the impacts of COVID-19 on cruise ship activity, arguing that proper crisis management can reshape traveler attitudes, depending heavily on effective communication and user experience. From the supply perspective, public health authorities must be convinced that operations are safe, thus relieving operational constraints. A well-established measure against respiratory diseases spreading is social distancing (WHO, 2020a; CDC, 2020), which directly impacts the airport capacity and was found to be scarcely addressed in the literature (see Section 2). As can be deduced from Salesi et al. (2022), COVID-19 has shown numerous examples of ineffective measures, calling for research on how to enhance readiness for the mitigation and control of communicable diseases in future scenarios. To fill such a knowledge gap, the present study aims to explore the implications of social distancing on landside capacity from the case of a Brazilian airport, by means of computer simulation. The herein-proposed approach intends to propose and test a systematic rationale to assess passenger processing under a disruptive scenario that requires increased passenger-to-passenger separation.

This study scope involves the security screening queueing area of Santos Dumont Airport (SBRJ), a busy domestic airport in the heart of downtown Rio de Janeiro. In 2019, SBRJ was ranked 5th among the airports with the highest traffic in Brazil, with around 9 million (enplaned + deplaned) passengers transported (HÓRUS, 2020). SBRJ together with Congonhas Airport (SBSP), located in São Paulo city, constituted in 2019 the second busiest route in Latin America, exceeding 5.5 million seats per year (OAG, 2020).

This paper is organized as follows: Section 2 presents background on historical ATV impact events, the new protocols related to COVID-19, and how they impact airport operations. Section 2 also discusses analytical and computational methods potentially useful for assessing the social distancing in the airside. Section 3 establishes the study methodology, which consists of a simulation model focused on the resumption of operations after the COVID-19 outbreak. The chosen period combines recovery of traffic and sanitary protocols. Section 4 presents results and discussions. Final remarks and research opportunities are presented at the end of this paper.

2. BACKGROUND

2.1. Events of impact on the air travel volume

During the past 20 years, before the COVID-19 pandemic, the events that most impacted ATV (Air Travel Volume) were the 9/11 attack, the SARS epidemic, the 2008 financial crisis, and the 2009 global recession that was accompanied by the H1N1 epidemic (Stalnaker and Usman, 2020). Regarding these events, ICAO (2020b) states that recovery tends to have a U or V shapes, as can be seen in Fig.1. The "U" and "V" shapes recovery patterns presume system resilience to withstand a perturbation, as the full recovery was reached at most six months after the disruptive event. An alternative to such pattern is the "L" shape, in which the incumbent level of performance is not resumed or is resumed slowly. The COVID-19 effects were different across markets.

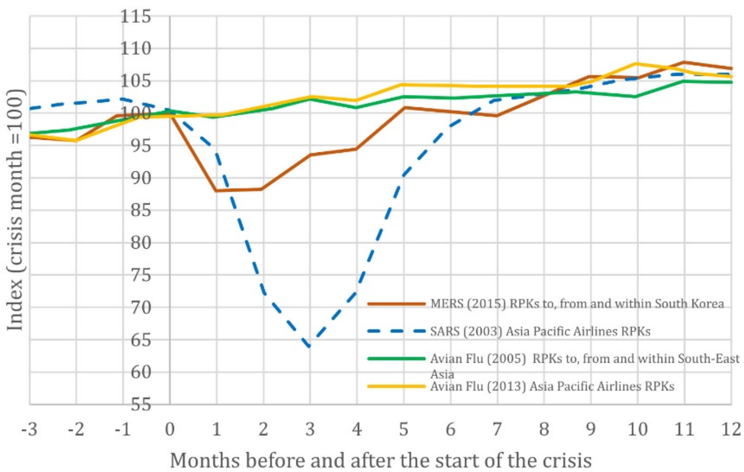

Figure 1. Recovery in Chinese and Korean ATV. Based on ICAO (2020b).

The actual domestic ATV in China resumed "V' format for COVID-19, as seen in Fig. 2 (ICAO, 2020a). In roughly 7 months the pre-pandemic levels were attained and even exceeded.

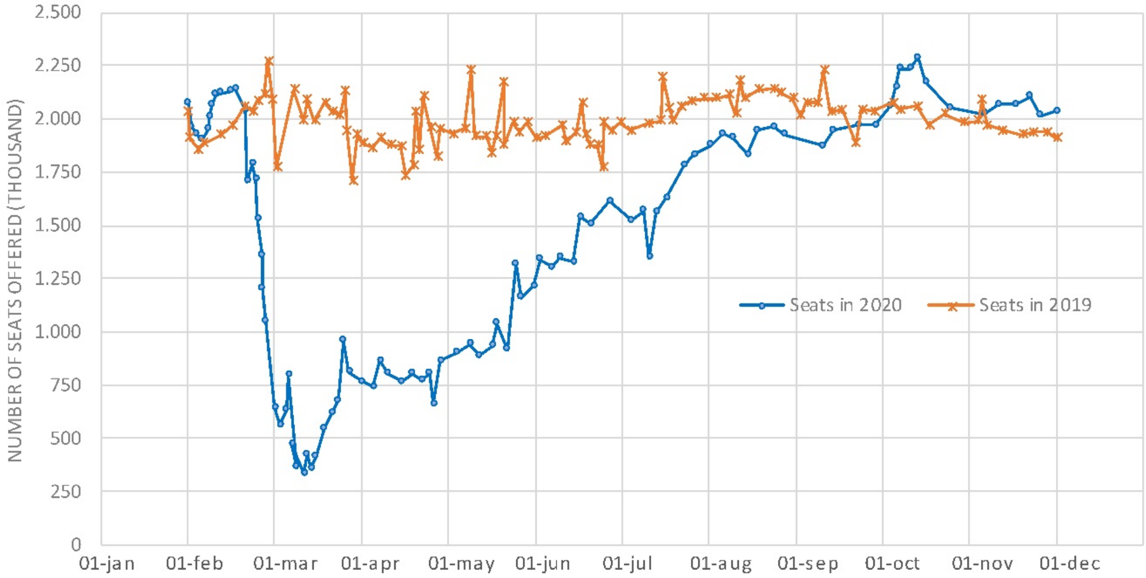

Figure 2. Evolution of Chinese domestic ATV (On terms of Nº of seats) in V-shape. Based on ICAO (2020a).

The above patterns exemplify different recovery scenarios for ATV after perturbations. In the context of social distancing measures, these are possible outcomes:

I. The recovery rate is high and the increased social distancing lasts for a long period.
II. The recovery rate is low and the increased social distancing lasts for a long period.
III. The recovery rate is high and the increased social distancing lasts for a short period.
IV. The recovery rate is low and the increased social distancing lasts for a short period.

Situation (I) is expected to produce higher stress on airport capacity, whereas for (IV) such stress is minimum.

Recovery for SBRJ after the COVID-19 pandemic

The ATV at the SBRJ did not suffer significant impacts in the wake of SARS. According to ANAC (2010), between January and Feb. 2008, there was a 2.5% of ATV decline in SBRJ. ATV was recovered and still increased by 49% at the end of the same quarter (HÓRUS, 2020). During the 2008 crisis, there was a 20% decrease in ATV between January and February at SBRJ, taking 11 months for the recovery to January ATV levels (HÓRUS, 2020). Due to the 2009 global recession, according to ANAC (2010), between January and February, there was a 9% loss in the SBRJ passenger movement. Nonetheless, 2009 ended with an increase of about 45% (ANAC, 2010) of traffic at SBRJ. On the other hand, Guarulhos Airport (SBGR), which is a domestic and international hub serving the São Paulo region, experienced a much lower ATV increase in the course of 2009: ≅ 5,5% ANAC (2010).

Brazil did not suffer a sudden loss in ATV in the abovementioned events, differing from the US, European, and Asian markets. However, in 2020, the drop in ATV presents a rather different scenario. Between January and April, there was a 97% decrease in passenger traffic at SBRJ. The operations in Apr. 2020 came to a standstill and gradually resumed. At the end of Nov. 2020, daily departing flights accounted only for 60% of the pre-pandemic levels.

The understanding of past global events and the forecasts of the academy and financial sectors support that the gradual resumption will happen at some point in the next years. What is not yet clear is the exact time to recover and the level of changes to expect in the structure of the market.

2.2. COVID-19 transmission mechanisms and mitigation measures

COVID-19 pandemic's impact on aviation is unprecedented in terms of severity but is not an unknown threat. Other communicable diseases brought concerns and losses in the recent past: SARS (Severe Acute Respiratory Syndrome) in 2003, Avian Flu in 2005, MERS (Middle East Respiratory Syndrome) in 2015 (ALG-Global, 2020). This is an indication that the knowledge applied to COVID-19 pandemic control and relief may be beneficial also in the future. This section aims to bring a glimpse into COVID-19 transmission mechanisms and mitigation measures at airports.

COVID-19 human disease was first reported in the end of 2019, being caused by the SARS-Cov-2 virus. On March 2020 WHO (World Health Organization) had already declared the pandemic. One factor that boosts COVID-19 spreading relates to the transmission by asymptomatic individuals, as they: *i)* move more freely; *ii)* are mistakenly considered safe for their social counterparts; and *iii)* they are less likely to get tested (Tosta, 2020).

Mitigation measures were deployed since the pandemic outbreak. Haug et al. (2020) ranks 21 of the most effective measures against COVID-19 spreading. The theme 'social distancing' appears under different categories of strategies (e.g., social gathering cancellation) and demonstrates a strong effect. The authors argue that the effectiveness of the measures depends on local context, being crucial in the absence of a proper vaccine and antiviral medication.

2.3. Airport passenger terminal sizing and operational assessment methods

Airports can be conceptually split into airside and landside (Wells and Young, 1996). Landside can be classified into operational and non-operational areas. This study emphasis is set on the operational areas of the Airport Passenger Terminal (APT), comprising areas for queueing, processing, circulating, and waiting. APT sizing and operational assessment are interrelated, as a terminal/component size is acceptable if the demand can be duly accommodated.

Whereas the area required for processing depends on processors (e.g., check-in desks) geometry, queueing area depends on the processing time. The faster the processing, the smaller the area required for queueing, as emphasized by Neufville and Odoni (2013). Keeping fixed the processing rate, such an argument leads to an interesting trade-off on area optimization, as an increase in the space reserved for processors will reduce the space required for queuing. The stochastic nature of the problem prompts the need for solutions such as computer simulation (Brunetta, et al., 1999; Mota, 2015; Kierzkowski and Kisiel, 2017) and queueing theory models (Stolletz, 2011). Simplified equations (IATA, 2019) are available if an ease-to-use approach is preferred, at the price of reduced operational details. Under ACRP 25 (TRB, 2010) approach, queuing theory results are used to build spreadsheet models.

The research of Dabachine et al. (2020) resembles ours in the sense that precautionary measures against COVID-19 are assessed through simulation. The authors propose a Python implementation based on the social force model to study check-in at an airport. Two scenarios are present: *i)* keeping current desks or; *ii)* closing half of the check-in desks, as a strategy to increase the physical separation between lines. Every scenario is assessed for three different social distances: 1 m, 1,50 m, and 2 m. The authors provide evidence that the closure of desks is not a feasible solution in this particular problem, as processing capacity is reduced, and several PAX would miss their flights. Keeping all the desks in operation would require the construction of an acrylic glass barrier, allowing the IATA-compliant processing capacity to be kept. The study focuses on the total number of PAX accumulated and lacks an assessment on the probability of queueing area overflows.

We differ from Dabachine et al. (2020) not only because the change from check-in to SS (Security Screening) but essentially focusing on the Available Area (AA) for queueing and how social distance measures impact the required area. Our concern about the queueing theory approach is that, despite the elegant solutions like the one presented by Stolletz (2011), the performance measures usually found in the literature are too aggregated and hence unsuitable for treating queueing area overflow. We consider that a deeper look at existing models or their extension might be an interesting alternative to simulation for the problem tackled in this research.

3. METHODS OF ANALYSIS

3.1. Case description and inputs

As described in the Background section, social distancing measures directly impact airport terminal subsystems' capacity. The scope of the case herein addressed rests in the queuing area of the Security Screening (SS) at the Brazilian airport of Santos Dumont (SBRJ) in Rio de Janeiro city. This is a fully domestic terminal with a centralized SS, that served 9.1 million passengers in 2019, with operations focused on aircraft models A318, A319, AT72, B737, B738, E190, E195 and five different carriers (HÓRUS, 2020). SBRJ airport has not a strong seasonal demand behavior, despite serving a touristic destination, given an important share of business travelers. According to HÓRUS (2020), in 2019 the passenger satisfaction for the indicator 'waiting time for SS' achieved 4.3 in a satisfaction scale that ranges from 1 to 5.

As depicted in Fig. 3, at the end of November 2020 flight departures at SBRJ accounted for only 60% of pre-pandemic levels. This simulation study focuses on the months after COVID-19 outbreak, combining demand resumption and sanitary protocols. With the gradual resumption of demand and application of social distancing protocols, stresses at SS queueing area are expected. Hence, simulation models were created to understand the impacts of social distancing on the security screening queueing area at SBRJ. First, public domain floor plans were obtained from SBRJ and analyzed from a technical point of view, identifying, and delimiting the area of operation of the security screening. From there, the current screening procedure was thoroughly studied, as well as the spatial layout of the queue and the layout configuration of the x-ray machines.

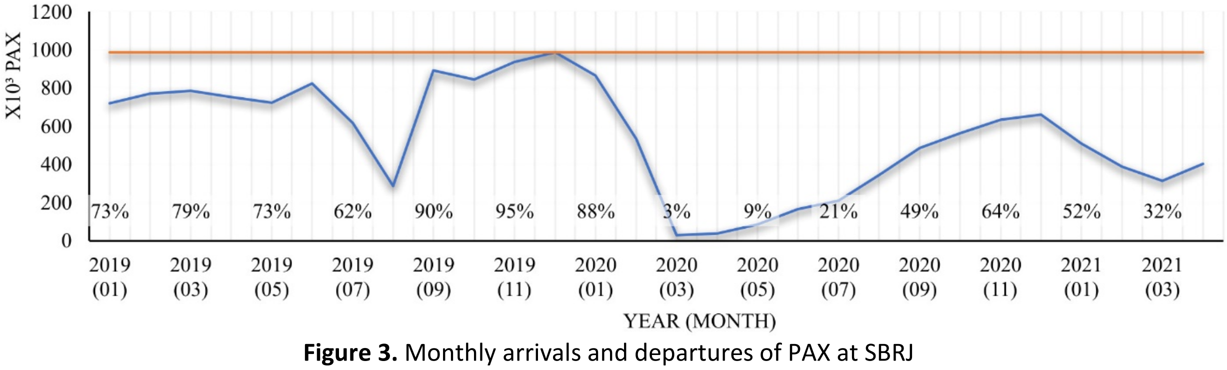

Figure 3. Monthly arrivals and departures of PAX at SBRJ

The "typical day" of operation of the year 2019 was used to build the flight schedule for the simulation, representing the pre-pandemic levels. The "typical day" was obtained from the Brazilian database for actual flights VRA (*Voo Regular Ativo*, in Portuguese), where detailed information on past flights is provided (ANAC, 2020). The flight schedule was validated with information provided by the Brazilian Civil Aviation Agency (HÓRUS, 2020) and can be seen at Fig. 4.

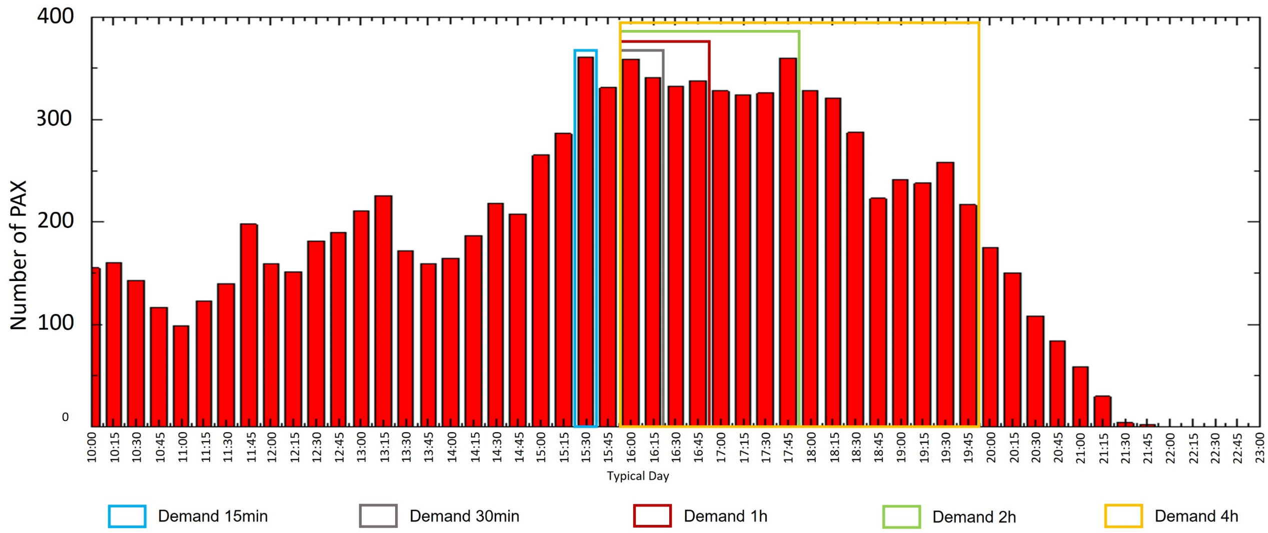

Figure 4. Typical day demand profile (departing pax) according to the flight departure times. Source: Based on ANAC (2020) data

Peak periods can be derived from flight schedule, as indicated in Table 1.

Table 1 – Demand analysis for different time intervals. Based on (ANAC, 2020) data

Time Interval (Δt)	Peak Demand	Peak Period
15 minutes	361	15h30 – 15h45
30 minutes	700	16h00 – 16h30
1 hour	1,371	16h00 – 17h00
2 hours	2,709	16h00 – 18h00
4 hours	4,822	16h00 – 20h00

The presentation profile was obtained from a national survey conducted since 2013 by the Secretariat of Civil Aviation (SAC) of the Brazilian Ministry of Infrastructure and available at (HÓRUS, 2020). Only 2018 data was considered, totalizing 628 observations. Other parameters were necessary for the simulation model, as outlined in Table 2. It is important to note that a certain number of passengers use the facilities at the terminal, such as restrooms and shops. As these procedures influence the arrival at security screening, the time consumed during the use of facilities was inserted in the model (Gwynnea et al., 2019).

According to the declaration of operational capacity, SBRJ has 8 x-ray machines, with an average processing time of 14.4 seconds per screening per machine (ANAC, 2020b).

The geometry of the area of interest is illustrated in Fig. 5 with its approximate dimensions. It is admitted that passengers obey a single row, organized as a snake line. The discipline is FCFS (First Come, First Served) and a small queue is formed just before the security channels with capacity for two passengers.

Table 2 – Simulation parameters and range of values

Parameter	Parameters	Source
PAX arrival distribution	Fig. 4 and data from SAC field survey	(HÓRUS, 2020) and (ANAC, 2020)
Walking time	F{77 m/min}; M{84.4 m/min}	(Young, 1999)
Restroom time of use	Female {145 sec}; Male {101 sec}	(Gwynnea, et al., 2019)
Available X-Ray machines	8 Units	(ANAC, 2020b)
Processing time of X-ray machine	14.4 sec	(ANAC, 2020b)

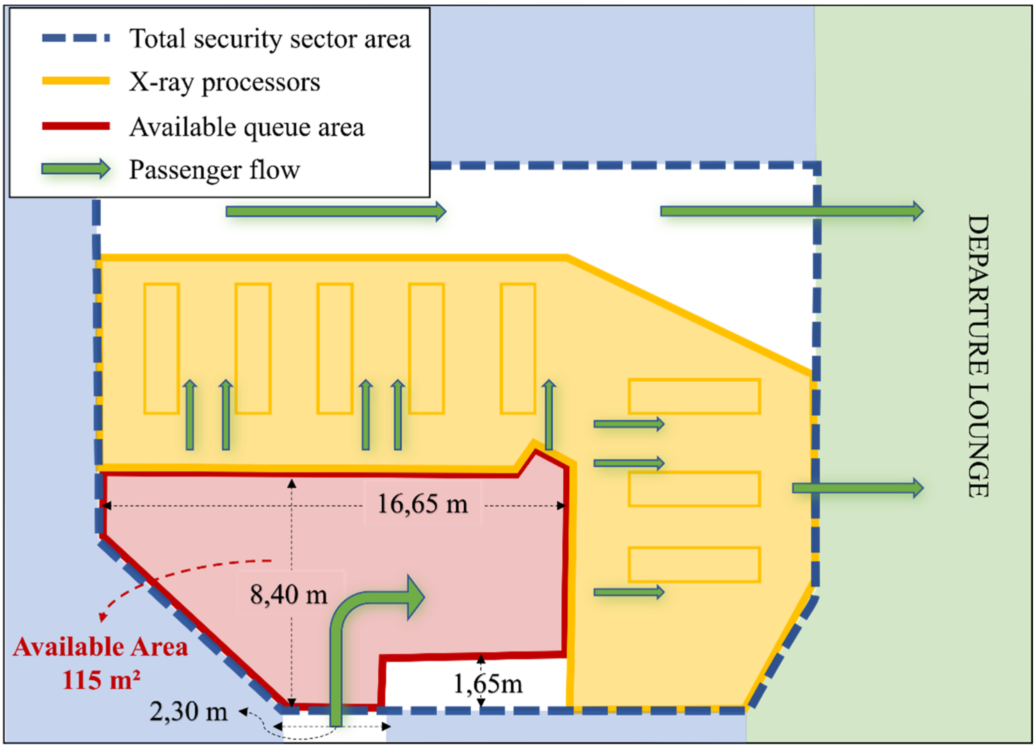

Figure 5. SS layout at SBRJ airport, with approximate dimensions

In the next section, the consistency of input data is checked.

3.2. Verification of input data

Model verification has several definitions in the literature, but the idea of checking for mathematical and logical issues is a common procedure. This section analyzes whether the peak periods shown in Table 1 are consisted with the declared capacity (8 channels) and with the available queueing area. A basic premise of such approach is that the airport operates at capacity in the peak period.

$$\#Units = \frac{Demand_i \cdot PT_i}{\Delta t_i + MQT} \tag{1}$$

$$\#A = \frac{\#Units \cdot MQT}{PT_i} \cdot SP \tag{2}$$

IATA LoS Guidelines for APT Facilities			
Recommendation	Over-Design	Optimum	Sub-Optimum
SS Control time [min]	<5	5-10.0	>10
SS space [m^2]	>1.2	1-1.2	<1
SS Queue width=1.2m			

Figure 6. LoS Guidelines. IATA (2019).

The ADRM 11 (IATA, 2019) is employed for capacity assessment, adopting the optimum LoS as demonstrated in Fig. 6. The ADRM 11 defines the number of processors (Units or channels) required, according to equation (1). The required area for queueing can obtained from equation (2). Different peak demand periods must be analyzed, looking for the most demanding situation, namely: 15 min, 30 min, 60 min, 120 min, and 240 min.

Demand$_i$ represents the peak period demand for each interval (Δt), as demonstrated in Fig. 6 and Table 2. PT indicates the processing time of the processor. *B* y its turn, MQT represents the maximum queuing time and is defined according to the Level of Service (LoS) that is assumed for the system. The LoS is characterized according to Fig. 6.

Situation A: #Units as required, 5min MQT					
PT	0.24	min	MQT	5	min
SP	1	m²			
Δt$_i$	Demand$_i$	#Units*	A**[m²]		
15	361	5	104.2		
30	700	5	104.2		
60	1371	6	125		
120	2709	6	125	*Rounded Up. Eq. (1)	
240	4822	5	104.2	**Eq. (2)	

Situation B: #Units set to 8, 10 min MQT					
PT	0.24	min	MQT	10	min
SP	1	m²			
Δt$_i$	Demand$_i$	#Units*	A**[m²]		
15	361	8	166.7		
30	700	8	166.7		
60	1371	8	166.7		
120	2709	8	166.7	*Set to declared capacity	
240	4822	8	166.7	**Eq. (2)	

Figure 7. Verification of input data for SBRJ SS

The results are shown in Fig. 7 and confirm the internal consistency of the input data, i.e., the queueing area is close to the floor plan area. Two situations are investigated: in situation A the number of channels is based on the minimum MQT, whereas in situation B the number of channels is set to capacity and waiting time (MQT) is set to the superior limit.

3.3. Simulation Model

The herein proposed model was built with one of the software cited by IATA (2019), entitled ArcPORT®, from Transoft Company©. This tool allows a combined modeling of processes through Discrete Event Simulation (DES) and passenger behavior via ABS (Agent-Based Simulation).

Regarding passenger behavior, a simplified approach was taken with default software configurations, unless for passenger free flow speed, based on Young (1999) parameters. Group behavior is not regarded, and agents are passengers belonging to either of two classes (male or female, differing only in walking speed). With this approach and the flow depicted in Fig. 8 it was possible to represent the process of interest.

The Conceptual model can be seen in Fig. 9. The inputs collecting and verification were previously explained. Additional verification was performed by means of visual inspection of graphic outputs of the simulation (see Fig. 11). Sensitivity tests were carried out in order to check model behavior (e.g., if adding one or more processing channels leads to a reduction in the number of passengers in queue). Field validation was not possible due to the pandemic outbreak. The interested reader can refer to Ferreira et al. (2020) for a discussion on simulation paradigms, to Mota and Flores (2020) for a discussion on simulation common pitfalls, and to Vieira et al. (2022) for a broader discussion on V&V (Verification and Validation) in the airport context.

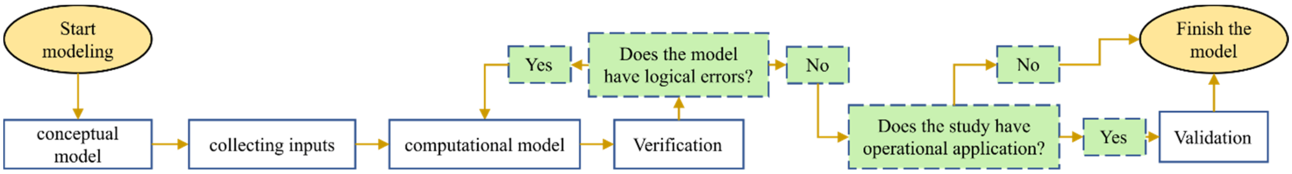

Figure 8. Simulation Approach

Three Abstraction levels (ALs): macroscopic, mesoscopic, and microscopic (see Cavada et al., 2017) are described in Table 3. The model here proposed rests between the levels mesoscopic and microscopic. Only passengers mutual distancing is modelled in a microscopic level.

Table 3 – Abstraction level of the simulations

AL	Assumption	Purposes
Macroscopic	System wide flows, omits most details	Strategic Analysis. E. g., number of passengers simultaneously in a hold room
Mesoscopic	Processes interrelates, intermediate level of detail	Sizing, operational assessment. E. g., calculation of the area required for check-in
Microscopic	Agent interaction, high level of detail	Analysis of operational issues with individual detailing and conflict resolution. E. g., effect of passenger density and free flow speed on the capacity of a corridor

The proposed simulation model considers the typical day flight schedule, and passenger presentation profile and generates a passenger arrival stream throughout the flow depicted in Fig. 9. Check-in facilities are not represented, but some discretionary processes are considered. Once passengers are modeled as agents, walking speeds react to local passenger densities. Security screening is basically a queueing system confined to an area of study.

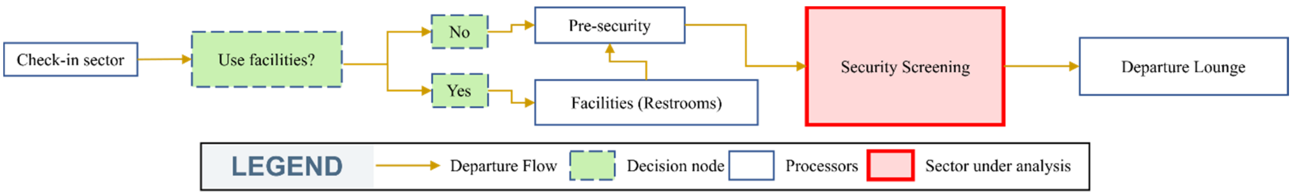

Figure 9. Flowchart representing the path of the entities

This study addresses airport demand resume as COVID-19 pandemic is surpassed towards the restoration of pre-pandemic operational levels. For this reason, the proposed scenarios are based on a percentage of baseline volume of operation (%PHP – the percentage of Peak Hour Passengers as observed before the pandemic). Such variable ranges 30% to 90%. It is important to note the limitation behind this rationale, as the pandemic may affect not only the total number of passengers but also the peak characteristics (Serrano and Kazda, 2020).

The second variable for the scenario's construction regards the number of available channels, which is set to either 6 or 8. While 8 stands for the declared capacity, 6 is the inferior limit for design. This variable is expected to heavily influence queue formation patterns.

The third variable has two levels and accounts for social distancing: before the pandemic (B) and during the pandemic (P). The distancing before the pandemic comes from IATA guidelines (i.e., 1 m^2/pax, with a queue width of 1.2 m^2). The distancing during the course of pandemic is set to 2 m between consecutive passengers. Fig. 11 shows ArcPORT® screens for the queuing area under study. In the frame I social distance was set to the pre-pandemic level (B). In the frame II, social distancing (P) is applied. Table 4 presents the assessed scenarios.

Table 4 – Scenarios and settings

Scenario Name	Nº of X-rays (processors) in operation	%PHP	Social distancing (meters)
8/90/B	8	90%	0.85
8/90/P			2.00
8/70/B	8	70%	0.85
8/70/P			2.00
8/50/B	8	50%	0.85
8/50/P			2.00
8/30/B	8	30%	0.85
8/30/P			2.00

Scenario Name	Nº of X-rays (processors) in operation	%PHP	Social distancing (meters)
6/90/B	6	90%	0.85
6/90/P			2.00
6/70/B	6	70%	0.85
6/70/P			2.00
6/50/B	6	50%	0.85
6/50/P			2.00
6/30/B	6	30%	0.85
6/30/P			2.00

The Fig. 10 exemplifies the scenario codification scheme.

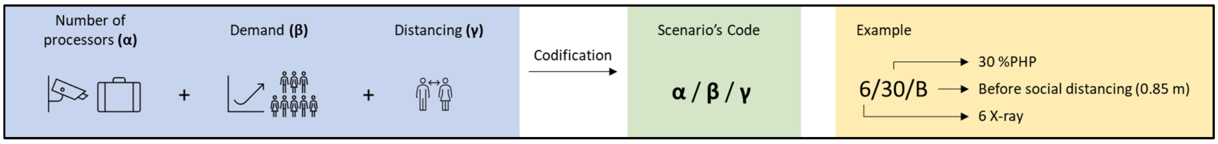

Figure 10. Codification of simulation scenarios

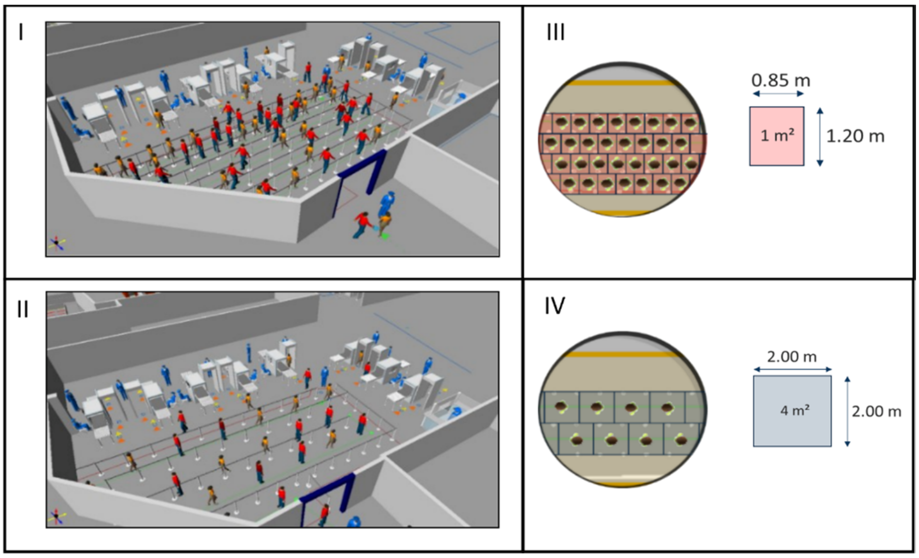

Figure 11. Screens of the simulation model under pre-pandemic and social distancing scenarios

4. ANALYSIS OF RESULTS

Fig. 12 presents the simulation results considering 8 channels (i.e., full capacity) functioning at the security screening. The blue line represents simulation results derived after forcing passenger-passenger distancing to 0.85 m (IATA Optimum LoS) in a 1,2 m wide queue. The green line portrays the results due to a distancing of 2 m between consecutive passengers in a 2 m wide queue. Both queues obey the snake line geometry previously discussed. Horizontal lines mark the density thresholds according to IATA Optimum LoS ($1m^2$, red) and to social distancing ($4\ m^2$, black). The density results presented are the quotient (Q) between the available queueing area and the number of passengers in queue.

All scenarios depicted in Fig. 12 indicate that IATA LoS is guaranteed. For 30% PHP, social distancing can be observed for the whole simulation day, even if social distancing is not forced. This is not, however, an indication that floor markings and similar measures are unnecessary, as individual level separations are possibly lost (remember the nature of the metric Q). In other cases, the imposition of social distance in the simulation is required to avoid an excessive number of passengers inside the queueing area. For 90% PHP the system is close to reaching its limit under the social distancing protocol.

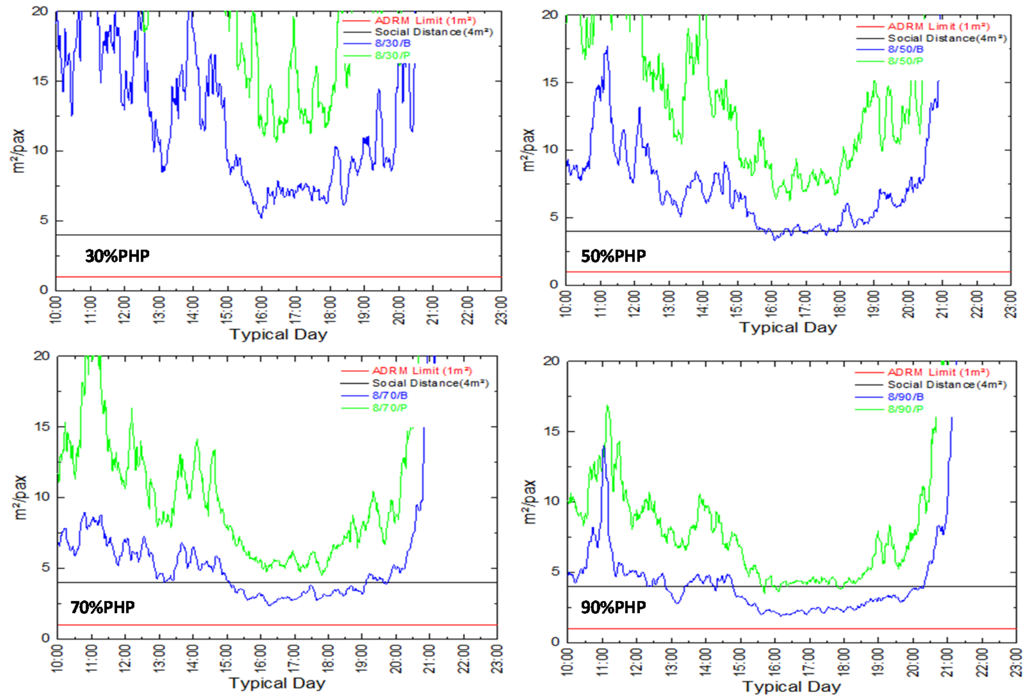

Figure 12. Results for the configuration with 8 service channels

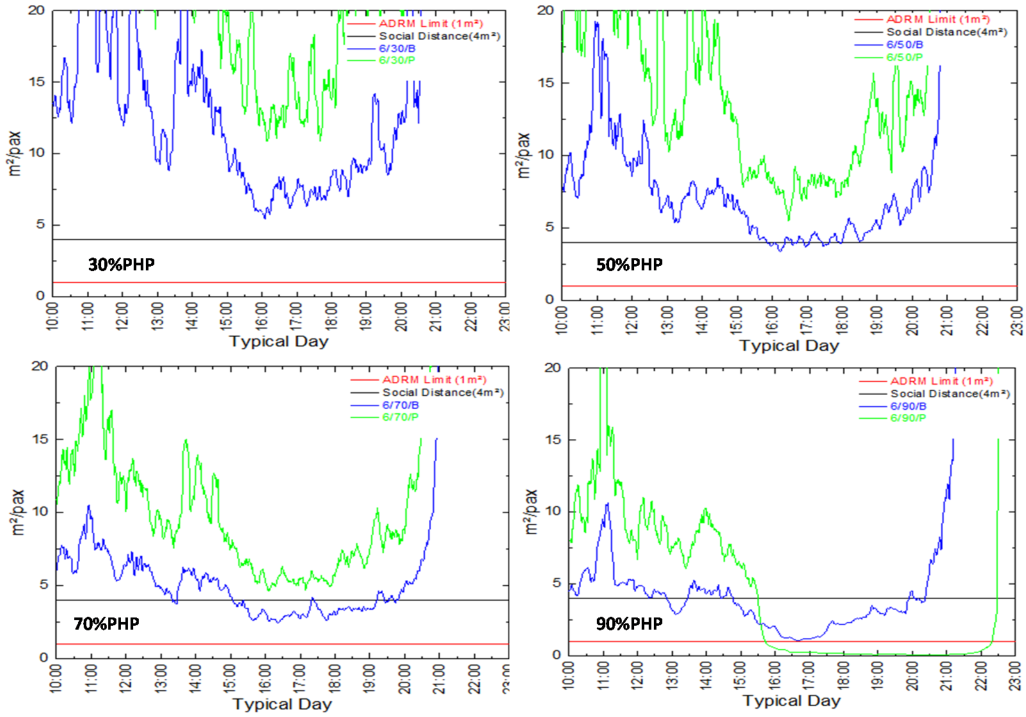

Figure 13. Results for the configuration with 6 service channels

The vertical separation between the blue and the green lines is evidence that the imposition of social distance in the simulation causes passengers to queue just in front of the security gate, before entering the queueing area under study.

Fig. 13 presents the results for a total of 6 security channels under operation. As expected, the curves moved downwards, as fewer channels means more passengers in queue. However, as the system retains almost 70% of capacity, the effect is not as pronounced as that observed by Dabachine et al. (2020), in which capacity was cut to half. It is important to note that the referred study relates to the check-in subsystem and to a different airport.

IATA target LoS is accomplished in all scenarios with some margin, except for 90% PHP, that marks the limit of queueing area capacity (under the 6 channels setting). Social distancing imposition, however, leads the simulation to a collapse for 90% PHP. Such collapse, however, says more about the simulation model than about the real-world problem. Anyhow, 90% PHP is not a feasible operational level, because social separation is lost before the simulation collapses. Consequently, the simulation model may be regarded as suitable for the problem, despite the collapse (under an extreme condition).

The simulation results show that the current layout of the SBRJ airport security screening area is compatible with IATA recommendations (Optimum LoS for spacing). It is important to emphasize that the time in queue was not analyzed and is out of the scope of this study but is an important metric for LoS assessment. Waiting times depend on the number and speed of the processors and not on queueing area.

The social distancing protocols in place as a mitigation measure against COVID-19 require the SBRJ queueing area to be augmented or the peak hour movement to be restricted to something between 70% and 90% of 2019 levels, depending on the availability of processing channels. This capacity limitation is expected and consistent with the discussion presented in Serrano and Kazda (2020).

Design implications

Hopefully, COVID-19 effects on air transport will vanish. But this painful experience can be valuable to improve design procedures and response strategies, considering that communicable diseases can reemerge somewhen. Social distancing might be a transmission mitigation measure, requiring wider waiting areas. For the specific case of the security screening waiting area at SBRJ airport, the IATA equations proved consistent with the simulation results, withstanding a demand ratio of at least 70%. However, the social distancing control came at the cost of keeping passengers outside the queueing area.

Therefore, that area must be designed to contain such overflow in a manner that social distancing can be assured. That means that an outside queue must be organized, otherwise, passengers will lose distancing. Such queue can be either physical or virtual, the latter requiring enhanced management techniques.

5. CONCLUSIONS

This research proposes a simulation model for assessing the impact of social distancing protocols on capacity of the security screening. The model was applied to the Security Screening (SS) of Santos Dumont Airport in Brazil and the results indicate a negative impact on capacity, which is offset by a demand drop. The results show that the airport was able to offer social distancing for several months since the COVID outbreak, as the traffic recovery rate was relatively low.

This study, however, emphasizes that such a combination of demand/capacity ratio is very specific to the case under scrutiny. The social distancing-related capacity shortage will depend on the exact combination of traffic recuperation and the duration of the special passenger-to-passenger distance policy. Our simulations also uncovered system-wide concerns, as some passengers were required to wait in the preceding facility of the processing flow. This can lead to an unintended loss of passenger distancing in the upstream facilities if proper management and architectural measures are not taken.

The proposed simulation model and analysis rationale can be tailored to other airport terminal components or even for the passenger terminals of other transport modes during future similar scenarios.

The key points of our analysis rationale can be summarized as follows: *i)* design for standard passenger-to-passenger separation; *ii)* determine the ratio of demand that the facility can accommodate under social distancing; *iii)* adjust the design for the target ratio; *iv)* assess the system-wide implications of social distancing enforcement; v) adjust the affected facilities or specify proper mitigation procedures. It is expected that authorities and operators introduce such precautions from now on toward a more resilient air transport system.

Observation of sanitary protocols is both a safety and an economic issue, as gaining traveler confidence is an important strategy for overcoming a health crisis such as COVID-19. Policies and protocols can be tested by redesigning the herein-studied simulation scenarios (e.g., flight schedule modification) or the simulation layout (e.g., augmenting the queuing area). Another possibility is the extension of the simulation model for the assessment of smart solutions such as virtual queues or faster passenger scanning methods.

Considering the limitations of the proposed model, some possibilities of enhancement can be listed: the metric used for queuing area density could be replaced by the passenger-passenger minimum distance; groups could be modeled, as family members walk in a bubble pattern, keeping separation only from other families; peak characteristics due to the impacts of COVID-19 on the air transport network could be explored and integrated into the simulation model.

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