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COVID-19-RELATED CHALLENGES FOR NEW NORMALITY IN AIRPORT TERMINAL OPERATIONS

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ABSTRACT

Airport operations are undergoing significant change, having to meet pandemic requirements in addition to intrinsic security requirements. Although air traffic has declined massively, airports are still the critical hubs of the air transport network. The new restrictions due to the COVID-19 pandemic pose new challenges for airport operators in redesigning airport terminals and managing passenger flows. To evaluate the impact of COVID-19 restrictions, we implement a reference airport environment. In this reference *Airport in the Lab* environment we will demonstrate the operational consequences derived from the new operational requirements. In addition, countermeasures to mitigate any negative impacts of these changes are tested. The results highlight emerging issues that the airport will most likely face and possible solutions. Finally, we could apply the findings and lessons learned from our testing at our reference airport to a real airport.

1 INTRODUCTION

Airports play a critical role in connecting people and transporting goods between different cities and countries. They are responsible for the smooth flow of aircraft, and therefore passengers and freight, within the airport network. Especially in large hubs, one issue is present by the use of the limited facilities to cope with the demand. From a passenger point of view, airports represent the inter-modal nodes of the door-to-door (D2D) journey. Disruptions at airports affect the whole door-to-door journey, and also the operations of the connected means of transportation (train, bus, taxi, etc.). In this context, initiatives for managing the entire D2D passenger journey have been launched as the EU-funded IMHOTEP Consortium (2020) and XTEAM D2D Consortium (2020). The role of the airport not only impacts the air traffic network itself, but also the inter-modal network. Therefore, it is relevant to examine airport operations and their integration with other modes of transportation. The main function of an airport terminal is to handle passengers before departure and/or after the departure of a flight. Several studies have focused

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on airport terminals, but mostly on specific operations, such as check-in allocation (Mota 2015), security process (Kierzkowski and Kisiel 2016), or boarding process (Schultz 2018; Schultz and Reitmann 2018). In this study, we want to evaluate the airport terminal departure operations by implementing an integrated approach, where all the terminal operations are considered. In this way, we can evaluate also the impact of interactions between operations on the overall airport terminal performance.

The COVID-19 pandemic is having a huge impact on the aviation industry (ICAO 2021), as the air traffic has seen a decrease by 65%, with the only exception of the cargo traffic which has seen an increase in traffic by 10% (EUROCONTROL 2021). The aviation sector has reported 11.9 billion losses in 2021, with 4.8 million direct jobs lost (IATA 2020b). EUROCONTROL (2020) forecasts show that in the most optimistic scenarios, where vaccines will be deployed in most of the European countries for the summer of 2021, recovery to 2019 levels (pre COVID-19) will be within 3 years, in 2024. The COVID-19 pandemic has forced authorities to implement various methods for protecting people and make sure to stop the spreading of the virus. Two examples are the enforcement of social distancing rules and the use of face masks. The airport processes are affected by the previously mentioned measures as well. For instance, social distancing rules for cabin crew members and air passengers applied both in the US (FAA 2020) and in Europe (EASA 2020), advising 2m (6 feet) and 1.5m, respectively. Moreover, airport operators had to adapt to the new situation by re-designing the terminal layout and re-thinking the use of the terminal space. Areas that previously were used for passengers' comfort (e.g. waiting areas in departure halls, waiting areas in the proximity of the gates) are now used for conducting COVID-19 tests, for controlling required passenger documents, or for measuring passengers' temperature. These new requirements have impacted airport terminals from an operational point of view, as passengers now follow different (forced) paths within the terminal and new boarding procedures have been implemented. In the report provided by EASA (2020) operational guidelines are provided to air passengers for arrival, departure, and transfer operations. In the USA specific instructions were given for the security checkpoints operations (TSA 2021).

1.1 Literature review

The performance of an airport is determined by efficient land- and airside operations. For example, limited runway or apron capacity affects operations, as do restrictions on security or passport control. The aircraft turnaround is the link between aircraft and passenger trajectories. Deviations (disruptions) on either side can lead to delays, and these can lead to further, cascading effects on the air transportation network. Therefore, airlines should consider coupled optimization of the airport (ground) and flight operations in their flight planning (Rosenow and Schultz 2018). In the work of Zografos et al. (2013), a tool for total airport operations management was developed. They considered airside (runways, aprons) and landside (check-in, security, gate lounge) elements and provided a decision support system for strategic, tactical, and operational scenarios. The tool was validated through case studies proving to be a good approximation of reality and a good tool for planning purposes. Scala et al. (2020), Scala et al. (2021) focused on the integration of airspace ad ground airport operations where they optimized the aircraft landing sequence as well as the capacity of the ground (runway, taxiway, and terminals).

Simulation techniques have been used extensively in the last decades for modeling passenger handling in the airport terminal. From observed behaviors, passenger models were derived and validated, and used to analyze the inherent variability of handling operations. In-depth evaluation of different operational scenarios analysis allows deriving appropriate strategies for passenger guidance, (dynamic) reaction on peak demands, or efficient information flow for the digital passenger. The most used simulation approaches have been agent-based (ABS) and discrete event (DES). The former fits best to instances where the individual behavior of passengers within the terminal is focused, as in this approach, the agents (passengers) of the simulation model can make their own decisions and interact with other agents. DES best fits cases that concentrate on the performance evaluation of specific terminal facilities. Here, passengers follow a predefined path and interact with facilities rather than with other passengers. Some authors focused on individual airport terminal operations, while other authors considered a more integrated approach by simulating the entire passengers' flow within the terminal. Among the former category, we can find Mota (2015), who focused on improving the check-in desks allocation by combining DES with a genetic algorithm. Discrete event simulation was used by Rauch and Kljajic (206) and Alodhaibi et al. (2017), focusing on passenger departure flow and airport terminal capacity assessment.

The combination of simulation and optimization techniques has been often applied to such issues, as their characteristics complement each other. On the one hand, optimization allows to come up with an optimal solution in a relatively fast time; on the other hand, simulation can evaluate aspects such as the variability of the systems and agent interactions. Ma et al. (2011) focused also on check-in operations, as they developed an agent-based simulation model for evaluating the behavior of passengers in the departure hall. Both Kierzkowski and Kisiel (2016) and Mota et al. (2019) evaluated the security checkpoint performance to improve their efficiency and ensure an acceptable passenger's service quality. Recently, Sanz et al. (2021) proposed a machine learning approach for capturing queuing behavioral patterns by using simulation for generating data about passengers' queuing at check-in and security checkpoint. By both Manataki and Zografos (2010) and Schultz and Fricke (2011), agent-based simulation models are developed for high-level and tactical decisions to influence and improve the flow of passengers within airport terminals. Similar studies cope with the stochastic behavior of passenger movements within airport terminals (Schultz 2013), and on providing efficient guidance to passengers and enable individual navigation in the complex terminal (Schultz et al. 2007). An agent-based simulation was used also in the work of Janssen et al. (2019), where airport terminal operations were modeled under an operational, tactical, and strategical point of view.

The COVID-19 pandemic regulations require adapted handling procedures, which imply new operational challenges. In the article of Choi (2021), the impact of COVID-19 on the operations within airport terminals has been evaluated from an economical point of view. The authors highlighted that the increase of passenger dwelling time can increase existing purchaser's spending rather than create new buyers. They pointed out the need for a change in sales strategy. Schultz and Fuchte (2020) developed a model for evaluating the transmission risk in the aircraft cabin, which was applied to optimize passenger group (e.g., families, couples) boarding (Schultz and Soolaki 2021). The results showed a reduction of boarding time by about 60% and less transmission risk (reduced by 85%) compared to the COVID-19 standard boarding, thus, contributing to near-to-normal operation progress. In the work of Kierzkowski and Kisiel (2020) the security control operations were modeled to evaluate the impact of social distancing.

1.2 Focus and structure of document

In this paper, we evaluate the impact of the constraints and requirements imposed on airport terminal operations due to COVID-19. To do this, we develop reference airport terminal layouts that we use as a testbed to test different potential scenarios and mitigation strategies. In this way, we can highlight the potential issues and challenges faced by airport operators. This work first follows a generic approach to then apply the obtained results and solution strategies to specific airport terminals. Through a dynamic agent-based passenger model, we can evaluate the inherent variability of the airport terminal system and evaluate the interactions between different agents (passengers) and the operational processes. The paper is structured as follows. After the introduction, we explain the airport terminal operations in detail and emphasize also how the new processes given by the COVID-19 regulations are implemented. In section 3, we describe the main characteristics of the simulation model for the generic airport terminal. In section 4, we test different scenarios and discuss the results. Finally, the conclusions section highlights the insights obtained by the main findings and possible further developments.

2 AIRPORT TERMINAL OPERATIONS

The airport terminal is the area that facilitates passengers in their journey. The processes to be undergone within an airport terminal differs depending on the type of passengers, i.e. arriving, departing, and transferring. Figure 1 depicts the passenger flows considering departure, arrival, and transfer processes.

Departing passengers will be forced to pass through the scan of boarding passes and security checkpoints before going to the assigned gate. Even before that, passengers have the option to stop by at check-in counters (manned/self-service) for checking in their flights and dropping off their luggage. The previous process is optional as nowadays airlines allow passengers to do the check-in online. Arriving passengers follow almost an inverse path compared to departing passengers, as their scope is to leave the airport terminal. These types of passengers are forced to follow a path that leads them from their assigned arrival gate, until the airport exit, through the baggage claim and the arrival hall. Transfer passengers need to move from their assigned arrival gate to the newly assigned departure gate. Depending on the flight origin/destination, passengers must undergo the process of passport control, and this applies to all the three previously mentioned types of passengers. Moreover, since non-aeronautical revenues have become a critical source of revenue for airports, shopping and catering areas are usually located before and after security so that passengers have the chance to spend their idle time there.

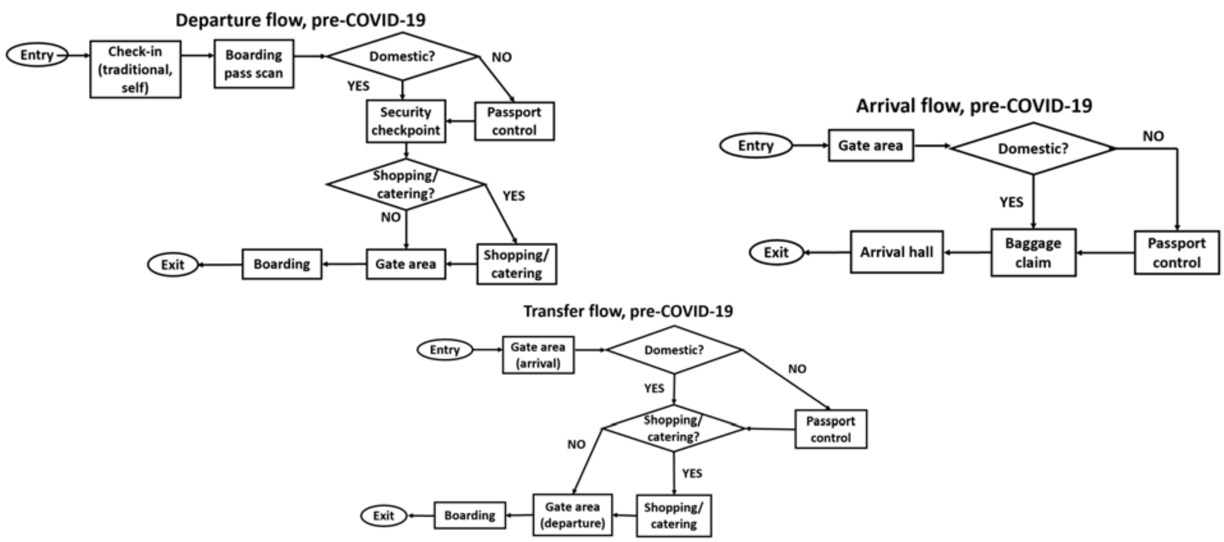

Figure 1: Passengers flows in pre COVID-19 scenarios: departure (left), arrival (right), transfer (below).

The COVID-19 pandemic has twisted all these predefined processes, as now airport operators require passengers to follow new safe measures (EASA 2020; TSA 2021). These measures have added extra processes to be undergone by passengers, they are highlighted in red in the diagrams of Figure 2. For instance, in the context of physical distance, the IATA (2020a) demands a distance of at least 1 meter and the FAA (2020) a minimum of 6 feet (2 meters). Additional processes such as temperature check, COVID-19 test certificate check, health self-declaration check have become standard procedures at most airport terminals. These processes are fitted into the existing airport terminal operations in different moments of the passenger trajectory (arrivals, departures, transfers). Moreover, some airports are equipped with facilities for conducting quick COVID-19 tests, to let passengers travel to countries where a negative test is required within few hours before the time of departure. These additional processes have affected the management of the passenger flow within the terminal, as now the existing spaces need to accommodate these additional processes. For example, the need for departing passengers undergoing various additional processes in the check-in area (e.g. temperature check, boarding pass control, quick COVID-19 test, health self-declaration checkpoint), has directly affected the subsequently following processes of the security control. Here, the check-in area does not act as a retention area anymore, and the passengers arrive at the security control without getting buffered. In particular, when peaks of departing passengers occur, it results in long queues and waiting times. For the efficient utilization of the terminal area, the (dynamic) space requirement is shifted to security control.

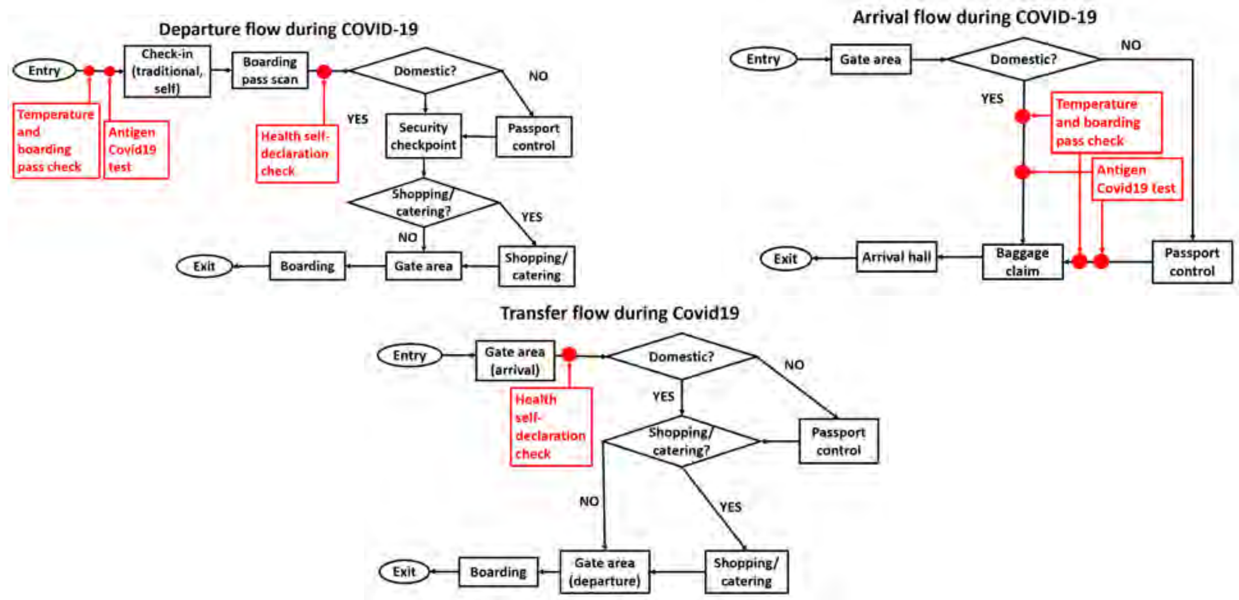

Figure 2: Passengers flows in COVID-19 scenarios: departure (left), arrival (right), transfer (below).

3 IMPLEMENTATION AND APPLICATION

The *Airport in the Lab* concept to create a reference terminal environment that would be used as a test-bed for the evaluation of the airport performance under different scenarios. The main advantage of developing such a standard model is that it can be easily shared between researchers and operators and that it is general enough to reproduce the results obtained. This includes the terminal layout as well as all the operations which are carried out at an airport, for the different passengers' flows (arrivals, departures, transfers). We modeled a linear airport terminal layout with specific characteristics to test various concepts, policies, and technologies at an aggregate level before applying them to a real-scaled airport layout. The main characteristics of our standard approach for the *Airport in the Lab* are described in the following by the airport terminal layout, the main terminal areas, and facilities considered (Figure 3).

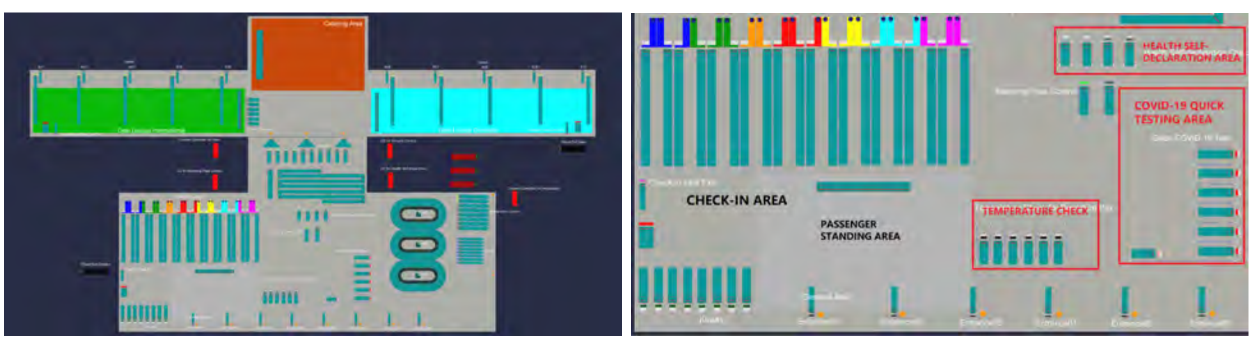

Figure 3: *Airport in the Lab* - Terminal (left) and departure hall (right) implemented in CAST.

The terminal has a centralized layout, where both departure and arrival operations are deployed in one building, gates are placed one after the other on one side of the terminal building. The terminal entrances are located on the other side of the building. The terminal areas and facilities are placed between the entrances and gates (Figure 3, left). Some of the terminal areas considered are related to departure passengers only, some for arrivals passengers, and others for both. The main terminal area shares both departures and arrivals areas like the passengers' standing/flowing area (arrival and departures). While, check-in area (manual and self), security area, passport control area, domestic lounge area, international lounge area, and a catering area are reserved for departure passengers. Arrival-only passenger areas are the immigration control area and the baggage claim area. We embedded in our *Airport in the Lab* specific areas for passenger safety such as temperature check and health self-declaration before security control, and quick COVID-19 test in the departure hall (see Figure 3, right).

Table 1 lists the terminal facilities and their (distributed) transaction times. The process with the longest transaction time is the quick COVID-19 test counters, as for this process, the passengers need to wait around 15 minutes for the test results. However, this process is not mandatory, as we assumed that only 10% of the passengers need to do it. The processing times follow a Normal Distribution (mean μ, standard deviation σ). Regarding the manual check-in counters, we assumed different airlines operating, with different processing times. Regarding Manual immigration counter processing time, we distinguished between EU and non-EU passengers, assuming that the latter will take more time. The processing times for the terminal facilities were chosen based on field experiences.

Table 1: Service characteristics of terminal facilities: Normal Distribution (μ, σ) and constant durations.

Facility	Amount	Transaction time for each passenger [s]
Temperature check counters	6	Normal(10, 2)
Quick COVID-19 test reception	1	Normal(120, 30)
Quick COVID-19 test stand	6	Normal(900, 120)
Manual check-in counters	20	Online: 100, Manned: 150
Self check-in kiosks	8	Normal(30, 6)
Boarding pass scan gates	2	Normal(5, 1)
Health self-declaration desks	4	Normal(10, 5)
Security checkpoint	10	Normal(140, 28)
Passport control	6	Normal(40, 4)
Boarding gates	10	Normal(3, 1)
Manual immigration counters	8	EU: 20, non-EU: 40
E-gate immigration counters	8	10

We modeled only the departure process, as it is the most relevant for evaluating the impact of COVID-19 restrictions (see Figure 3 (right)). Passengers must have a negative COVID-19 certificate to enter the terminal. Therefore, passengers' companions are not considered in our model. The passengers follow the departure as already shown in Figure 2. Due to COVID-19 measures, the check-in kiosks are assumed inactive, however, they are still in the terminal as these operations could resume once the restrictions will be relieved. We set the passenger distance in a queue before the facilities to $1.5m$ to $2m^2$ as the minimum comfortable area for each passenger. We apply a nominal half-day flight schedule with three peaks. We implemented several scenarios which resemble the COVID-19 measures applied in different airports worldwide. Moreover, the general guidelines provided by institutional bodies such ICAO (2021), EASA (2020), FAA (2020), IATA (2021) are considered.

Table 2 contains implemented measures and scenarios. We define S1 as the reference case for standard handling processes. In this scenario, we implement the COVID-19 restriction widely in place at airports such as distancing and extra processes like self-declaration checkpoint. We then develop two further scenarios where extra restrictions take place. In S2, a temperature checkpoint is added, while in S3 a dedicated area for a quick COVID-19 test was considered. After these three scenarios were settled, we also developed two policies that attempted to mitigate the facilities congestion under COVID-19 pressure, which are: **policy A** - early arrival of passengers at the terminal (1 hour early), and **policy B** - same conditions as policy A, but the check-in counters will open 1 hour earlier than planned.

Table 2: COVID-19 measures considered in the simulation model and scenarios to be evaluated.

Measure	Abbreviation	Scenarios 1	2	3
Distancing of 1.5 meter for any queuing and dwelling area	M1	x	x	x
Frequent cleanings of security check trays	M2	x	x	x
Negative COVID-19 test to show at the check-in desk	M3	x	x	x
Temperature check in terminal departure hall	M4		x	x
Boarding pass check in the terminal departure hall	M5	x	x	x
Check point for filling in and showing the health self-declaration	M6	x	x	x
Dedicated area for quick COVID-19 test	M7			x

4 ANALYSIS AND RESULTS

We focus on the most affected areas (check-in area, security checkpoint, dwelling areas) and missed flights.

4.1 Check-in area

Figure 4 depicts the overall number of passengers waiting at the check-in area overall counters. The colored area includes the results of all simulation runs and is limited by the respective minimum and maximum values for each investigated timestamp. From an infection-prevention point of view, a low number of simultaneous waiting passengers is favored. A high number of waiting passengers would lead to a high area utilization especially with the application of social distancing. The queue length is characterized by two high peaks in the first half of the morning and several smaller peaks in later hours.

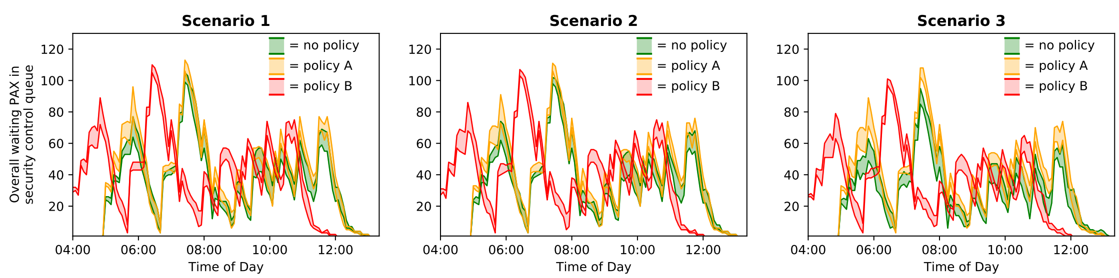

Figure 4: Number of waiting passengers in check-in queue during the day.

Since the number of passengers and the processing times did not differ, the curves do not change significantly amongst different scenarios. However, the application of different policies influences the number of waiting passengers. Using policy A leads to an increased queue length compared to the use of no policy. This occurs due to the early arrival of passengers at the airport. As the opening hours of the check-in counters do not change, there will be a larger number of passengers waiting in front of the check-in area. When the counters open, the initial queue is correspondingly higher. policy B mitigates this effect due to the earlier opening of the check-in counters. This leads also to a time-shift of the curves by the one-hour forwards. The processing times for check-in procedures remain in all scenarios the same. Longer waiting times can therefore be directly attributed to longer queue lengths at the counters. Figure 5 exhibits characteristic values describing the waiting time at check-in counters considering all airlines. Policy A and B lead for all scenarios to higher waiting times for all four characteristic parameters compared to the use of no policy. The average and median waiting times are below 10 minutes in all cases. The IATA Airport Development Reference Manual recommends optimum waiting times between 10 and 20 minutes for economy passengers (IATA 2019). The service level at the check-in counters fulfills this condition in almost 95% of check-in procedures in all conditions. The worst case shows waiting times up to 30 minutes.

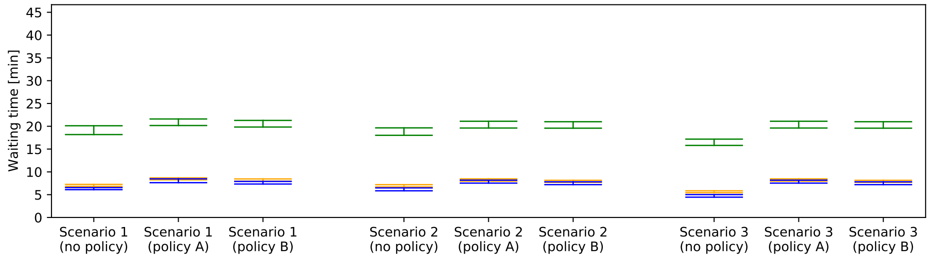

Figure 5: Simulation results for the waiting time at the check-in counters (95%-quantile (green), average (orange), and median (blue).

Figure 6 displays the median (blue) and the 95%-quantile (green) of the waiting times in scenario 1 divided by airlines. The service quality differs considerably between the carriers. Worse service quality can be observed for check-in procedures from airlines 2, 5, and 7. On the other hand airline, 3 and 6 are characterized by comparatively low time parameters. The usage of policy 1 leads to increased waiting times for the 95%-quantile at all check-in counters. Except for airline 6, the median also increases in all cases. Applying policy 2 can slightly absorb the negative effect, but the values for the case with no policy used are not achievable.

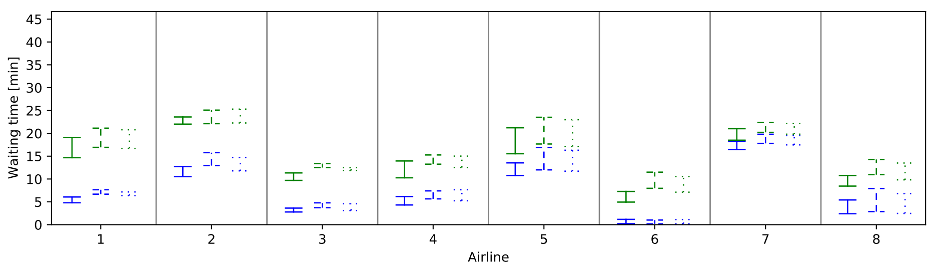

Figure 6: Median (blue) and 95%-quantile (green) of waiting time at check-in queue for all airlines under different policies (solid line = no policy; dashed line = policy A; dotted = policy B) in scenario 1.

4.2 Security checkpoint

Security controls are always inevitable in every airport for departures, which is the most important check to guarantee the safety of not only the air transportation system but also the passengers themselves. Figure 7 shows the simulation results for security control waiting time values in all scenarios. The average and median values for both scenarios 1 and 2 are similarly around 20 minutes, and the 95%-quantile can reach up to 45 minutes depending on the scenario and the implemented policy. For airport planning the IATA emphasizes a maximum waiting time of 5 to 10 minutes at the security check (IATA 2019). As this threshold is significantly exceeded, the service level of the security control in the airport model is classified as sub-optimal. The almost unchanged values distribution for both scenarios 1 and 2, as well as, they under the additional policies indicates that the temperature checking in the terminal departure hall (M4) does not affect the security process, and the security waiting time only relates to the number of passengers waiting. The values in scenario 3 are slightly smaller compared to scenario 1 or 2. It reflects that due to some passengers requiring a long time on the COVID-19 quick test, a buffer is generated there so that fewer passengers congest at the security control. The waiting time values increase slightly if policy A or B is added to scenario 3. When the passengers arriving 1 hour earlier, under this situation more passengers would appear at the security in the meantime.

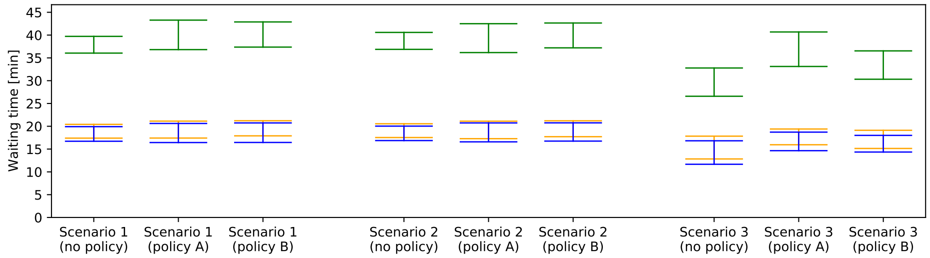

Figure 7: Waiting times at the security control 95%-quantile (green), average (orange), and median (blue).

In brief, COVID-19 restrictions result in a longer process time than usual because of the regular trays cleaning and stricter security checking. Therefore, the current number of security counters in the *Airport in the Lab* are under-designed, which can not cope with the congestion at security under COVID-19. This is a universal phenomenon in many real airports, where their available security counters have been already under tremendous pressure.

The number of passengers waiting at the security control varies with the rate of the passengers arriving at the terminal (see Figure 8). According to policy B, check-in counters open 1 hour earlier, the security process is shifted 1 hour ahead correspondingly. In the highest peak in scenario 1 or 2, a maximum of 200 passengers wait in front of the security area, where the capacity of the queue length and available space is almost reached, taking into account the 1.5 m spacing requirement. In scenario 3, we observe fewer waiting passengers because of the buffering effect from the COVID-19 quick tests. But there are still 180 passengers at the highest peak time of scenario 3 (policy A).

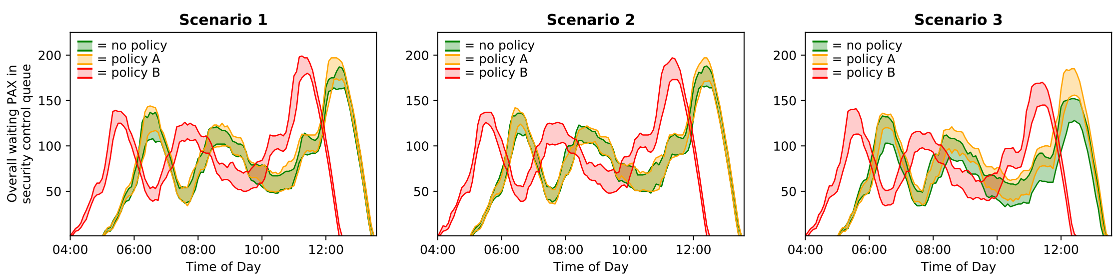

Figure 8: Number of waiting passengers in security control queue during the day.

4.3 Dwelling areas

Passengers are waiting until their responsible check-in counter opens. The airside dwelling area includes a catering court as well as the domestic and international gate lounge for passengers, which are waiting for boarding. Figure 9 (next page) exhibits the number of waiting passengers and the corresponding waiting time for both areas in scenario 3 (no policy) and scenario 3 (policy B). If policy B is implemented, no significant changes in the number of passengers waiting and waiting time can be observed for the landside area. However, this is not the case for the airside. policy B results in a doubled number of dwelling passengers after 5 a.m. compared to the usage of no policy. Additionally, the time spent in the areas is also significantly increased compared to the application of no policy. When using policy B, terminal processes start earlier, resulting in earlier access to the gate area and thus higher space utilization in this area.

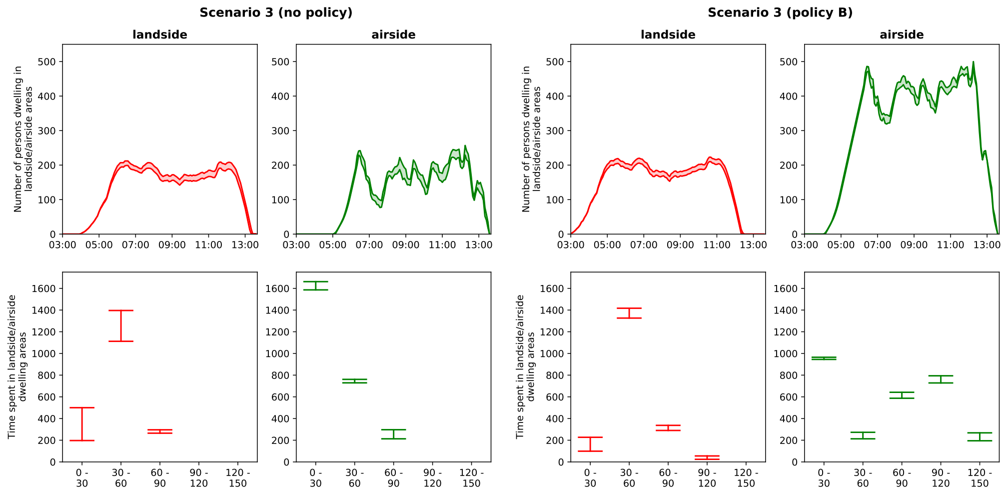

Figure 9: Number of passengers dwelling in land-/airside areas (top) and duration of stays (bottom).

4.4 Missed flights

A negative effect of the new mandatory processes (COVID-19 measures) is missing the flight in our scenarios (i.e. passengers will arrive too late to be served in time). The model considers two points of missing a flight: (a) the passenger arrives too late at the check-in desk and (b) the passenger is too late at the gate. The first case can occur due to late arrival at the airport or because of long waiting times at pre-check-in procedures (temperature check and COVID-19 quick test) or the check-in counter. The second case is a result of long waiting times at the security control. Figure 6 shows the number of missed flights.

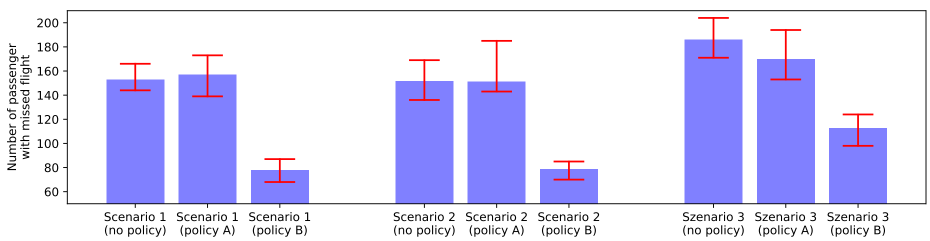

Figure 10: Median (blue bar) and minima/maxima (red range) missed flights.

In scenarios 1 and 2 for the use of no policy, about 150 passengers are not reaching the flight. For scenario 3 the value is increased to 180 passengers, due to the additional processing time for COVID-19 quick test. If only the passengers arriving earlier and the check-in opening times remain the same (policy A) no significant influence can be observed for scenarios 1 or 2. However, in scenario 3 the number of passengers with missed flights is reduced. The earlier access at the airport can absorb the additional time needed for COVID-19 quick test before the check-in. If The check-in opening times are also adjusted (policy B), the number of passengers, who miss their flights, can be reduced by up to 50%.

5 CONCLUSION AND OUTLOOK

In this work, we have evaluated the impact of COVID-19 measures on airport terminal departure operations by developing a dynamic passenger flow simulation model. The findings reveal that the performance is negatively impacted especially the check-in area in terms of the number of passengers in the queue. This leads to significant congestion in the security checkpoint area, making it the bottleneck of the airport system. The two policies implemented did not result effectively in mitigating the congestion in both check-in and security areas. In particular, policy B was shifting the congestion earlier in time compared to policy A, as in this policy check-in desks were opened sometime in advance. policy B was effective in reducing the number of passengers who would miss their flights due to congestion, on the other hand, it generated congestion in the airside dwelling areas (gate lounges, catering area), which is not ideal under the pandemic point of view. The opposite phenomena are seen when no policy is active or when policy A is implemented. This leads to a trade-off, between the benefit of reducing the number of missed flights and the disadvantage of an increasing number of passengers at the airside area of the terminals. The implementation of policy B requires the coordination of airport operators and airlines for managing resources like check-in desks amount and opening times. Our reference implementation provided in this work could be beneficial to airport operators as they can evaluate which areas might be the most congested. Moreover, operators can choose an appropriate tested policy, which should be applied for avoiding this congestion. Our approach has the advantage of predicting and identifying potential bottlenecks in the system, and easily evaluate different scenarios which would be difficult to achieve in real operations. In real operations, there are often complex interactions and dependencies that are difficult to model or resolve and in particular prevent the identification of appropriate candidates for operational improvements. However, the model requires reliable input data, in terms of processing times, to obtain reliable results. Therefore, the authors will focus on the calibration and validation of the model in the next steps. In further developments, we will transfer the insights and lessons learned from the *Airport in the Lab* to a real case study. Also, additional mitigation policies can be implemented based on the use of technology and new management paradigms.

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REFERENCES

Alodhaibi, S., R. L. Burdett, and P. K. Yarlagadda. 2017. "Framework for airport outbound passenger flow modelling". *Procedia Engineering* 174:1100–1109.

Choi, J. H. 2021. "Changes in airport operating procedures and implications for airport strategies post-COVID-19". *Journal of Air Transport Management* 94:102065.

EASA 2020. *COVID-19 Aviation Health Safety Protocol : Operational Guidelines for the management of air passengers and aviation personnel in relation to the COVID-19 pandemic*.

EUROCONTROL 2020. "EUROCONTROL, Five-Year Forecast 2020-2024".

EUROCONTROL 2021. "EUROCONTROL, Comprehensive Assessment of COVID-19's Impact on European Air Traffic".

FAA 2020. "COVID-19: Updated Interim Occupational Health and Safety Guidance for Air Carriers and Crews".

IATA 2019. "Airport Development Reference Manual, 11th Edition".

IATA 2020a. "Guidance for Cabin Operations During and Post Pandemic, edt. 4".

IATA 2020b. "European Air Transport COVID-19 Impacts and recovery to be Worse than other regions".

IATA 2021. "COVID-19 Travel Regulations Map".

ICAO 2021. *Effects of Novel Coronavirus (COVID-19) on Civil Aviation: Economic Impact Analysis*.

IMHOTEP Consortium 2020. "IMHOTEP - Integrated Multimodal Airport Operations for Efficient Flow Management".

Janssen, S., A. Sharpanskykh, R. Curran, and K. Langendoen. 2019. "AATOM: an agent-based airport terminal operations model simulator". *SummerSim-SCSC, 2019 July 22-24, Berlin, Germany*.

Kierzkowski, A., and T. Kisiel. 2016. "Simulation model of security control system functioning: A case study of the Wroclaw Airport Terminal". *Journal of Air Transport Management* 64:173–185.

Kierzkowski, A., and T. Kisiel. 2020. "Simulation model of security control lane operation in the state of the COVID-19 epidemic". *Journal of Air Transport Management* 88:101868.

Ma, W., T. Kleinschmidt, C. Fookes, and P. K. Yarlagadda. 2011. "Check-in processing: simulation of passengers with advanced traits". In *Proc. of the 2011 Winter Simulation Conference*, edited by S. Jain et al., 1778–1789. Phoenix, Arizona: IEEE.

Manataki, I. E., and K. G. Zografos. 2010. "Assessing airport terminal performance using a system dynamics model". *Journal of Air Transport Management* 16(2):86–93.

Mota, M. M. 2015. “Check-in allocation improvements through the use of a simulation-optimization approach”. *TRA* 77:320–335.

Mota, M. M., A. Orozco, and C. Ruy. 2019. “Design of selective lines for security filters in airports and multimodal facilities”. In *In the proceedings of Multilog 2019*. Huatulco, Mexico.

Rauch, R., and M. Kljajic. 206. “Discrete event passenger flow simulation model for an airport terminal capacity analysis”. *Organizacija, letnik 39*.

Rosenow, J., and M. Schultz. 2018. “Coupling of Turnaround and Trajectory Optimization in an Air Traffic Simulation”. In *Proc. of the 2018 Winter Simulation Conference*, edited by M. Rabe et al. Gothenburg, Sweden: IEEE.

Sanz, A. R., A. F. de Marcos, J. A. Perez-Castan, F. G. Comendador, R. A. Valdes, and A. P. Loreiro. 2021. “Queue behavioural patterns for passengers at airport terminals: a machine learning approach”. *Journal of Air Transport Management* 90.

Scala, P., M. M. Mota, J. Ma, and D. Delahaye. 2020. “Tackling uncertainty for the development of efficient decision making support system in air traffic management”. *IEEE Transactions on Intelligent Transportation Systems* 21:3233–3246.

Scala, P., M. M. Mota, C.-L. Wu, and D. Delahaye. 2021. “An optimization-simulation closed-loop feedback framework for modeling the airport capacity management problem under uncertainty”. *TRC* 124:102937.

Schultz, M. 2013. “Stochastic Transition Model for Pedestrian Dynamics”. In *Pedestrian and Evacuation Dynamics 2012*, 971–985. Springer International Publishing.

Schultz, M. 2018. “Implementation and application of a stochastic aircraft boarding model”. *TRC* 90:334–349.

Schultz, M., and H. Fricke. 2011. “Managing passenger handling at airport terminals”. *9^{th} EU/US ATM Seminar*.

Schultz, M., and J. Fuchte. 2020. “Evaluation of Aircraft Boarding Scenarios Considering Reduced Transmissions Risks”. *Sustainability* 12(13):5329.

Schultz, M., and S. Reitmann. 2018. “Prediction of aircraft boarding time using LSTM network”. In *Proc. 2018 Winter Simulation Conference*, edited by M. Rabe et al., 2330–2341. Gothenburg, Sweden: IEEE.

Schultz, M., C. Schulz, and H. Fricke. 2007. “Enhanced Information Flow and Guidance in Airport Terminals using best Passenger‘s Visual Perception”. In *6th EUROCONTROL Innovative Research Workshop*, 149–156. Bretigny sur Orge.

Schultz, M., and M. Soolaki. 2021. “Analytical approach to solve the problem of aircraft passenger boarding during the coronavirus pandemic”. *Transportation Research Part C: Emerging Technologies* 124:102931.

TSA 2021. “Coronavirus (COVID-19) information”.

XTEAM D2D Consortium 2020. “XTEAM D2D - eXTEnded AtM Door2Door travel”.

Zografos, K. G., M. A. madas, and Y. Salouras. 2013. “A decision support system for total airport operations management and planning”. *Journal of Advanced Transportation* 47:170–189.

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