IMPACT OF DISRUPTIVE SCENARIOS IN PASSENGER PROCESSING AT INTERNATIONAL AIRPORT TERMINALS: A SIMULATIVE STUDY

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ABSTRACT

Fast growing passenger traffic, technology push and security concerns are some of the main challenges in the context of international travel nowadays. Investigating such disruptive scenarios is not only relevant but necessary to handle potential issues that may arise. In this work, our main goal is thus the investigation of the effects of disruptive scenarios in passenger processing systems at international airport terminals in a simulative environment. First, we developed base simulation models in AnyLogic to measure waiting times at both security checkpoints and passport control stations for varying sizes of airport and used flight and share data from different European airports, as well as sensitivity, visualization, and analytical approaches, to verify and validate the models. Then, adapting the simulation models, and corresponding relevant inputs and parameters, we implemented various scenarios of disruptive events, including both non-intrusive technological procedure and system failure at security check, as well as system failure at automated kiosks for passport control. We carried out numerous simulations runs, varying passenger flows and number of processing stations. At a same arrival rate, we found that less than a half of the processing stations are needed for security screening when using technologies like corridors instead of typical gates. In case of a partial system failure, for example, larger sized airports are associated with lower impacts in terms of waiting times. If more personnel are not made available in such an occurrence, however, passenger throughput is expected to drop to a third of its normal operations levels. At emigration, automated kiosks enhance service quality and require less infrastructure and personnel, even during system failures. This comparison between typical operations and disruptive scenarios are particularly important, given that it evidences the impact of new equipment, procedures, and concepts, and enable informed decision making under such circumstances.

Keywords: Disruption, Passenger Processing, Airport Terminal, Simulation.

1. INTRODUCTION

Airports are crucial infrastructures, responsible for transporting and connecting people and goods all around the world. The air transportation industry has developed significantly along the past decades, not only in terms of passenger volume, but also regarding technological innovations in airports. (TRB, 2010) While passenger's traffic almost tripled over the two decades before the COVID-19 pandemic (The World Bank, 2020), concerns about security, efficiency, as well as economy also increased significantly. Some reasons for these growing challenges are terrorist attacks, accidents, competition, and changing business models.

IATA (2022) forecasts passenger volume to continue to grow after the pandemic, recovering the traffic level of 2019 in 2024. Solutions aiming to avoid physical contact and to improve passenger flow, such as biometrics and self-service stations, should become more present in airport terminals. (Bakker, 2015) According to Khan & Efthymiou (2021), such measures tend to enhance passenger's satisfaction and to reduce their stress levels. Therefore, it is important that not only the infrastructure of both terminal and airside facilities is prepared for future changes, but also the passenger's experience must be considered while designing and operating an airport.

Critical facilities are, in this sense, e.g. security and border control. It is commonly where bottlenecks (i.e. waiting queues longer than acceptable) occur for departing or transfer passengers, due to insufficient number of equipment, peak of passenger flows, or inefficient operations. (Alodhaibi et al., 2016) These process stations represent main stress factors for passengers, not only because of waiting in queues, but particularly issues like devesting, invasive screenings, manual checks, and possible denial of entrance. If not reasonably dimensioned and operated, these process station can lead to long waiting times, less perceived safety, as well as decrease of future travel intentions. (Alards-Tomalin et al., 2014)

At the same time, when disruptions take place, terminal procedures must be adapted, generating modified passenger flows, which are difficult to predict but should ideally still provide good operational performance. Technologies like automated passport controls and non-intrusive security checks aim to solve these issues while keeping or even growing passenger throughput. Still, terminal clearances, troubles in IT-Systems, as well as strikes are the most common disruptive events in Germany, for instance. (Metzner, 2020)

Properly understanding the behavior of these passenger processing systems is therefore essential for adequate design and operation of airport terminals, especially under disruption. In this work, we thus aimed to investigate the effects of disruptive scenarios in passenger processing systems at international airport terminals in a simulative environment. Due to their relevance for the processing of passengers at airport terminals, we focus our analyses in security and border control, for departing passengers, and explore these steps under different circumstances in varying set ups of simulation models.

2. THEORETICAL FRAMEWORK

IATA (2014) describes passenger terminals as a series of interconnected subsystems. For a departing passenger, these subsystems include essentially: arrival, check-in and bag drop, security screening, border control (when applicable), and boarding.

During the security screening stage, all passenger and carry-on luggage go through x-ray screening and, in some cases, also through a secondary screening check. This process aims to ensure that no hazardous items enter departure lounges and aircrafts. At this stage public landside and secured airside areas are physically separated. (De Graeff, 2020)

The border control (in the case of departing or some transferring passengers, also called emigration) stage includes either automated kiosks and common counters for passport control. Government agents perform the passport and border control, in order to prevent that non-legally authorized passengers enter the airside area and are able to depart. For this reason, border control is only conducted for passengers with international destinations. (De Graeff, 2020)

Like for all other processes at the terminal, one of the most relevant parameters that drives design and operations of passenger processing stations at airport terminals is performance. Lemer (1992) describes performance as relations between passenger movements and comfort, convenience, as well as costs and ambiance factors. Passengers' experience is thus directly related to the time spent waiting in queues. (Manataki & Zografos, 2009) Airport terminals are planned to accommodate capacity to serve the peak hour passenger volumes on a given busy day and performance at security screening and emigration tend to be driven by departure peaks. (IATA, 2014)

Innovations in areas such as screening technologies, data analytics, automation, and robotics are thus catalysts for change in future airport environments. According to Nowacki and Paszukow (2018) security issues are particularly relevant in this case, where a uniform deployment of technology across the aviation sector is crucial, though associated with less capability to react against novel threat cases. Solutions in this direction are, e.g.: pre-screening, e.g. TSA PreCheck program in the USA (TSA, 2022); non-invasive security checks, e.g. scanning corridors proposed by EUROCONTROL (2017); smart borders, e.g. EasyPASS procedure in the EU (Nowacki & Paszukow, 2018); or biometrics, e.g. iris recognition for border control in some European airports (CSES, 2011).

According to Metzner (2020), however, airport operations are daily exposed to a range of disruptive events. These unexpected events negatively influence the performance of processing stations. In a high-technological scenario, problems such as power outage and equipment failure are particularly of interest. System unavailability in essential equipment and operational procedures result mostly in economic and image issues, thereby causing disruptions for travelers and airport employees. (Romero, 2020) With a tendency of airports being increasingly more dependent on IT-systems, attacks can target planes, airlines, or passengers, and can result in limitations at airport operations, economic consequences, as well as passengers' dissatisfaction. (Prevost, 2021)

In sum, the Level of Service (LoS) of passenger processing stations at airport terminals is directly related to waiting times in these stations and disruptive events have a great impact on their performance.

3. METHODS

Based on our objective, we first developed an initial discrete event simulation model in AnyLogic™ to measure waiting times at both security checkpoints and passport control stations for varying sizes of airport and used flight and share data from different European airports, as well as sensitivity, visualization, and analytical approaches, to verify and validate the models. Then, adapting the simulation models, and corresponding relevant input parameters, we implemented various scenarios of disruptive events, including both non-intrusive technological procedure and system failure at security check, as well as system failure at automated kiosks for passport control. We carried out numerous simulations runs, varying passenger flows and number of processing stations.

In this work, forecasts were not considered, as passenger activities (i.e. arrival rates) were predetermined. Only the flows and processes for departing passengers were analyzed and we did not include transfer passengers. For the analysis of emigration procedures, we considered the airport to be inside the Schengen area, which can be adapted for other regions around the world. The output results regarding IATA's Level of Service (LoS) are only related to the criterion maximal waiting time.

The simulation models were built assuming: empty systems at the beginning; two-hour simulation period of peak traffic for departure passengers; 10 simulation runs for each parameter variation's combination of each scenario (Schwienhorst, 2020); single-lined first-in-first-out waiting queues with infinite capacity and measurement points right before and after each queue.

In terms of inputs, the parameters varied either according to the modeled scenario (processing times) or inside the scenario itself (arrival rates, number of processing stations). Shares of passengers owning EU-passports also varied in scenarios of emigration. We assumed triangular distributions for processing times, due to the little data available and to ensure a certain degree of randomness. For these distributions we used the values set up by Qualmann (2019), an average of processing times of terminal facilities according to diverse authors and EUROCONTROL (2006).

We use fix arrival rates, i.e. the number of individuals (departing passengers) entering the system in a period of time, in the simulation. This method was also used by Schwienhorst (2020) and consists in a parameter that represents departure passenger flows of an airport on a specific point on time. Therefore, it is possible to apply the simulation results for each point of time which corresponds to a specific arrival rate of an airport. Starting at 100 passengers per hour (PAX/h) in all simulated scenarios, this value was increased by 200 PAX/h till reaching a sub-optimum level of service at the maximal number of processing stations. Arrival rates were also randomly seeded, with different arrival patterns, producing more realistic simulations.

The number or processing stations was increased gradually till reaching a maximum, which was assumed as the number of facilities in the Frankfurt International Airport (FRA), as one of the largest airports in Europe regarding passenger traffic. For security controls, this represents 32 lines and equipment, whereas for emigration procedures, 16 passport control counters and automated kiosks. (Qualmann, 2019)

As a baseline scenario, in which verification and validation were carried out, the parameter for Cologne/Bonn airport (CGN) are assumed, as an average European point-to-point airport in the Schengen zone. This means, an arrival rate of 1500 PAX/h, 12 security controls and 4 passport controls. For border control scenarios, an 80% share of EU-passport-owning passengers was assumed, and the arrival rates were reduced to 500 PAX/h, which corresponds to 1/3 of international flights taking place in average in European airports. (Qualmann, 2019; Schwienhorst, 2020).

A range of verification and validation tests was carried out to confirm that the simulation model makes sense logically and can represent real systems. For one, a general sensitivity analysis was conducted in order to verify the behavior of outputs while varying parameters in each scenario. We reduced and increased the number of processing stations, arrival rates, and waiting times, one at a time, while maintaining the other two parameters constant. Another verification method was model visualization, by checking input parameters and their quantitatively correct processing with a tolerance of 10%.

Analytical approach by IATA ADRM's (2014) was also used to check the required number of processing stations for the given number of passengers arriving the facility in a specific period and a given LoS (maximal waiting time).

4. SCENARIOS AND RESULTS

A total of five scenarios were modeled and simulated in this work. Scenarios 1, 2, and 3 focus on passenger security screening procedures, whereas Scenarios 4 and 5 regard to the analysis of emigration procedures.

4.1. Scenario 1: Typical Operations at Security Check

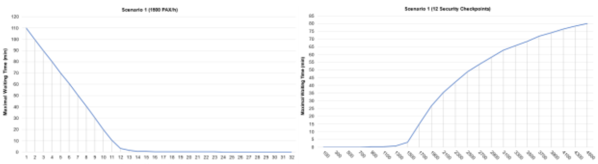
This scenario represents standard security control procedures of European airports. This means, state-of-the-art equipment is used to screen departing passengers and hand-baggage, such as Walk-Through Metal Detectors and X-ray machines, respectively. When the alarm is triggered or a suspicious illegal item is detected, a manual check must be conducted by a security officer. When the system is already saturated and there are more passengers arriving for security checks than being processed, a single-lined waiting queue arises before the screening equipment, and passengers are sequentially allowed to proceed in the moment that a screening equipment becomes available. Table 1 summarizes the input parameters for this scenario.

Table 1 Input parameters of Scenario 2

Security_1: typical security screening procedure	
Delay time [s]	triangular (20, 27, 40)
Capacity	1 - 32 (baseline: 12)
alarmSecurity_1: alarm not triggered at security check	
Probability	0.9
manualCheck_1: manual check (when alarm triggered)	
Delay time [s]	triangular (60, 120, 180)
Capacity	1 - 32 (baseline: 12)

We found that airports with an infrastructure of 32 security screening lanes can handle an arrival rate of 4300 PAX/h with still optimum LoS-standards. Until the arrival rate of 1500 PAX/h, it was not possible to constantly achieve optimum LoS-standards, what means the lowest the number of processing stations, the largest the sensibility of waiting times. Therefore, small airports should be conservative while designing security control areas, since equipment or procedure failures cause significant impacts in waiting times. The largest the number of security screening lines, the less the impact of single failures.

The average flow of arriving passengers passing through a single security screening line providing optimum LoS-standards calculated was approximately 130 PAX/h for each screening equipment. Figure 1 illustrates these results graphically.



(a) (b)

Figure 1 Scenario 1 - Max. waiting time per (a) number of security controls and (b) PAX flow at security controls

4.2. Scenario 2: Technological Security Check

This scenario represents the security control being executed by non-intrusive screening measures. The system modeled was based on EUROCONTROL (2006) description for scanning corridors. Passengers have their screening procedures accomplished while walking through the terminal towards the boarding area. Automated gates are allocated in the end of the scanning process, and permit or deny the passenger to continue to the next facility, depending on the result of the screening. If the access is rejected, a manual check must be carried by security officers, which closely follow the procedures at the automated gates. Table 2 summarizes the input parameters for this scenario.

Table 2 Input parameters of Scenario 2

Security_2: automated gates after scanning corridors	
Delay time[s]	triangular (8, 10, 20)
Capacity	1 - 32 (baseline: 12)
alarmSecurity_2: alarm not triggered at security check	
Probability	0.75
manualCheck_2: manual check (when alarm triggered)	
Delay time [s]	triangular (60, 120, 180)
Capacity	1 - 32 (baseline: 12)

For the automated gates, it was not possible to achieve a sequence of optimum waiting times during the simulations of the baseline scenario. This means, there is a high sensibility of ideal number of processing stations over the whole range of arrival rates. On the other hand, the manual checks achieved stability of optimum waiting times after 1500 PAX/h, meaning that there is a greater sensibility only for small arrival rates.

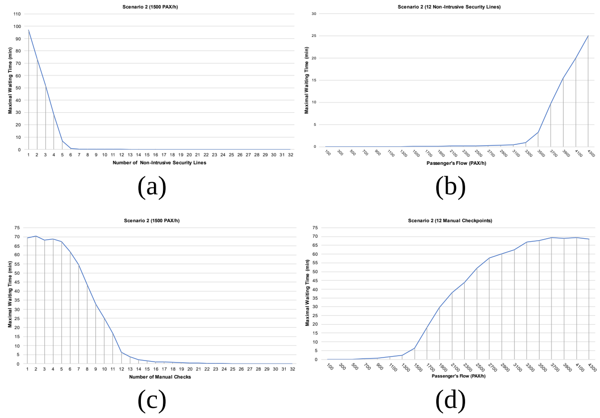


Figure 2 Scenario 2 - Max. waiting time per (a) number of automated gates, (b) PAX flow at automated gates, (c) number of manual checks, and (d) PAX flow at manual checks

The average flow of arriving passengers passing through a single automated gate providing optimum LoS-standards calculated was approximately 300 PAX/h for each screening equipment. For manual check, this value was approximately 125 PAX/h for each security officer. As the values of average passenger flows in this still theoretical scenario result in a proportion of 2,4, a suggestion is to consider two to three extra officers for each automated gate, ensuring that security controls and manual checks operate at optimum LoS-standards. Figure 2 illustrates these results graphically.

4.3. Scenario 3: System Outage at Security Check

This scenario also represents a standard security control of European countries, however with the disruptive event of e.g. a power outage. This means, the whole scanning equipment is out of operation, and all screening procedures must be carried out through manual checks. It represents a situation of system unavailability, as well as obligatory manual checks for all departing passengers caused by imminent risks or threats. Table 3 summarizes the input parameters for this scenario.

Table 3 Input parameters of Scenario 3

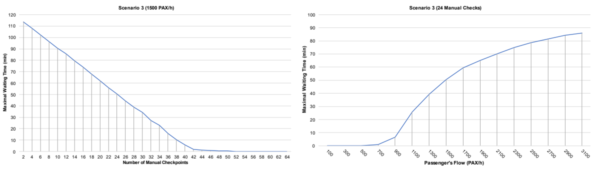
manualCheck_3: manual check (always)	
Delay time [s]	triangular (30, 90, 180)
Capacity (double of Scenarios 1 and 2)	2 - 64 (baseline: 24)

Before the arrival rate of 1300 PAX/h, it was not possible to constantly achieve optimum LoS-standards, what means the lowest the number of processing stations, the largest the sensitivity of waiting times. After 1300 PAX/h, optimum values of waiting times were achieved, meaning that there is a stabilization of system’s behavior.

The average flow of arriving passengers passing through a single manual check providing optimum LoS-standards calculated was approximately 38 PAX/h for each security officer.

As complete failures cases in the security control system are rare, the outcomes were also compared to more flexible LoS-standards, representing a broader tolerance of waiting times for departing passengers. The second LoS-standard analyzed had the minimum and maximum values of 10 and 30 minutes, respectively. Before the arrival rate of 500 PAX/h, it was not possible to constantly achieve optimum LoS-standards, what means the lowest the number of processing stations, the largest the sensibility of waiting times. After 500 PAX/h, optimum values of waiting times were achieved, meaning that there is a stabilization of system’s behavior.

The average flow of arriving passengers passing through a single manual check providing optimum LoS-standards calculated was approximately 45 PAX/h for each security officer. Figure 3 illustrates these results graphically.



(a) (b)

Figure 3 Scenario 3 - Max. waiting time per (a) number of manual checks and (b) PAX flow at manual checks

4.4. Scenario 4: Typical Operations at Passport Control

This scenario represents standard emigration facilities in airports inside the European Union. After security checked, passengers of international flights proceed to the passport control, which can be conducted by automated kiosks (for passengers with EU-passports) or by counters with government officers (for other passengers). The processing times of both stations are different, since automated kiosks are normally much faster due to rapid biometric identification. One officer was allocated at the automated kiosks, with the objective of supporting EU-passengers with difficulties.

Besides arrival rates and number of processing stations, a variation of EU-passport shares was also included into the system, in order to model different categories of airports regarding nationality of passengers. The maximal waiting time outputs of this scenario were two, one for the queues at automated kiosks, and one for the counters. Table 4 summarizes the input parameters for this scenario.

For the automated passport controls, as well as for the passport control counters, it was not possible to achieve a sequence of optimum waiting times during the simulations of the baseline scenario. This means, there is a high sensibility of ideal number of processing stations over the whole range of arrival rates. The only model where a stabilized behavior of waiting times was achieved was for the passport control counters at 50% EU-passport shares, from 1700 PAX/h on.

The average flow of arriving passengers passing through a single automated kiosk providing optimum LoS-standards calculated was approximately 250 PAX/h for each equipment.

The average flow of arriving passengers passing through a single passport control counter providing optimum LoS-standards calculated was approximately 100 PAX/h for each equipment.

Table 4 Input parameters of Scenario 4

sharesNonEUPass: proportion of non-EU passports	
Probability	0.8 or 0.5 (baseline: 0.8)
PassNonEU_4: passport control non-EU (counters)	
Delay time [s]	triangular (20, 30, 60)
Capacity	1 - 12 (baseline: 4)
PassEU_4: passport control EU (automated)	
Delay time [s]	triangular (8, 12, 20)
Capacity	1 - 12 (baseline: 4)
Alarm_4: failure of EU-passenger identification	
Probability	0.95
ManPassEU_4: manual check (failure EU identification)	
Delay time [s]	triangular (8, 12, 20)
Capacity	1

A proportion between 0,8 and one passport control counter for each automated kiosk should be considered to ensure optimum LoS-standards for 80% EU-passport shares. On the other hand, when 50% of the departing passengers are EU-passport holders, 2 to 3 passport control counters for each automated kiosk must be planned. Figure 4 illustrates these results graphically.

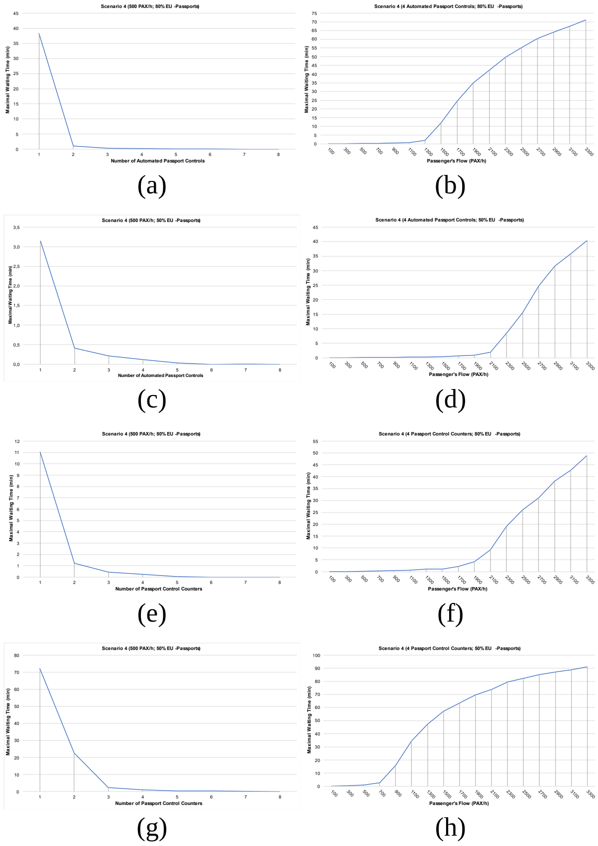


Figure 4 Scenario 4 - Max. waiting time per (a) automated kiosks (80% EU-passports), (b) PAX flow at automated kiosks (80% EU-pass), (c) automated kiosks (50% EU-passports), (d) PAX flow at automated kiosks (50% EU-pass), (e) passport counters (80% EU-passports), (f) PAX flow at pass. counters (80% EU-pass), (g) passport counters (50% EU-passports), and (h) PAX flow at pass. counters (50% EU-pass)

Scenario 5: Only Counters at Passport Control

This scenario can represent two different situations; the first one is a failure at automated kiosks, which obligates also passengers owning EU-passports to have manual emigration controls at counters, together with non-EU passengers. The second possible situation is the simulation of airport emigration procedures in regions where there is no technology being used yet for automated recognition of passengers' identity.

This means, all passengers of international flights pass through the same type of emigration procedure, therefore must wait in same queues, if needed. An important point is that "domestic" passports still constitute more agile process times even when checked by personnel, due to more standardized procedures.

Also, in this scenario different shares of passengers owning EU-passports were simulated, in order to analyze the influence of regionality on waiting times for emigration procedures. Table 5 summarizes the input parameters for this scenario.

Table 5 Input parameters of Scenario 5

sharesNonEUPass: proportion of non-EU passports	
Probability	0.8 or 0.5 or 0.2 (baseline: 0.8)
PassEU_5: passport control non-EU (counters)	
Delay time [s]	if EU passenger: triangular (8, 10, 20) if non-EU passenger: triangular (20, 30, 60)
Capacity	1 - 12 (baseline: 4)

For the passport control counters, it was not possible to achieve a sequence of optimum waiting times during the simulations of the baseline scenario for the three different EU-passport shares. However, this time it does not mean that there is a high sensibility of ideal number of processing stations over the whole range of arrival rates. This behavior is explained by optimum values of arrival rates for the respective number of passport counters being between the values simulated.

The average flows of arriving passengers passing through a single passport control counter providing optimum LoS-standards calculated were approximately 220 PAX/h, 150 PAX/h, and 120 PAX/h for each counter for 80%, 50%, and 20% EU-passport shares, respectively. With this "rule-of-thumb", passport control systems of airport terminals could be dimensioned and provide efficient operations. Figure 5 illustrates these results graphically.

5. DISCUSSION

We have found that maintaining a fix arrival rate and varying the number of processing stations, the optimum number of processing stations represent a point of change for the maximal waiting times' pattern. When the number of processing stations is maintained, on the other hand, LoS-standards represent a division point for systems' behavior. When both parameters are simultaneously varied, similar graphical patterns are achieved in each scenario, however with different values and inclinations.

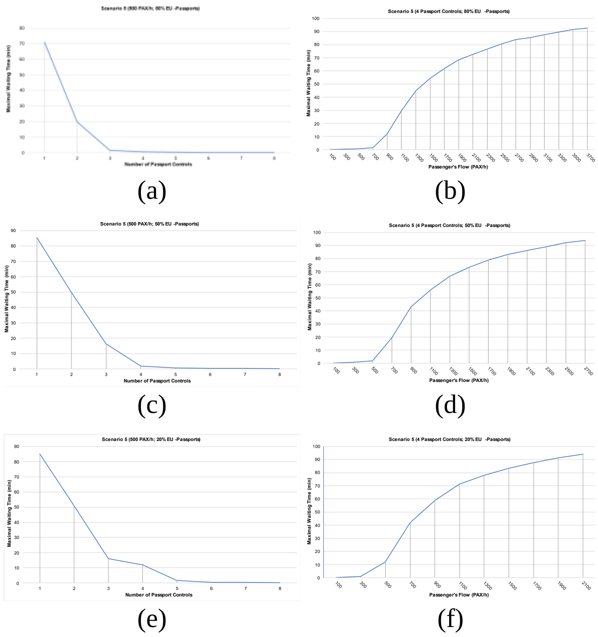


Figure 5 Scenario 5 - Max. waiting time per (a) passport counters (80% EU-passports), (b) PAX flow at pass counters (80% EU-pass), (c) passport counters (50% EU-passports), (d) PAX flow at pass counters (50% EU-pass), (e) passport counters (20% EU-passports), and (f) PAX flow at pass counters (20% EU-pass)

Analyzing the whole range of simulation results we can observe that the optimum number of processing stations for each scenario and parameters' combination follow linear patterns. When arrival rates are too low or too high in a simulation scenario, however, graphics become more difficult to analyze and to derive conclusions. This was the case in some graphics of Scenarios 4 and 5, where zones could not be clearly identified.

Some of the simulated scenarios had results stabilized in optimum LoS-standards when an arrival rate was reached. In other words, the larger the airport, the less the influence at the passengers' flow when there is an equipment failure, for example. The scenarios which did not reach a stabilization of optimum waiting times can be justified by the respective arrival rates being of a value between the ones simulated.

The main differences between Scenarios 1 and 2 are the agility and the non-intrusiveness at security screening procedures of passengers that do not must pass through manual checks. At a same arrival rate, less than a half of the processing stations are needed when using the technology of automated gates after being scanned by screening corridors instead of typical security control facilities. Automated gates become more efficient the higher the passenger throughput.

Implementing the technology of scanning corridors would represent an expressive transformation of current security control areas regarding airport terminal's architecture. However, the required number of screening equipment to optimally attend passenger flows would not be dramatically changed, since manual checks still must take place at conventional screening equipment even in Scenario 2.

For the design of security control areas, the decisive procedure for Scenario 1 was the security screening, which resulted in bottlenecks when passenger throughputs exceeded optimum values. On the other hand, Scenario 2 presented bottlenecks at manual check procedures, caused by a much larger share of departing passengers having to pass through such manual checks due to higher equipment sensitivity. One suggestion for Scenario 2 is to tighten LoS-standards for automated gates to 1-5 minutes, since the implementation of new technologies should also improve passenger experience regarding waiting times. This could be achieved by slightly increasing the number of automated gates, which would theoretically not result in too much additional space and costs issues.

Regarding Scenario 3, the decrease of operational performance in case of a complete system outage was not as large as expected. Comparing with typical operations (Scenario 1), using the same infrastructure with two instead of one officer carrying out manual controls in each security lane, there is a passenger throughput loss. However, if it is not possible to double the personnel in this case of disruption, the maximal arrival rates still providing satisfactory waiting times decrease significantly, representing about a third of the original passenger throughputs for both LoS-standards considered.

Regarding the simulations of passport controls, it was observed that shares of EU-passports represent an influencing factor for the outcomes. The higher the proportion of international passengers (without EU-passports), the larger the number of passport control counters needed, and therefore also the more the personnel required. This happens due to the longer processing times of passengers without EU-passports, which must pass through a more laborious passport control.

It was also confirmed that automated kiosks enhance service quality at emigration procedures, by comparing Scenarios 4 and 5 outcomes. The suggested number of processing stations, however, remains almost the same when comparing both Scenarios. However, LoS-standards of Scenario 4 are more restricted than Scenario 5, since optimum LoS-standards of automated kiosks can only be achieved when maximal waiting times are between one and 5 minutes, meaning that European passengers have more agile procedures. Nevertheless, it is also important to notice that, automated kiosks only require one officer for all kiosks at the same time to help at operations, while passport control counters demand one officer for each passport control counter. This means less personnel costs for boarder control procedures while improving service quality.

6. CONCLUSION

The main objective of this work was the simulative investigation of disruptive scenarios in the context of passenger processing systems in international airports. The five scenarios built were characterized according to different literature sources, which provided intermediate parameters and thereby neither too conservative nor too optimistic results. The components and respective attributes of logical systems constructed with the simulation tool can be used as a basis for modeling other simulation scenarios of airport terminal systems.

Through comparison between the scenarios modeled, statements regarding infrastructure and operational efficiency could be derived. Comparisons between typical operations and disruptive scenarios are particularly important, since they provide assessment for deployment of new equipment, procedures, and concepts. Additionally, knowledge about operational performance in case of disruptive events provide helpful information for decision making also in this kind of situation.

The outcomes of this work also provided useful data for airport terminals of a range of magnitudes and types, being a generic tool that can be used by many airport operators around the world, despite considering European properties as standard.

Among the possibilities for further development of our work are: the confirmation of the model validity though empirical data; the inclusion of arriving and transfer passengers in different procedures; a more detailed modeling of passenger behavior under typical operations; the consideration of LoS-standards instead of only waiting times for service quality; as well as the consideration of partial failures and a correlation with airport terminal's resilience.

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