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Modeling the implementation of technology in a passenger security screening checkpoint at Amsterdam Airport Schiphol

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Abstract

Amsterdam Airport Schiphol has faced capacity constraints, particularly during peak periods. At the security screening checkpoint, this is due to the growing number of passengers and a shortage of security staff. To improve operating performance, there is a need to integrate newer technologies that improve passing times. This research presents a discrete event simulation (DES) model for the inclusion of a shoe scanner at the security screening checkpoint at Amsterdam Airport Schiphol. Simulation is a frequently used method to assess the influence of process changes, which, however, has not been applied for the inclusion of shoe scanners in airport security screenings yet. The simulation model can be used to assess the implementation and potential benefits of an optical shoe scanner, which is expected to lead to significant improvements in passenger throughput and a decrease in the time a passenger spends during the security screening, which could lead to improved passenger satisfaction. By leveraging DES as a tool for analysis, this study provides valuable insights for airport authorities and stakeholders aiming to optimize security screening operations and enhance passenger satisfaction.

Keywords: Security screening checkpoint, discrete event simulation, airport operations, airport management

1. Introduction

Security in the aviation industry has been subject to major operational and technological improvements over the years. One major event that changed the whole industry was the catastrophic attack on 9/11, 2001. After this event, the Transportation Security Administration (TSA) was created to safeguard the US against similar attacks (Pekoske, 2021). Another event that resulted in strict regulations (Ye et al., 2022) and the development of new technologies (Anderson, 2023) was Covid-19. From X-ray scanners and CT scanners to body scanners and artificial intelligence, security technologies are advancing every year (Careless, 2022). Airport Council International (ACI) predicts a growth of 29% in passenger traffic for the upcoming year (ACI, 2023). With the rapid growth of passengers in combination with security technologies, there is a pressing need for a comprehensive evaluation of how these advancements impact passenger throughput, stakeholder interests, passenger profiles, and the overall layout of the airport.

This research addresses the complex relationship between security technologies, operational efficiency, and passengers throughout the security operations at Amsterdam Airport Schiphol (AAS) in The Netherlands. The current problem at AAS is that the security operations are experiencing capacity constraints.

Recent and ongoing technological changes in the security operations have the potential to either enhance or affect the operations. The aim of this paper is to present a simulation model that can assess how the security process impacts passenger throughput when new security technologies, in this case a shoe scanner, are introduced.

2. State of the art

Several studies relate to using security technology in aviation security. For example, in Hättenschwiler et al. (2018), the authors examine the use of explosive detection systems for cabin baggage to assess screening benefits for security agents' decision making. Naji et al. (2020) focus on the design of airport security screening, using queueing theory and swarm optimization to predict and optimize process times.

There are several policies both globally and EU focused that are related to aviation security. The International Civil Aviation Organization (ICAO) formulates standards and recommended practices (SARPs) for international aviation. Annex 17 of the Convention on International Civil Aviation (also known as the Chicago Convention) specifically describes the SARPs for aviation security. These SARPs are focused on safeguarding against acts of unlawful interference, including measures relating to e.g. access control, cabin baggage, and hold baggage (ICAO, 2022).

Within the European Union (EU), international standards are adopted, and policies are created based on EU regulation 300/2008 and 2015/1998, which state common basic standards for screening and security and implementation measures (EC, 2008; EC, 2015; EC, 2019). These include, for example, the introduction of security scanners as an alternative screening method for detecting both metallic and non-metallic items carried on a person (EC, 2011), regulation that restricts travelling with liquids, aerosols and gels (EC, 2013), shoe metal detection and shoe explosive detection regulation for the use of shoe scanner equipment able to detect specified metallic and explosive items.

Taking off shoes for explosive detection screening is a time-consuming process that decreases the throughput and operational efficiency of security operations. Several organizations are developing technologies to improve passenger throughput. For example, Stage Gate 11 (2024) developed the Delta R shoe scanner as a new and efficient method to detect traces of illicit materials on shoes, specifically designed for security-sensitive spaces. This type of scanner automates the security process and is assumed to increase the passenger throughput considerably, without compromising the security level.

The European Civil Aviation Conference (ECAC) also focuses on enhancing aviation security by developing policies and procedures for passenger and baggage screening across its member states (ECAC, 2023). In this sense, it has developed the Common Evaluation Process (CEP), a testing program to assess security equipment against ECAC/EU performance standards. It provides lists of endorsed equipment configurations. At present, the Delta R shoe scanner does not have configurations included in the endorsed list. Simulation can be a means to compare the usefulness of specific configurations of this kind of scanner.

Simulation of screening filters in airports has mainly been used to predict passenger waiting times and optimize filter capacity. Used modeling software includes Arena (Dorton and Liu, 2015; Wang, 2017), Flexim (Li et al., 2022), Simio (Ruiz and Cheu, 2020; Mota et al., 2021; Martínez et al. 2023) and Anylogic (Zhao et al., 2020; Ye et al., 2023). Dorton and Liu (2015) analyzed the effect of the number of baggage items and alarm rate on the screening process time. Ruiz and Cheu (2020) identify bottle necks within a security screening checkpoint to determine performance improvement efforts. Martínez et al. (2023) assess the dynamic allocation of airport security screening resources in airports. Mota et al. (2021) carry out an impact analysis on policies used for improving capacity in airports. Zhao et al. (2020) analyze the efficiency of a differentiated security strategy based on passenger's risk, while Ye et al. (2023) evaluate a differentiation strategy to improve disabled people's comfort.

Recent studies focus on increased automation in airport security screening. Li et al. (2022) simulate how the use of intelligent passenger security equipment influences passenger throughput, and Thiessen et al. (2024) elaborate on autonomous self-screening checkpoint design. The proposal in this work is to expand on the previous papers, focusing on a new technology introduced into the security screening process to improve capacity at the security checkpoint and passenger experience.

3. The security process in AAS

Most of the security systems consist of queueing lines where passengers, typically a mix of various types, and their baggage undergo some type of scanning. When passing a security checkpoint, passengers encounter a sequence of activities crucial for ensuring safety and compliance.

The passenger security process in an airport has the following steps:

1. Boarding pass scanners
2. Pre divesting queue
3. Divesting allocation
4. Divesting station
5. Body scanner
6. X-ray
7. Manual passenger check
8. Passenger collecting items
9. Manual recheck of belongings

Figure 1 visualizes the security system for AAS that is used in this research.

Initially, the boarding pass scanner verifies the travel documentation, facilitating a smooth entry into the security process. Subsequently, passengers navigate through designated queues, organized to manage the flow efficiently. Security checkpoint lane allocation optimizes resources, directing passengers to available screening lanes. The divesting stage prompts individuals to remove personal belongings and electronic devices for screening, contributing to thorough security measures.

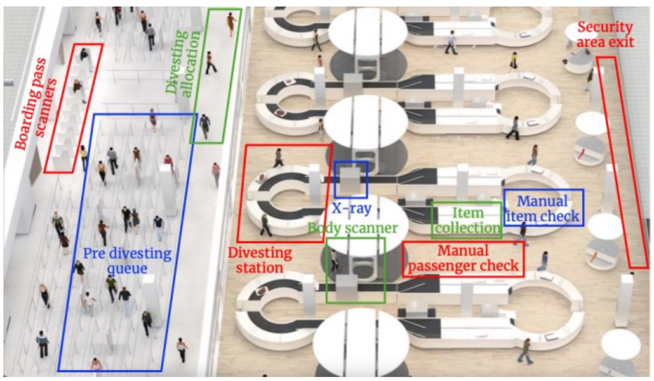

Figure 1 The security process at Schiphol (Based on Louwerse, 2014)

After divesting, passengers undergo primary screening procedures, where personnel inspect carry-on items and conduct body scans. It is at this point where the additional shoe-scanner would be placed. In certain circumstances, additional passenger or item screening may be required, enhancing security protocols. Finally, post-screening activities include retrieving belongings from the conveyor belt and proceeding towards the departure gates, concluding the security checkpoint journey. Each activity within this process is meticulously orchestrated to uphold security standards while minimizing inconvenience for travelers.

3.1. Passenger types

The types of passengers that will be considered for this paper are business passengers, VFR (Visiting Friends and Relatives) passengers and leisure passengers. Every passenger type has a unique set of characteristics and behaves differently in the security process. This can be backed up by several papers written on passengers' profiles. Janssen et al. (2020) examined the security checkpoint process at Rotterdam the Hague Airport, analyzing 2277 passengers. Results show that business passengers are the fastest, while reduced mobility passengers and families are the slowest.

Figure 2 shows the typical passenger profile in AAS. In 2022, Schiphol processed 22% business passengers, 46% leisure travelers, 26% VFR and 6% others. Business passengers are frequent flyers which prioritize efficiency and flexibility in their travels, often showing a willingness to pay a higher fare for convenience and speed (Morphet and Bottini, 2014). As they are experienced users, these passengers are likely to cause fewer incidents at the security checkpoint. However, they typically carry electronics and sensitive documents that require careful handling.

Leisure travelers often plan to travel with their family; they are generally more price sensitive, and flexible to the destination. Leisure passengers do not travel as frequently as business passengers. Therefore, they are less familiar with the security protocols, potentially leading to a longer overall processing time. Leisure travelers are also more likely to carry vacation items such as sports equipment or odd items which can make the security process more complicated.

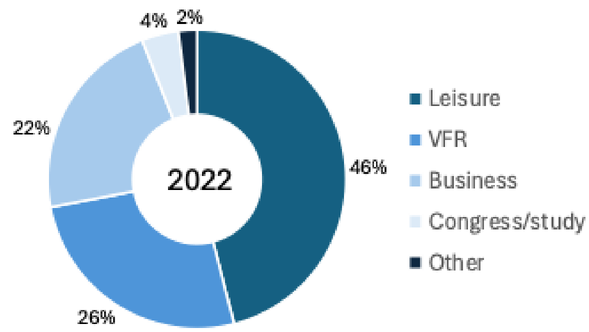

Figure 2 Passenger profile in AAS for 2022 (Schiphol, 2023)

VFR passengers share similarities with business passengers and leisure passengers. VFR passengers have less flexibility in their destination but are sensitive to fares. VFR passengers travel frequently, similarly to business passengers, which makes them experienced travelers that are processed relatively fast in the security filter. However, VFR passengers may carry gifts or cultural items which can make the security process more complicated (Morphet and Bottini, 2014).

Schultz (2010) estimates the walking speed of business passengers to be 1,44 m/s and the walking speed of leisure passengers to be 1,39 m/s. The walking speed of VFR passengers is not stated in the literature, but was assumed in this research as 1,41, a value between leisure and business travelers. This paper considers that VFR passengers have more baggage than business passengers, which slows down the walking speed of passengers. The bag and shoes have a limited "walking" speed, this due to the fact that the conveyer belt moves with a speed of 0,2 meters per second.

3.2. Key performance indicators

The main KPI considered in this research for the overall effectiveness of the inclusion of a shoe scanner in AAS' security operation is *passenger throughput*, which can be defined as the number of passengers they can process in a specific period of time (Mota et al., 2021). Other KPIs important for passenger satisfaction is average time in system, representing the time that a certain type of passenger spends on average in the security filter system. A third KPI is the average utilization of specific processes for example the body scanner or the shoe scanner.

Passenger throughput is defined by Mota et al. (2021) as the number of passengers which can be processed in a specific time period. The hourly passenger throughput in the simulation model is determined by dividing the total number of passengers by the total run length of the simulation (Eq. 1).

$$Tp = \frac{B_p + L_p + V_p}{\text{Run length}} \tag{1}$$

T_p stands for the throughput of the model (passengers/h). B_p, L_p and V_p are respectively the total number of business, leisure and VFR passengers passing through the security checkpoint. The simulation run length is the simulated duration of the security process, expressed in hours.

The average time in system can be determined by Eq. 2:

$$\frac{\sum_{i=1}^{p} TS_i}{p} \tag{2}$$

p stands for the number of completely served passengers, while TS_i stands for the service time of passenger i. Note that i and p are integers. This formula can be further split into the passenger type, which will give a more detailed outcome.

The average utilization of the server (boarding pass scan, body scan, X-ray scanner, etc.) shows the percentage of how occupied the servers were throughout the simulation run and can be determined by dividing the time the server is busy by the total run length of the simulation (Eq. 3).

$$u = \frac{\text{Occupation time}}{\text{Run length}} \tag{3}$$

The average number of passengers queueing can be calculated through Little's law (Little, 1961) (Eq. 4).

$$L_q = \lambda W_q \tag{4}$$

L_q stands for the average number of passengers in a queue. λ is the passenger arrival rate and W_q is the average time a passenger spends in the system.

4. Methodology

The simulation applied in this research was carried out in Simio (Smith and Sturrock, 2021) and corresponds to discrete event simulation (DES), in which some states can only occur at discrete points in time (e.g., length of a queue), state variables are random (stochastic), and time evolution is important (dynamic). In the case of this research, the system is the security operation at Amsterdam Schiphol Airport, where a foot scanner was added, and the operation of the security system is represented as a sequence of events over time.

Figure 3 illustrates the used methodology. In an initial phase, the simulation problem was formulated, and variables were defined. In a second step, the model was designed conceptually and with the aid of data collection and analysis, the simulation model was build, verified and validated. An appropriate experimental design permitted the simulation of different scenarios, and, as a final step, model results were analyzed to be able to propose some recommendations on the installation of the shoe scanner.

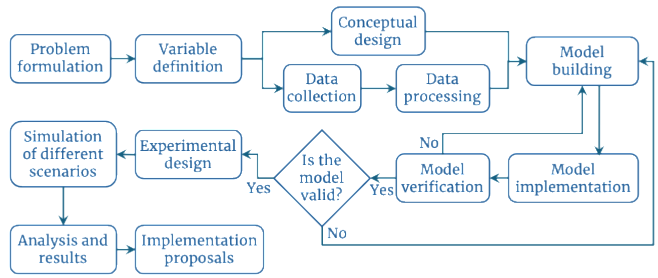

Figure 3 Study methodology

5. Model building and data collection

5.1. Description of the simulation system

The activities that can be expected while passing through the modeled security checkpoint correspond to the ones described in section 3. The simplified description of figure 1 was used to develop the conceptual model.

Figure 4 presents the simulation logic.

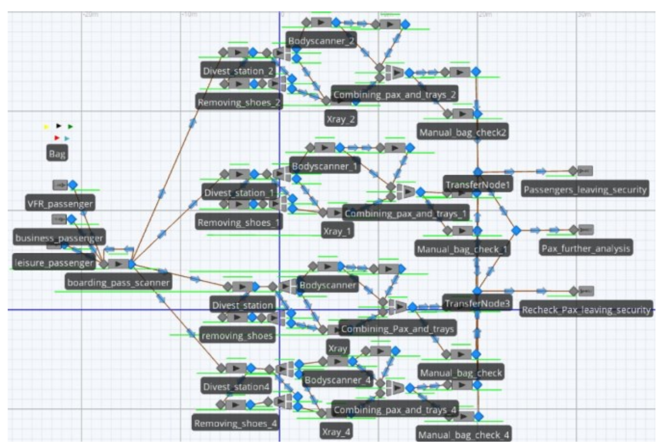

Figure 4 Visualization of the simulation model of the security process at Schiphol.

The three types of passengers are introduced in the model as entities passing through the system (see Figure 4: VFR_passenger, business_passenger and leisure_passenger). They are originated in three sources, each of them corresponding to a specific passenger type.

In the first version of the model, the activities listed for Figure 1 are represented by 8 types of servers (boarding pass scanner, divesting station, shoe removal process, body scanner, manual body check, x-ray scanner, manual bag check, and item collection by passengers). Five boarding pass scanners are considered in the simulation model, that serve four security lanes. These lanes are represented in Figure 4 by the arrows leading to Divest_station(i) and Remove_shoes(i).

The model includes two separators. The tray separator splits the passenger entity into a parent entity and a bag, to enable him to put his belongings on the belt. The shoe separator works in a similar way, although not all passengers must pass this object. A combiner object combines the bag and shoes with their parent entity after passing the security process.

Finally, three sink objects distinguish between passengers leaving security without or with a manual bag check and passengers considered not safe for travel. These are represented at the right side of Figure 4.

The model will process a continuous flow of passengers representing peak hours, and where the server usage will be high. The final KPI is the average number of passengers queueing. Simio will calculate this automatically and report the average time in system per passenger type. Similarly, the simulation model will determine the utilization rate and the number of passengers queueing.

A second version of the model includes the shoe scanner as an additional server. In this case, the shoe removal process is not included. The essence of the model stays the same: after the passengers have divested, the tray separator splits up the passenger and their bags. However, instead of going to the shoe removal process, the passengers go through the shoe scanner. The rejection rate of the shoe scanner can be set as desired to generate the proportions of shoes that need to be rechecked. After the shoe scanner, the passenger passes the body scanner; the rest of the simulation process is programmed in the same way as in the first version of the model (without shoe scanner).

5.2. Simulation parameters

For the sources that create the passenger entities, the passenger type proportions are taken from Figure 1. The model creates 48,9% leisure passengers, 27,7% VFR passengers and 23,4% business passengers.

The arrival process in queueing theory refers to how entities arrive in the system, characterized by distribution and frequency. The passenger interarrival time was not available from measurements. Passengers are supposed to arrive independently; considering a constant arrival rate, the Poisson distribution can be used for the passenger arrival pattern. The random exponential distribution (λ = 0,25 or 4 passengers per minute) is then used to model interarrival times based on a Poisson process. As the model was developed to compare the functioning of the shoe scanner, a more accurate selection of λ is not required.

The processing times for the boarding pass scanners were also unknown. In the absence of data, they were roughly modeled with a random triangular distribution where the minimum, most likely (mode) and maximum values are defined. For leisure passengers, respectively 15, 20 and 25 s were used, for VFR passengers 9, 10 and 11 s, while business travelers with more experience were expected to pass with 4, 5 and 6 s as minimum, mode and maximum processing times. If the boarding pass scanner cannot read the boarding pass, for example if a previous pass is still being processed, or due to low brightness, big distance or unproper size of the shown QR-code, passengers need to scan it again. The model considers 40% of the passengers to enter this loop.

The model selects the passengers to pass through the least busy divesting station, considering a station capacity of 3 passengers at a time, as is the case in Schiphol. The divesting time is taken to have a random triangular distribution with minimum 30, most likely 45 and maximum 50 s to pass. After divesting, the tray separator creates the entity bag, representing the trays. Keeping in mind that passengers use 2 or 3 trays on average, the separator creates randomly either 2 or 3 trays per passenger.

The simulation model assumes that 100% of the passengers must take off their shoes. This percentage depends on factors such as passenger type, passenger travel destination and the current weather in Amsterdam. The time a passenger needs to take off his shoes depends also on multiple factors, such as age, difficulties in taking off the shoes, care for little children and passenger type. The shoe remover server in the model uses the random triangular function with a minimum of 20 s, a mode of 30 s and a maximum of 35 s. In the second version of the model, the shoe remover server is replaced by the shoe scanner server, modeled by a random triangular function with a minimum of 5 s, a mode of 8 s and a maximum of 11 s.

The body scanner has a capacity of one passenger. Its processing time does not depend on the type of passenger and has a low variability. The scanner is modeled with a random triangular distribution with parameters 29, 30 and 31 s. The body scanner has two output links, one to the manual passenger check, and the second one to the passenger- tray combiner. The body scanner will show on the screen with a red box which areas of the body might have something suspicious. According to information obtained from an airport security consultant, 72,5% of the passengers were modeled to pass to the manual passenger check; the remaining 27,5% are clear and pass to the passenger-tray combiner. The number of manual body checks seem high but is realistic, as several clothing configurations (for example, a rolled-up sleeve, forgotten coins in a pocket, etc.) may generate an alarm that does not correspond to a threat but would still require manual checking.

The capacity of the physical check is one passenger at a time, and the processing time depends on the severity of the outcome of the body scanner. The model considers a random triangular distribution with a minimum time of 15 seconds, representing a single red spot due to, for example, a watch. The mode corresponds to 30 seconds, and the maximum is 45 seconds, representing a full body check. When these passengers are clear for security, they also pass to the combiner. The different servers are simulated as timepaths, depending on the walking speeds of the passengers.

While the passenger passes the body check, the associated trays, including the shoes, pass the x-ray machine. Its speed is limited to 0,2 meters per second. The processing time depends on several factors, such as the staff's experience, the kind of x-ray technology and the complexity of the items in the tray. This server uses a random triangular distribution with a minimum value of 10 s, a mode of 15 s, and a maximum of 30 s.

Rejected trays need to be rechecked by staff, in presence of the passenger. To simulate this correctly in the model, this server called "manual bag check" is placed after the combiner. The processing time in this server depends on what suspicious items were visible on the screen. For this server, a random triangular distribution was considered with a minimum of 120 s, a mode corresponding to 135 s and a maximum of 150 s. Based on on-site consultation, the percentage of passengers that need to go through a manual bag check is set at 8%. The remaining 92% of passengers pass to the next process.

The combiner object combines the passengers back with their belongings. This can be seen as the moment where the passenger sees his bag coming out of the X-ray machine. The model uses a matching rule set, selecting the option "match members and parents". The processing time of the combiner object is zero.

Afterwards, the passengers pick their items and put the trays away. The passenger may need to wait for his belongings. As the reclaim area offers more space to collect the items at AAS than the other processes, the capacity is set at five passengers. The processing time of this process depends on a number of assigned trays. Again, a random triangular distribution was used, with respectively 10, 20 and 30 s as minimum, mode and maximum values.

At this moment, the passenger leaves the system through three different sinks. "Passengers leaving security" and "Passengers with manually checked bags" correspond to passengers cleared to leave to their final destination. The third sink represents the passengers found not safe for travel; the "passengers for further analysis" (assumed to be 1%) must get in touch with the royal Marechaussee for further processing.

5.3. Model verification

In the verification step, the model logic was reviewed to check if the model operates as intended. This step was done with the help of an expert in airport security systems. Verification activities also included the comparison of the total time that the passenger is in system with values expected in a real-life situation. The results of the comparison were used to finetune the proposed interarrival distributions and process times. The model was ensured to reproduce the operating configuration of the security filter at AAS, as expected in average conditions. The model is not yet validated with Schiphol personnel; this is planned to be done in a next phase.

6. Expected results

With the verified simulation model, the simulation of selected scenarios can assess the improvement in passenger throughput and security level for different percentages of shoe removal, the use or not of a shoe scanner, or its most optimal configuration. These results are valuable in the decision making related to the security filter in AAS and can be easily extrapolated to other airports or similar applications.

Different policies can be analyzed, one focusing on the screening process without the shoe scanner and the other focusing on the performance impact with the shoe scanner, considering different assignment policies. As the model is at present in its validation phase, no final results are available yet.

7. Conclusions

The development of a simulation model for analyzing the impact of new scanning technologies on passenger throughput in security operations underscores the complexity and importance of considering multiple input variables. This study shows that a successful simulation model needs a comprehensive understanding of the security process and its underlying logic. By meticulously incorporating various factors such as boarding pass scanning, queue management, divesting procedures, screening protocols, and potential additional screenings, the model accurately represents real-world scenarios encountered at security checkpoints.

The primary objective of this simulation model is to identify the repercussions of integrating advanced scanning technologies on the efficiency of security operations. Through rigorous analysis and simulation, insights gleaned from this study offer valuable guidance for airport authorities and stakeholders seeking to enhance security protocols while optimizing passenger throughput. Ultimately, this research contributes to the advancement of airport security practices by providing a robust framework for evaluating the implementation of innovative technologies in real-world environments.

The main limitation of this research is that while the simulation model offers valuable insights in the complex airport security screening process, it is based on assumptions and average values, which may not fully capture the complexity of real-world screening scenarios. This may lead to differences between simulation results and actual outcomes. The validation phase is important to finetune the simulation results. On the other hand, this simulation model can be easily adapted to other airport configurations, and can form the basis for evaluating the introduction of other technologies that improve the security filters' throughput.

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