TRANSPORT PROBLEMS 2024 Volume 19 Issue 3
PROBLEMY TRANSPORTU DOI: 10.20858/tp.2023.19.3.17

Keywords: airport management; security screening; fuzzy inference system; epidemic threat; terrorist threat

Jacek SKORUPSKI[1]*, Piotr UCHROŃSKI[2], Katarzyna CHRUZIK[3], Iwona KRZYŻEWSKA[4], Magdalena LETUN-ŁĄTKA[5], Małgorzata ŻMIGRODZKA[6], Jerzy UCHROŃSKI[7]

CAPACITY OF AN AIRPORT SECURITY SCREENING CHECKPOINT UNDER VARIOUS OPERATIONAL CONDITIONS

Summary. The equipment of airport security screening checkpoints undergoes frequent modifications due to technological or organizational changes. New solutions complement or replace existing ones to improve the effectiveness of the equipment or formal requirements. An example of this process is the replacement of the walk-through metal detection gate with a newer solution: the body scanner. The present study aimed to analyze the capacity of an airport security checkpoint under different operational conditions, depending on the equipment used. For this purpose, a previously created model (implemented as a colored, timed, stochastic Petri net) was used. Simulation studies were performed in four real-world operational scenarios, and their results were compared to those of a nominal scenario. The results show that, in terms of capacity, it may be advantageous to redirect a more significant stream of passengers to a station equipped with a specific device, depending on the specific operational situation. The results demonstrate the necessity of analyzing the applied strategy of operation with each change in the operational environment. In particular, for an airport with characteristics similar to Katowice Airport, using older technology is beneficial under nominal conditions and after increasing the staffing so that both genders work simultaneously. In other cases, the more intensive use of Body Scanner-equipped security screening checkpoints is advantageous.

1. INTRODUCTION

Security screening at airports is one of the basic processes of passenger handling. Tasks performed using new technologies must fully comply with the law [4] and ensure the required screening efficiency. Implementing new, more efficient technical solutions and procedures for screening people may limit the security screening checkpoint (SSC) capacity. An excellent example of this phenomenon is the replacement of walk-through metal detection (WTMD) gates by body scanners. Since traditional devices (WTMD gates) are less effective in detecting items prohibited for transport, replacing them with

[1] Warsaw University of Technology, Faculty of Transport; Koszykowa 75, 00-662 Warsaw, Poland; e-mail: jacek.skorupski@pw.edu.pl; orcid.org/0000-0002-0869-4217
[2] WSB University; Zygmunta Cieplaka 1c, 41-300 Dąbrowa Górnicza, Poland; e-mail: puchronski@wsb.edu.pl; orcid.org/0000-0002-0127-8026
[3] WSB University; Zygmunta Cieplaka 1c, 41-300 Dąbrowa Górnicza, Poland; e-mail: kchruzik@wsb.edu.pl; orcid.org/0000-0002-6936-8706
[4] WSB University; Zygmunta Cieplaka 1c, 41-300 Dąbrowa Górnicza, Poland; e-mail: ikrzyzewska@wsb.edu.pl; orcid.org/0000-0003-1739-0925
[5] Silesian University of Technology; Akademicka 2A, 44-100 Gliwice, Poland; e-mail: magdalena.letun-latka@polsl.pl; orcid.org/0000-0003-1107-1317
[6] Polish Air Force University; Dywizjonu 303 no. 35, 08-521 Dęblin, Poland; e-mail: m.zmigrodzka@law.mil.pl; orcid.org/0000-0003-3896-0819
[7] Belchatow District Police Headquarters; 1 Maja no. 7, 97-400 Bełchatów, Poland; e-mail: jurek143@op.pl; orcid.org/0009-0009-3247-372X
* Corresponding author. E-mail: jacek.skorupski@pw.edu.pl

body scanners is beneficial for security reasons. At the same time, a body scanner requires more time to inspect a single passenger under nominal conditions. Thus, SSCs equipped with body scanners have lower capacities than those equipped with WTMD gates. This was demonstrated in Section 3.

At the same time, there are situations in which capacity is not very important. Thus, there is a problem with choosing the right strategy for the operation of the airport screening system, depending on the current operational conditions. This article proposes a solution to this problem. To this end, the authors analyzed four scenarios that could affect passenger handling times at an SSC. The research attempted to quantify the practical throughput of a security screening checkpoint depending on the device used. The experiments included an analysis related to planned changes in the organization of the security checkpoint or changes in the SSC environment, such as increased terrorist or epidemic threats. The process of preparing passengers for screening is similar, regardless of the type of device used. Thus, only the throughput of screening devices, particularly metal detectors (WTMDs) and body scanners, were considered in the analyses.

2. PASSENGER SECURITY SCREENING CHECKPOINT AT THE AIRPORT

2.1. Handling departing passengers

Passenger screening is a part of the passenger handling process at a departure airport and, less frequently, during their transfer at a hub airport. The handling of departing passengers begins when they enter the terminal and ends when they board an airplane. It consists of several stages, the most important of which are:

1. Check-in. Flight tickets are checked, boarding cards are issued, and baggage is checked in. Moreover, a passenger with overweight baggage must go to checkout and pay an appropriate fee. Oversized baggage must also be checked in at an appropriate station. The check-in procedure may be performed by an employee or automatically.
2. Access control to restricted areas. A boarding card is checked to allow access to a restricted area.
3. Security screening. This stage consists of controlling passengers and their hand baggage. It is the main subject of this article.
4. Passport control. This stage consists of controlling documents required to cross a state border.
5. Gate. At this point, passengers wait to board; once this stage has begun, boarding cards are checked, and passengers are handled according to the applied boarding strategy.
6. Transport to aircraft. This service delivers passengers on board; passenger platforms, bus transport, and pedestrian access are the most common methods.

2.2. Literature review

A security screening system, as an essential element of the pre-flight operation process, has been the subject of numerous studies. In the following short literature review, we present only a few aspects of these studies, which are essential to show what the extension of state of the art presented in our paper consists of. The most important elements are security screening system throughput and WTMD gates and body scanners as screening devices.

The literature has shown that passenger screening system throughput largely depends on passenger preparation process organization [11]. Optimal assignment policies increase security and passenger throughput by efficiently and effectively utilizing available screening resources. In baggage screening, the time necessary to classify baggage as potentially dangerous is crucial to the throughput [19]. This time was found to be relatively stable across threat categories, but the decision time increased in proportion to the decrease in the detection rate. Decision time closely reflects changes in detection sensitivity caused by different threats and image difficulties.

The dependence of throughput on economic factors is presented in [7]. Sterchi and Schwaninger [18] conducted tests using an explosive detection system to check hand baggage in terms of throughput. The results show that this approach results in moderate increases in the false alarm rate but that this can be buffered by employing more experienced and trained X-ray screeners. More significant false alarm rate increases require faster resolution and additional manual search resources. The throughput and checked baggage system reliability analyses are presented in [6]. An example of the screening system throughput analysis for a selected airport is presented in [9].

The throughput of SSCs equipped with WTMD gates was investigated with different stand organizations, considering the number of devices and the number of queues handled by one device. The capacity of the checked baggage control system was analyzed in [16]. The studies employed a microscale model of object movement implemented as a colored, timed, stochastic Petri net. Janssen et al. [8] studied the impact of a passenger type on the screening system throughput. They attempted to form a so-called service lane to mitigate the problem of waiting for the slowest passengers. They found that the mean throughput of the service lane setups was higher than the average throughput of the standard lanes, making it a promising setup to investigate further.

Wu and Mengenstern [21] presented a very interesting review of methods and tools for modeling various complex processes that occur at an airport. They pointed out the importance of using microscale models for security screening analysis [14, 20]. Moreover, quite a few studies analyzed the strategy of modifying security screening procedures based on risk analysis and assessment conducted for each passenger [3, 13].

All the discussed literature concerning passenger control considers SSCs where WTMD gates are used. The literature on the use of body scanners in security control is relatively scarce and primarily focuses on ethical and medical issues [1, 10, 12]. This trend is also present in newer publications [5]. In recent years, studies have also included body scanners in analyzing passenger satisfaction with airport services [15]. The context of operational problems is also worth considering, but the capacity issues of SSCs have not been analyzed [2].

2.3. Paper concept

The literature review indicates the existence of a group of publications analyzing the capacity of SSCs equipped with WTMD gates. However, they have focused on the organization of the checkpoint, passenger preparation for screening, and the division of passengers into groups with different characteristics. Meanwhile, there is a lack of studies analyzing capacity regarding the screening process itself (i.e., passing through the gate, the need to repeat this procedure, etc.). Moreover, there is a lack of studies addressing the operational conditions in which passenger security screening is conducted. Our article fills these gaps. First, we examine the capacity of the screening process itself. Additionally, we consider numerous operational issues, such as the season, which determines passenger clothing, the level of terrorist or epidemic threat, and even issues related to the availability of appropriate screening personnel.

The second group of publications related to the capacity of SSCs concerns the inspection of cabins and checked baggage. While this issue is not directly addressed in our article, the experiences with modeling methods for these processes have been utilized here. This mainly involves the application of microscale models and their analysis using simulation methods, taking into account the randomness of passenger arrival times and the duration of inspections. The research presented in this article was conducted using a model implemented as part of the work [17] as a colored, timed, stochastic Petri net. This model is a valuable tool for examining the capacity of the security control system (as demonstrated in this work) and other aspects of the passenger screening process.

The literature shows a lack of studies analyzing the capacity of SSCs equipped with body scanners. More attention has been given to ethical and medical issues. In this article, we explore the capacity of the screening process itself, along with all its conditions. Ethical and organizational issues are also present in the context of capacity. As part of one experiment, the screening process was analyzed considering the gender of the screened individual and the operator performing the screening.

The conclusion drawn from the literature review is that there is a lack of studies comparing WTMD gates and body scanners. This work fills this gap, as the entire research, across all analyzed operational scenarios, focuses on such a comparison.

Due to the lack of this kind of comparison, there is a need to support security managers at airports with tools that make it possible to reasonably (quantitatively) estimate the impact of using specific solutions exerted on operations performed at an airport. As mentioned above, this is a practical and common problem, especially in small and medium-sized airports where screening equipment replacement may face financial and organizational barriers (e.g., due to the lack of space for creating new security screening stations).

WTMD and body scanner manufacturers declare the throughput of devices in a given work environment. For example, the declared throughput for the tested WTMD device was 360 passengers per hour. On the other hand, for the tested body scanner, the declared throughput was 1200 passengers per hour. However, operational practice experience indicates that such throughput is unlikely to be achieved in real-life conditions. A model of a security screening checkpoint was developed and calibrated based on measurements carried out at the Katowice Airport (KTW) to assess the suitability of tested devices in actual operating conditions and with the existing infrastructure [17]. This model was used to estimate the practical throughput of devices in the conditions of a regional airport handling about 5 million passengers a year. The model was validated by a statistical analysis of obtained measurement data and then an analytical determination of the throughput of a station equipped with the tested device.

The second important aspect influencing the decision to use body scanners is the conducted screening effectiveness. While analyzing it roughly and qualitatively, it seems this device's efficiency is higher because it detects metallic and non-metallic objects. However, considering the practical decision-making issue, it is essential to consider the increase in effectiveness and compare it with installation costs and possible difficulties related to the loss of SSC throughput. Data regarding the effectiveness and practical throughput of devices of various types indicates that more conscious planning of SSC equipment is possible. It is worth noting that there is a need to determine the number of security screening checkpoints necessary to handle passenger traffic at an airport and, thus, the number of security screening checkpoint operators required. When more SSCs are utilized, there is a need for more operators (SSOs) to staff them, and such operators must have unique predispositions and qualifications; thus, acquiring new employees may be challenging and long-term. All these aspects must be considered when deciding to equip an SSC with a particular type of passenger screening equipment. Studies examining these aspects are planned for the future.

We believe that the proposed approach to determining the practical throughput of a screening device will allow the effects of decisions to be accurately determined and meaningfully supported. It is worth noting that the method can be applied to both current airport operating conditions and conditions anticipated in the future and in the presence of disruptions resulting from emergencies. Example analyses for such scenarios were carried out as part of our research and are presented later in this article. They are concerned with the dependence of throughput on external events, such as the increased threat of terrorist attacks, epidemiological threats, or changes in seasons, as well as organizational actions, such as changes in SSC staffing.

3. PASSENGER SECURITY SCREENING CHECKPOINT AT THE AIRPORT

The passenger security screening process consists of several activities. The first stage is to verify the passenger's identification on their boarding card. The second stage consists of preparing for a check, during which passengers place all their metal and electronic items in a dedicated container. Then they put their remaining hand baggage on a conveyor belt. Then, the main check is carried out, which is the subject of our research (described in detail in Sections 3.1 and 3.2).

Two basic devices support the personnel performing the check. The first is an X-ray scanner used for screening baggage, and the other one is a personal screening device, which is intended to verify that there are no hidden objects on the controlled person's body that may pose a threat to the safety of aviation operations. Baggage and passenger screening procedures are usually performed simultaneously.

Apart from these basic tools, SSCs also use devices to control liquids and detect trace amounts of explosives. These devices can be configured differently. Most frequently, one X-ray device operates one screening line, and therefore, there is also one WTMD or body scanner detector. However, there are cases where one X-ray device operates two personal screening lines or vice versa. The use of these spatial systems depends on the volume of traffic, available space, and financial capabilities.

One of the most popular airport passenger security screening solutions is a walk-through metal detector (WTMD) operated based on electromagnetic induction. Applicable legal regulations [4] provide detailed specifications of the parameters of such a device. The device detects metal objects hidden on the screened person's body. Most items that may be considered weapons (and, therefore, are not allowed for air transport) are made of various metals. However, it is possible to design dangerous objects prohibited for transport using non-metallic materials, so the WTMD screening is supported by manual checks performed at the frequency and in the manner specified by applicable regulations [4].

The technology of screening people using this tool depends on detailed technical solutions provided by individual manufacturers. These include, for example, the number of detection areas and the possibility of individual programming of detection zones in a detector.

Body scanner technology constitutes an alternative to security screening using a WTMD. The principle of a body scanner's operation is different from that of a walk-through metal detector. A body scanner uses non-ionizing radiation, which makes it possible to detect all objects (not only metallic ones) that are transferred to a passenger's body. For this reason, the screening procedure is also different. In the case of a WTMD, one goes through the detector, whereas in the case of a body scanner, it is crucial to set a passenger in a specific position inside the device. This results in a precise indication of places where a hidden and potentially dangerous tool can be expected. Therefore, a manual check has slightly different characteristics than one performed after WTMD use. A security screening operator manually checks the locations indicated by a body scanner (directional screening). If the number of indicated places is large, an operator manually checks the entire passenger's body (full screening).

The individual devices and processes in an SSC are closely related to one another and determine the effectiveness of pre-flight operation. For example, in a typical situation, when a passenger's manual screening is performed, the entire screening line is blocked, both concerning subsequent passengers and, partially, subsequent baggage. Such a situation occurs when one person is assigned to perform manual screening procedures. If there are more operators, the line is blocked only when all SSOs are occupied performing manual checks. A similar situation occurs when a suspicious object is detected in a passenger's baggage. Then, it is re-screened or checked manually. In such a case, the screening line operation is blocked to baggage and passengers.

More detailed information about the procedures and control principles considered in the studies can be found in [17], which presents the passenger flow and the analyzed process's quantitative parameters (including probabilistic). These parameters were obtained from measurements conducted at Katowice Airport.

4. PASSENGER SCREENING STATION THROUGHPUT ANALYSIS

This section presents a throughput analysis of a passenger screening station equipped with a WTMD and a body scanner. It was carried out under nominal conditions following the measurements conducted. This section also compares the results obtained from the model with the actual results to verify the obtained results.

4.1. Throughput of an SSC equipped with a WTMD

The measurements presented in Fig. 1 were directly used to assess the throughput under nominal conditions.

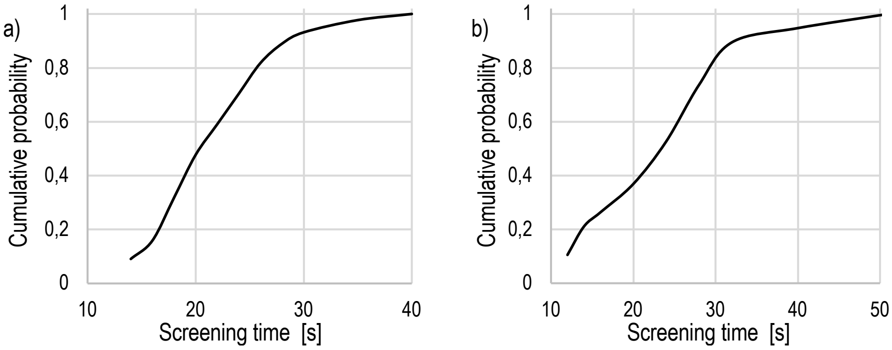

Fig. 1. Empirical screening time distribution functions for different sequences: a) Alarm → Manual check, b) Alarm → Walk-through repeated → No check

For this data set, 10^6 seconds (about 280 hours) of continuous station operation were simulated. Assuming a constant influx of passengers ready for security screening, the station can handle 79,770 passengers. This means that the capacity of a station equipped with a WTMD, under nominal conditions, is 287 passengers per hour.

To verify the correctness of the tool, we compared the results with analytical calculations, whose throughput result is equal to 281 passengers per hour, which is very close to the result obtained from the model (2% difference).

4.2. Throughput of an SSC equipped with a body scanner

The measurements presented in Fig. 2 were directly used to assess the throughput under nominal conditions. Examples of screening time distribution functions for the sequence are also shown in Fig. 2.

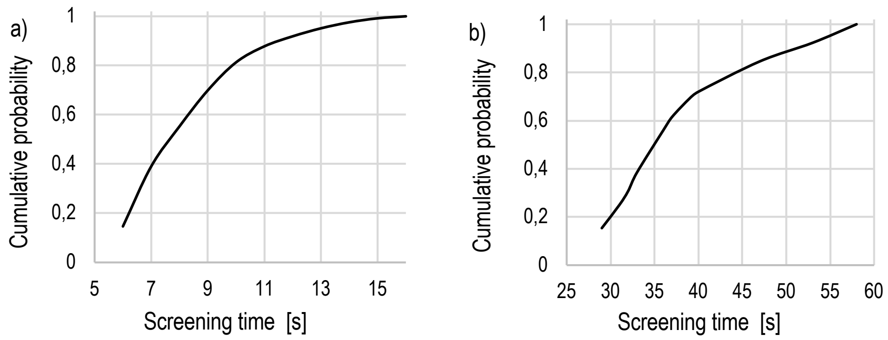

Fig. 2. Empirical screening time distribution functions for different sequences: a) No alarm → No check, b) Alarm → Manual check (full)

For this data set, 10^6 seconds (about 280 hours) of uninterrupted station operation were simulated. Assuming a continuous influx of passengers ready for security screening, the station can handle 69,716 passengers. This means that the throughput of a station equipped with a body scanner under nominal conditions is 251 passengers per hour.

5. SIMULATION EXPERIMENTS

The developed models enabled us to determine screening station throughput in typical conditions and perform simulation experiments for various non-standard cases. We have defined the following research scenarios:

1. The nominal variant, the results of which are presented in Section 3.

2. Scenario 1, where we study the situation in winter (Section 4.1).
3. Scenario 2, where we study a higher terrorist threat level (Section 4.2).
4. Scenario 3, where we study an increased epidemiological threat (Section 4.3).
5. Scenario 4, where we study the number and gender of SSOs operating a single device (Section 4.4).

Simulations were carried out for all scenarios using the model described in [17]. For the relevant data sets, 10^6 seconds (about 280 hours) of uninterrupted station operation were simulated. The random phenomena during passenger screening were reproduced and represented by the probability of a specific sequence of actions and the random time of each action. The values of these probabilities and the characteristics of the random variables describing these times were determined based on measurements carried out during the actual operation of Katowice Airport.

5.1. Scenario 1 – Winter period

The analyzed KTW airport is located in a moderate climate zone, which is essential for passenger handling. It results from how passengers adapt their clothes to changing weather conditions. Although the method of performing safety checks does not change in the winter period, the clothing type is significant. In particular, this relation is reflected by passengers' footwear, which, due to additional metal reinforcements, trigger alarms more often than in the summer when passengers usually wear light sports footwear. This makes it necessary to prepare a passenger more thoroughly for a check, and thus, the total time of handling a single passenger in winter may be extended by up to 30–40%. Of course, most of the time is spent preparing the passenger for the check, which is beyond the scope of this paper. However, during the check, there are also differences.

For example, for the reasons referred to above, the probability of alarm occurrence when passing through WTMD is higher in winter than in summer. Practical observations estimate that this difference is about 20% when passengers walk through the detector for the first time and about 30–40% when they possibly walk through it for the second time. Therefore, in the winter, the number of manual checks increases. Because a passenger usually wears more layers of clothing in winter, a manual check usually takes about 20% longer than the basic screening variant.

When using a body scanner, there is also an increased probability of alarm activation. We estimate that the number of these alarms is higher by approximately 20% compared to the measurements in the basic variant. At the same time, since body scanner technology enables the better location of places to be checked, the check duration does not change significantly. Owing to the algorithm of selecting passengers for complete manual checks, their frequency is expected to rise by approximately 10%. Also, the check duration does not change significantly due to the previous reasons.

5.1.1. Throughput analysis – WTMD

A summary of changes in the screening model using WTMD (Scenario 1) is included in Table 1.

For such parameters, the simulated throughput of a station equipped with WTMD in winter conditions (for Scenario 1) was 231 passengers per hour, equaling 81% of the nominal variant throughput.

Table 1

Data for the model with the use of WTMD for Scenario 1

Parameter	Nominal	Scenario 1
The frequency of alarms triggered when passengers walk through the detector for the first time	0.345	0.414
The frequency of alarms triggered when passengers walk through the detector for the second time	0.28	0.378
Manual check duration	t	$1.2t$

5.1.2. Throughput analysis – Body scanner

A summary of changes in the screening model using a body scanner (for Scenario 1) is included in Table 2.

Table 2

Data for the model with the use of a body scanner for Scenario 1

Parameter	Nominal	Scenario 1
Alarm frequency	0.36	0.432
Frequency of full manual check selection	0.194	0.213

For such parameters, the simulated throughput of a station equipped with a body scanner in winter conditions (for Scenario 1) was 232 passengers per hour, which equals 92% of the nominal variant throughput.

5.2. Scenario 2 – Increase in terrorist threats

The main objective of security screening at airports is to prevent acts of unlawful interference, often related to the activity of terrorist groups. A certain average probability of a terrorist act is assumed while establishing operational standards for the application of security screening. However, there are special situations where this probability is estimated to increase based on various types of information. It is then necessary to change the system operating parameters or even introduce additional procedures that are adequate to the present threat. These actions affect both screening effectiveness and station throughput.

In Experiment 2, we assume that the WTMD sensitivity is maximized, allowing the detection of metal objects of less than the standard weight. In this case, the probability of detector alarm activation rises proportionally to the increase in device sensitivity. Our observations show that this case's alarm activation frequency reaches 60%. Since WTMDs detect only metals, more manual checks are necessary. Therefore, we assumed that each WTMD alarm would be verified by a manual check without the possibility of passing through the detector again. Thus, the frequency of manual checks is expected equal the frequency of alarms. The increased risk of terrorist-related events results in more checks performed by SSOs. This translates into the manual check duration; we assumed it would last 30% longer than usual.

In the case of body scanners (in the devices available to us), it was not possible to increase their sensitivity. However, awareness of the real threat mentioned above means that the duration of a directional and full check will be longer than that of standard security screening. We estimate that this increase amounts to about 20%. At the same time, the surveyed SSOs declared their readiness to perform complete manual checks more frequently in cases when directional checks are typically performed. We estimated that approx. 15–20% of manual checks would be conducted in the complete check mode instead of directional checks.

5.2.1. Throughput Analysis – WTMD

A summary of changes in the screening model using WTMD (Scenario 2) is included in Table 3.

For such parameters, the simulated throughput of a station equipped with a WTMD in increased terrorist threat conditions (for Scenario 2) was 174 passengers per hour, which equals 61% of the nominal variant throughput.

5.2.2. Throughput analysis – Body scanner

A summary of changes in the screening model using a body scanner for this scenario is included in Table 4.

For such parameters, the simulated throughput of a station equipped with a body scanner in increased terrorist threat conditions (for Scenario 2) was 208 passengers per hour, which equals 83% of the nominal variant throughput.

Table 3
Data for the operating model with the use of a WTMD for Scenario 2

Parameter	Nominal	Scenario 2
The frequency of alarms triggered when passengers walk through the detector for the first time	0.345	0.6
The frequency of situations in which passengers walk through the detector for the second time	0.362	0.0
The frequency of manual checks after the first alarm	0.628	1.0
Manual check duration	t	$1.3t$

Table 4
Data for the operating model with the use of a body scanner for Scenario 2

Parameter	Nominal	Scenario 2
Full manual check duration	t_1	$1.2t_1$
Manual directional check duration	t_2	$1.2t_2$
The frequency of directional manual check selection	0.806	0.626
The frequency of full manual check selection	0.194	0.374

5.3. Scenario 3 – Epidemiological threat

Air transport is extremely sensitive to various external factors affecting people's ability to travel. As shown by the experience of the latest COVID-19 pandemic, the risk of a contagious disease spreading globally may result in the almost complete grounding of all planes worldwide. Using the developed models, we compare passenger screening technologies in the context of additional actions necessary to reduce the threat. These actions include measuring the body temperature of departing passengers or maintaining the required distance between passengers. Observations of this type translate into work organization at a security screening checkpoint, changing its throughput.

However, maintaining the distance of 2 m results in an extension of the time necessary to walk through WTMD by approximately two seconds. Two measures are applied to minimize the contact between a passenger and SSO. On the one hand, the frequency of situations in which passengers trigger an alarm and need to walk through the WTMD for the second time increases by 40% compared to an immediate manual check. On the other hand, instead of complete manual checks, only the areas of the body indicated by the device are inspected. Therefore, the screening time is about 50% shorter. The SSO performs a full manual check only for a justified suspicion based on passengers' behavior analysis (i.e., they may be carrying a prohibited object). In our scenario, we investigate a situation when a full manual check takes place in approximately 10% of cases when a manual check is performed.

In the case of security screening performed with a body scanner, we also consider the extension of the check duration resulting from the need to maintain a correct distance between passengers. As in the case of WTMD checks, the ratio between directional and complete checks is also expected to change. In our scenario, we investigate a situation when only about 5% of manual checks are complete checks.

At the same time, in the passenger screening process using both WTMD and body scanner, it would be possible to consider situations when a passenger with an elevated body temperature is detected. Special sanitary procedures are implemented in this case, such as separating the passenger and disinfecting a station. In such cases, it is estimated that the time of excluding SSC from use may be between 15 and 60 minutes. This analysis type is planned in the future when measurement data concerning the frequency of such cases is available.

5.3.1. Throughput analysis – WTMD

A summary of changes in the screening model using WTMD (Scenario 3) is included in Table 5.

Table 5

Data for the operating model with the use of WTMD for Scenario 3

Parameter	Nominal	Scenario 3
The time required to walk through a detector	t_1	$t_1 + 2$
Manual check duration	t_2	$0.5t_2$
The frequency of situations in which passengers walk through the detector for the second time	0.362	0.762
Frequency of complete manual checks	N/A	10%

For such parameters, the simulated throughput of a station equipped with a WTMD in epidemiological threat conditions (for Scenario 3) was 272 passengers per hour, which equals 95% of the nominal variant throughput.

5.3.2. Throughput analysis – Body scanner

A summary of changes in the screening model using a body scanner for this scenario is included in Table 6.

Table 6

Data for the operating model with the use of a body scanner for Scenario 3

Parameter	Nominal	Scenario 3
The time required to walk through a detector	t	$t + 2$
Frequency of full manual check selection	0.194	0.05

For such parameters, the simulated throughput of a station equipped with a body scanner in epidemiological threat conditions (for Scenario 3) was 233 passengers per hour, which equals 93% of the nominal variant throughput.

5.4. Scenario 4 – Changes in SSC personnel

According to applicable legal regulations, SSC personnel includes at least three operators performing security screening-related tasks. One person screens the baggage, the other checks passengers, and the third person prepares the passengers for checks. In such a configuration, possible disturbances in the continuity of the checks performed may most often occur in two cases:

- the person to perform a manual check of a passenger of a given sex is absent at a checkpoint;
- the continuity of passenger checks is stopped due to the need to perform a manual check.

Disturbing the passenger security screening continuity because an operator of a given sex is absent at an SSC is quite a frequent phenomenon. For objective reasons, a manual check should be performed by an operator of the same sex as the passenger. In the absence of an appropriate person, the screening continuity is disturbed for a short moment, and operators are changed between SSCs. In practice, this takes 5–15 seconds. The solution to this problem is to ensure constant staffing of women and men performing passenger screening duties. We consider this situation as Scenario 4.

Additionally, in the case of sex non-compliance, an SSO may more often ask a passenger to walk through a detector again, hoping that there will be no alarm during the second pass and it will not be necessary to change SSOs to carry out the check. In the case of double staffing, this is not required, and it is possible to immediately start a manual check of a passenger who has triggered the alarm. In this scenario, we perform calculations, again assuming that the number of passengers walking through a detector would decrease by 20%.

Double staffing of passenger screening stations partially solves the second of the problems mentioned above, consisting of SSC standstills for the duration of a manual check. In the case considered in this scenario, one of the SSOs performs a manual check (in a designated place located near the SSC) for a passenger of the same gender). Meanwhile, another passenger will be subjected to a security check using WTMD.

In the case of a station equipped with a body scanner, there are precisely the same problems related to the necessity of performing manual checks by a person of the same sex and blocking the station for the duration of a manual check. Therefore, in this case, we deal with the same changes in system parameters so that we can compare the effects of the analyzed change in SSC staffing for both types of devices.

5.4.1. Throughput analysis – WTMD

A summary of changes in the screening model using a WTMD (Scenario 4) is included in Table 7.

Table 7

Data for the operating model with the use of a WTMD for Scenario 4

Parameter	Nominal	Scenario 4
Manual check duration	t	$t-5$
The frequency of situations in which passengers walk through the detector for the second time	0.362	0.162

For such parameters, the simulated throughput of a station equipped with a WTMD staffed by two people of different sexes to handle the passenger flow (for Scenario 4) was 574 passengers per hour, which equals a 100% increase related to the nominal variant throughput.

5.4.2. Throughput analysis – Body scanner

A summary of changes in the screening model using a body scanner for this scenario is included in Table 8.

Table 8

Data for the operating model with the use of a body scanner for Scenario 4

Parameter	Nominal	Scenario 4
Full manual check duration	t_1	t_1-5
Manual directional check duration	t_2	t_2-5

For such parameters, the simulated throughput of a station equipped with a body scanner staffed by two people of different sexes to handle the passenger flow (for Scenario 4) was 392 passengers per hour, which equals a 56% increase of the nominal variant throughput.

6. DISCUSSION OF RESULTS

The developed models for testing screening throughput at security screening checkpoints facilitate conducting a wide range of simulation experiments. Four such experiments presented in this paper were selected based on assessments of the operational problems occurring within the practical operation of the analyzed KTW airport. A summary of the results obtained is presented in Table 9.

Table 9

Summary of simulation experiment results

Case analyzed	WTMD throughput [pax/h]	Body scanner throughput [pax/h]
Nominal conditions	287	251
Scenario 1	231	232
Scenario 2	174	208
Scenario 3	272	233
Scenario 4	574	392

The results for the nominal case perfectly show the existing dilemma between providing higher throughput and higher SSC effectiveness. However, long-lasting and detailed checks ensure the greater effectiveness of prohibited material detection at the expense of throughput. Our experiment shows this relationship quantitatively. SSC throughput under nominal conditions is 14% higher if a WTMD is used for screening purposes. This value may help operators make decisions about which screening technique to apply. However, other elements like traffic volume and investment funds also influence the final decision.

In a standard situation, it seems more beneficial for the KTW airport to carry out passenger checks using the previously available WTMD devices. This makes it possible to achieve greater SSC throughput at a good level of screening effectiveness consistent with international regulations without requiring any capital expenditures related to purchasing body scanners.

In the event variant described in Scenario 1, we tested the passenger security screening throughput sensitivity to seasonal changes. The winter season was selected as the most deviating from the nominal values when passengers wear more layers of clothing, potentially hindering SSO's control process. The results show that the throughput of a station in both cases decreases but to a greater extent when a WTMD is used, which makes it practically equal for both variants.

Scenario 2 concerns the possibility of an increased terrorist threat at an airport. In such situations, a standard action is to implement additional screening activities or increase the frequency of activities usually performed sporadically. In this scenario, the WTMD throughput decreases much more than the body scanner throughput. Thus, in this scenario, the evaluation parameters are better for body scanner. The results obtained are very practical and show that, it is beneficial to use an SSC with a body scanner in the case of an increased terrorist threat. This finding may provide meaningful guidance for operational security management services.

The third analyzed scenario concerned a current problem (i.e., an epidemiological threat). The state of the epidemiological danger in 2020, connected with COVID-19, clearly showed its negative impact on the global transport system, particularly on air transport. Airports are pivotal locations in such situations, as viruses can be easily transmitted in these environments. For this reason, significant restrictions are introduced to minimize the direct contact of passengers with airport personnel. Such limitations can also be observed during passenger security screening.

An analysis of the results for the two discussed passenger screening methods shows a slight (approx. 5–7%) decrease in SSC throughput when a body scanner is used. Methods implemented in such a situation to protect personnel against infection may mean that not all screening elements are performed with the same effectiveness as in standard conditions. The results obtained in Scenario 3 show that body scanners are a better solution in the case of an epidemiological threat. Under these conditions, there is a significant decrease in the number of aviation operations, which reduces the number of passengers handled. This means that the issue of SSC throughput is secondary to the screening effectiveness and protection of personnel against possible contact with an infected passenger.

Scenarios 1–3 concern changes in the screening system environment, which may hurt its throughput. Conversely, Scenario 4 concerned modernization activities that could be undertaken under nominal conditions. We considered the impact of screening checkpoint personnel changes on its throughput. In particular, the research very often concerned the lack of SSO of the same sex as a passenger in the direct vicinity of a screening location. The results of the simulation experiment show that, regardless of the selected method, such factors as an increase in SSC personnel by one person and ensuring that persons of both sexes work at a station result in a significant increase in SSC throughput (by 100% for SSCs with a WTMD and by more than 50% for those with a body scanner).

The results obtained for Scenario 4 allow a significant practical conclusion to be formulated. Implementing the proposed organizational changes increases the advantage of WTMDs over body scanners in terms of throughput without impacting screening effectiveness. Therefore, for airport managers, developing the infrastructure and purchasing additional screening equipment may be an alternative to much more expensive solutions.

7. CONCLUSIONS

Based on the four scenarios presented, the current research showed that many possible events affect the choice of which passenger screening technology an airport should utilize. This finding is valuable for airport managers because it allows them to consciously plan the terminal infrastructure of the airport depending on the geopolitical situation, geographical location, and the adopted passenger check-in methodology. This action, based on concrete knowledge about the effects of implemented solutions, in turn, allows them to adapt to the current needs resulting from the formal or operational conditions of the airport. The studies described in this paper, which presented four scenarios, showed that it could not be clearly stated which technology should be selected.

References

1. Accardo, J. & Chaudhry, M. Radiation exposure and privacy concerns surrounding full-body scanners in airports. *Journal of Radiation Research and Applied Sciences*. 2014. Vol. 7(2). P. 198-200.
2. Carr, A. & Biswas, T. & Wheeler, J. Airport operations and security screening: An examination of social justice. *Journal of Air Transport Management*. 2020. Vol. 85. No. 101814.
3. Chawdhry, P. Risk modeling and simulation of airport passenger departures process. *Winter Simulation Conference (WSC).* Austin, TX, USA. 2009. P. 2820-2831,
4. Commission implementing regulation (EU) 2015/1998 of 5 November 2015 laying down detailed measures for the implementation of the common basic standards on aviation security.
5. Dillon, T. & Thomas, D. Exploring the acceptance of body searches, body scans and TSA trust. *Journal of Transportation Security*. 2015. Vol. 8. P. 51-67.
6. Feng, Q. & Sahin, H. & Kapur, K. Designing airport checked-baggage-screening strategies considering system capability and reliability. *Reliability Engineering & System Safety*. 2009. Vol. 94(2). P. 618-627.
7. Gillen, D. & Morrison, W. Aviation security: Costing, pricing, finance and performance. *Journal of Air Transport Management*. 2015. Vol. 48. P. 1-12.
8. Janssen, S. & van der Sommen, R. & Dilweg, A. & Sharpanskykh, A. Data-driven analysis of airport security checkpoint operations. *Aerospace*. 2020. Vol. 7(6). No. 69.
9. Kierzkowski, A. & Kisiel, T. Simulation model of security control system functioning: A case study of the Wroclaw Airport terminal. *Journal of Air Transport Management.* 2017. Vol. 64. Part B. P. 173-185.
10. Klitou, D. Backscatter body scanners – A strip search by other means. *Computer Law & Security Review.* 2008. Vol. 24(4). P. 316-325.
11. Lee, A. & Jacobson, S. The impact of aviation checkpoint queues on optimizing security screening effectiveness. *Reliability Engineering & System Safety*. 2011. Vol. 96. P. 900-911.
12. Mironenko, O. Body scanners versus privacy and data protection. *Computer Law & Security Review*. 2011. Vol. 27(3). P. 232-244.

13. Nie, X. & Batta, R. & Drury, C. & Lin, L. Passenger grouping with risk levels in an airport security system. *European Journal of Operational Research*. 2009. Vol. 194(2). P. 574-584.
14. Pendergraft, D. & Robertson, C. & Shrader, S. Simulation of an airport passenger security system. *Proceedings of the 2004 Winter Simulation Conference*. Washington, DC, USA. 2004. P. 874-878.
15. Rubio-Andrada, L. & Celemín-Pedroche, M. & Escat-Cortés, M. & Jiménez-Crisóstomo, A. Passengers satisfaction with the technologies used in smart airports: An empirical study from a gender perspective. *Journal of Air Transport Management*. 2023. Vol. 107. No. 102347.
16. Skorupski, J. & Uchroński, P. & Łach, A. A method of hold baggage security screening system throughput analysis with an application for a medium-sized airport. *Transportation Research Part C.* 2018. Vol. 88. P. 52-73.
17. Skorupski, J. & Uchroński, P. & Chruzik, K. & Krzyżewska, I. & Letun-Łątka, M. & Żmigrodzka, M. & Uchroński, J. Impact of the Body Scanner application on passenger screening throughput. *Transport Problems*. 2024. Vol. 19(2). P. 5-18.
18. Sterchi, Y. & Schwaninger, A. A first simulation on optimizing EDS for cabin baggage screening regarding throughput. *2015 International Carnahan Conference on Security Technology (ICCST).* Taipei, Taiwan. 2015. P. 55-60.
19. Wales, A. & Halbherr, T. & Schwaninger, A. Using speed measures to predict performance in X-ray luggage screening tasks. *43rd Annual 2009 International Carnahan Conference on Security Technology.* Zurich, Switzerland. 2009. P. 212-215.
20. Wilson, D. & Roe, E. & So, S. Security checkpoint optimizer (SCO): an application for simulating the operations of airport security checkpoints. *Proceedings of the 2006 Winter Simulation Conference.* Monterey, CA, USA. 2006. P. 529-535.
21. Wu, P. & Mengersen, K. A review of models and model usage scenarios for an airport complex system. *Transportation Research Part A: Policy and Practice*. 2013. Vol. 47. P. 124-140.

Received 06.02.2023; accepted in revised form 06.09.2024