Modelling and Optimization of Airport Security Screening System with AnyLogic Simulation: A Case of Dublin Airport

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Abstract. Airports worldwide have undergone a significant transformation to provide a more efficient, secure, and enjoyable travel experience for passengers. The delays or inefficiency of aviation security checks not only reduces the effectiveness of airport security operations, but also leads to worthening of passengers’ experience and increases criminal and terrorist threats. This paper examines the issue of airport security system modelling with AnyLogic simulation to increase its efficiency, using Dublin Airport as a case study. The research aimed to identify the causes of queues in the airport security lanes and to develop recommendations for airport authority regarding optimal resources utilization at the security checkpoints. Various airport security systems were analyzed in the paper, followed with the airport’s epidemiological safety assessment through the correspondent optimization experiments in the simulation software AnyLogic.

The research results indicate the necessity to implement a new strategy for improving the efficiency of the airport security procedures. It was found that the optimal security system for the case airport is Rapiscan 620XR. It can reduce the average passenger’s processing time at security checkpoint to 0.635 min. It was also determined that in case of the new security system usage the morning hours (6 am–1 pm) are the least congested with the resources utilization at 78%, while the system operates at full capacity during the afternoon and evening hours. In future research, it would be beneficial to evaluate alternative simulation tools and

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examine other scenarios to compare their outcomes with the results discussed in this paper.

Keywords: Simulation modelling · AnyLogic · Airport · Security control · Resources management · Queue management · Pandemic

1 Introduction

Ensuring airport security helps to promote trust in air travel and to ensure the smooth operation of the aviation industry [1]. Safety of airport operations depends on the efficiency of security checks, which in turns ensure the welfare and well-being of passengers, airport staff and other airport users. Delays in aviation security checks not only compromise the effectiveness of airport security operations but also negatively impact passengers experience and increases criminal and terrorist threats [2, 3].

Managing queues in airport security systems is a very complicated issue. It is not only about long lines, which create unsatisfactory passengers experience, this issue also makes difficult to manage aircraft take-offs and landings. Due to the long queues at security checkpoints passengers can miss their flights, which is associated with a high stress level and bad passengers experience. Additionally, the long period in crowded security lanes will decrease the level of epidemiological safety within an airport environment [4, 5].

Nowadays, at Dublin Airport (daa), delays at security checks sometimes exceed 20 min (Fig. 1), highlighting an urgent need to investigate the causes of these queues [6, 7].

The root causes of such a huge delay may include inappropriate resources allocation, suboptimal queue management techniques, or inefficiencies in the security screening operations. Such long queues not only inconvenience passengers but also pose potential security risks and operational inefficiencies.

As airlines are trying to enhance passenger experience within a terminal building, particularly through minimizing passengers waiting time in queues especially at security checks, it is extremely importation to provide an effective queue management mechanism to improve passengers handling processes at an airport.

Currently, issues of modelling and optimization of airport operations have attracted the attention of many researchers. In the works of [1, 3, 8–12], various approaches to air passengers flows modelling were considered, which made it possible to identify key factors influencing the formation of queues. In studies [13–16], the effectiveness of various security systems of international airports was evaluated, highlighting the importance of considering the passengers processing time when developing optimization strategies.

However, the most previous studies were focused on the specific aspects of airport operations only, lacking comprehensive models that include all terminal operations and considers specific features of different categories of passengers handling. Additionally, the issues of the resources management at aviation security checkpoints depending on the time of a day, as well as the impact of security systems on queue management and the epidemiological safety of the airport, remain insufficiently studied.

Thus, *the purpose of this paper* is to examine and address the issues related to the queue management, resources utilization and epidemiological safety assessment during

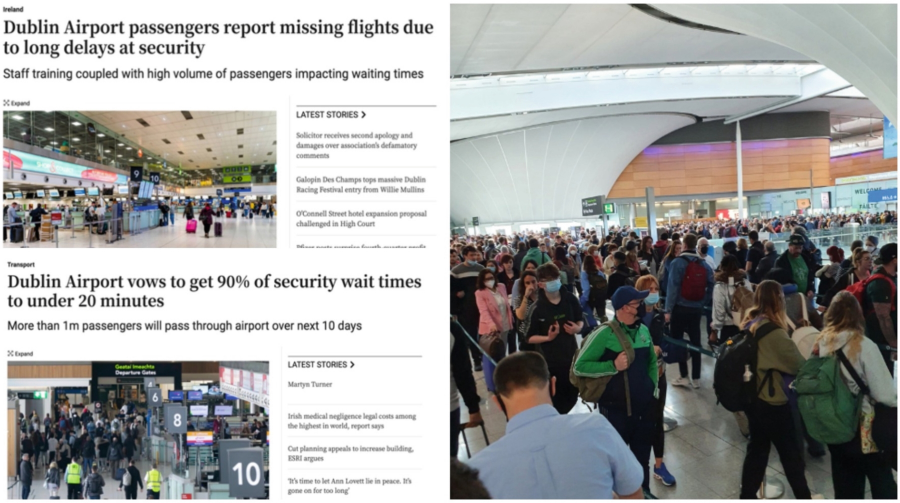


Fig. 1. Dublin Airport's delays at security checks [6, 7].

passengers processing at the airport's security checkpoints with the help of simulation modelling technique, using Dublin Airport as a case study.

The research objectives of the paper are as follows:

- to develop a simulation model of the Dublin Airport's Terminal 1 for establishing the reasons of queues formation at security checkpoints;
- to conduct an analysis of various security systems used at the leading airports worldwide;
- to perform optimization experiments in order to determine the most effective security system for the investigated airport, followed by its stress test in the simulation software AnyLogic;
- to evaluate the epidemiological safety of the investigated airport and assess the impact of airport's operations on it;
- to provide recommendations to the airport authority regarding the optimal usage of airport security system resources at different periods during a day.

The paper's research findings help to identify operational issues in the airport's queue management using simulation modeling techniques for enhancing passengers experience and increasing the overall efficiency of terminal operations. Moreover, the study makes a theoretical contribution to the research regarding the airport security systems modelling and optimization using a simulation software AnyLogic.

The paper is organized as follows. Section "Research methodology" describes the paper's research approach, developed to answer on the research questions. The analysis and discussion of findings regarding the optimization of the airport security system to enhance overall passengers experience and terminal operations efficiency are presented in the section "Findings and discussions", followed by the research conclusions in the section "Conclusion".

2 Research Methodology

The research methodology utilized in the paper for answering on the research question consisted of the three steps: (1) analysis of the passengers' traffic and passengers' handling procedures at the airport; (2) creation of the simulation model of the airport terminal in the specialized simulation software AnyLogic; (3) conducting of the optimization experiments with the developed model to optimize airport security system in terms of queue length, passengers processing time and resources utilization.

The first step of the study involved formation of the dataset for the simulation model development, which was obtained through the analysis of the 2023 Dublin Airport Annual Report [18]. Figure 2 illustrates the overall passengers' traffic at the daa from 1998 to 2023.

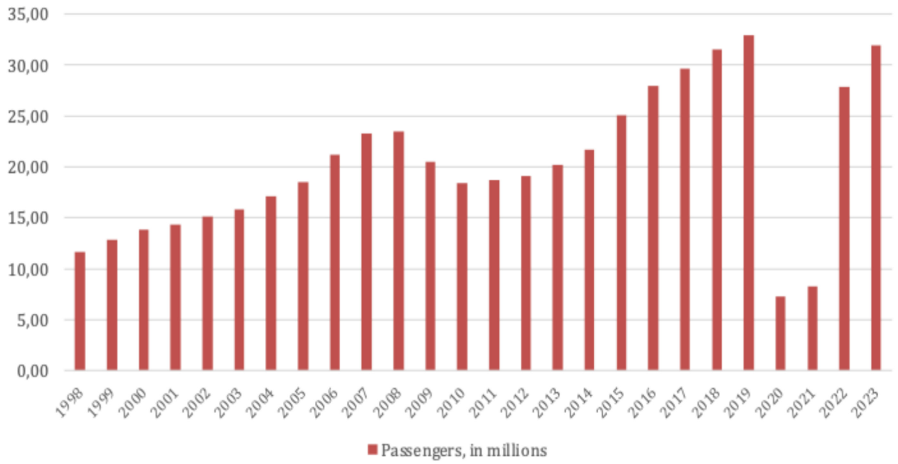
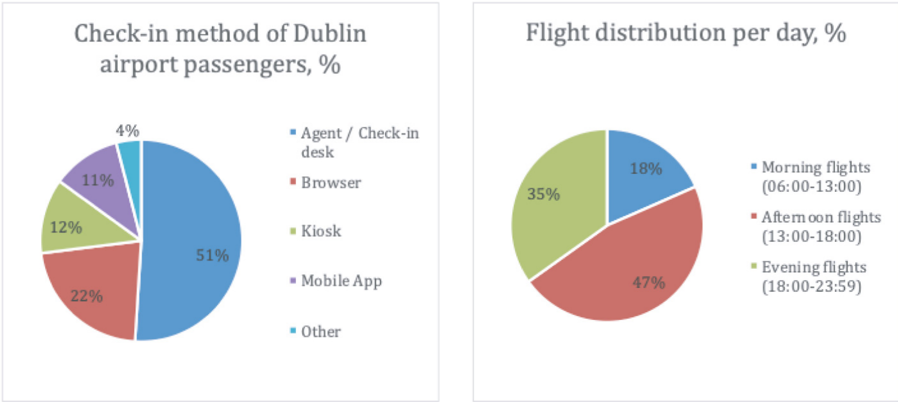


Fig. 2. Passenger traffic dynamics at Dublin airport from 1998 to 2023 [17].

Figure 3 shows the results of the analysis of passengers' check-in methods and flights distribution per a day at the investigated airport.

Then, passengers handling procedures at the airport have been analyzed (Fig. 4). Check-in service is the first stage of departure passengers processing within the terminal, which can be of three different types: self-check-in; traditional check-in and web check-in [3]. Check-in procedures are followed by security and passport control operations and finished by aircraft boarding after passengers spend some time at concessions and waiting zones at the airport's airside.

To construct the terminal optimization model for further queues modelling the process of basic queuing system formation has been analyzed. This process consists of the following components: (1) the «population of passengers» component, which represents the total number of passengers entering the system and contributing to the queue; (2) the «arrival» component is the point, where passengers arrive and join the queue (arrivals are random and follow a specific distribution pattern based on the initial dataset); (3) the «queue» component, which represents the waiting line, where passengers stand before



a) b)

Fig. 3. Check-in methods (a) and flights distribution per a day (b) at Dublin airport, % [18, 19].

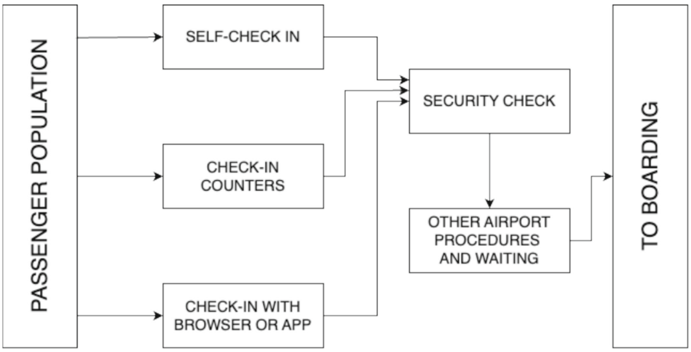


Fig. 4. Terminal operations for passengers processing at the airport.

receiving a service. The "queue" component of the system can increase or decrease depending on the arrival rate and the speed of service; (4) the «service» component is the process, where passengers receive the required service, with the service stations having different levels of efficiency and capacity, affecting the length of the queue; (5) the «output» is a component, where passengers exit the system after receiving a service, with the output rate depending on the efficiency of the service process (Fig. 5).

Existing layouts of the investigated airport security control lanes, check-in counters, and self-service check-in areas were thoroughly examined during the research with a further development of the correspondent schemes (Fig. 6). This analysis gives possibility to construct a simulation model that takes into account the key aspects of the organization and the efficiency of these facilities under the conditions of increasing passengers flows.

Parameters of passengers' processing time at aviation security checkpoints, traditional check-in counters, and self-service check-in counters were determined empirically and are presented in Fig. 7. The collected data allowed us to assess the duration of

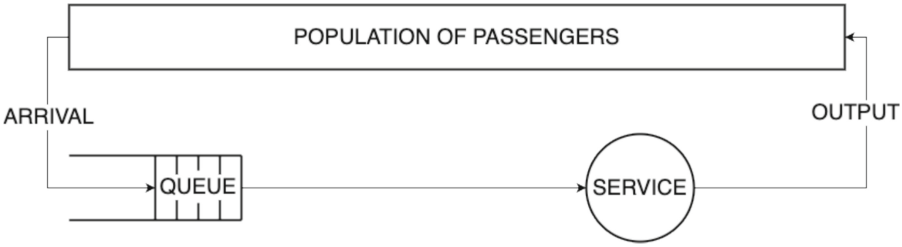


Fig. 5. Queuing process formation and the queuing system [21].

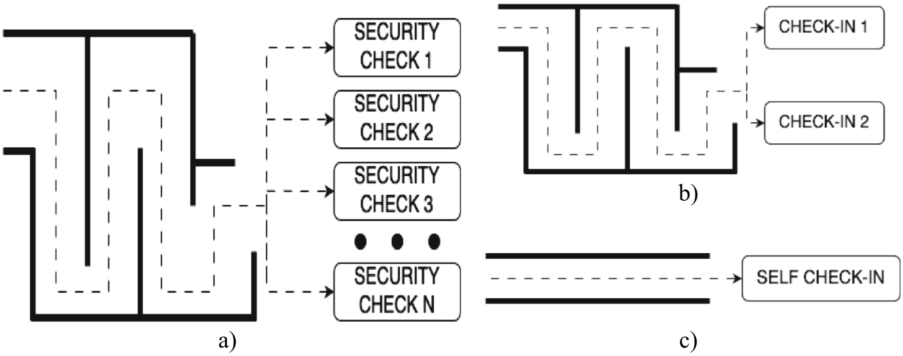


Fig. 6. Basic queuing process and the queuing system formation at Dublin Airport T1: a) security control area layout; b) check-in area layout; c) self check-in area layout.

each stage of departure passengers handling at the airport, which is crucial for further modeling and optimizing of the airport security system under the live conditions.

At the second stage of the research the simulation model of the daa Terminal 1 has been developed, using the collected and analyzed data at the first stage of the study. Simulation modelling is a powerful analytical approach that involves creation of a virtual representation of a system or process to mimic real-world scenarios. In the realm of aviation management, simulation modelling allows researchers and decision-makers to recreate the precise details of passengers' flows, handling processes, and resources utilization within an airport environment. By inputting relevant data and variables into a simulation model, it is possible to observe how different factors interact and influence the overall system performance.

A model of Dublin Airport's Terminal 1 (Figs. 8 and 9) was developed utilizing the AnyLogic software platform, as it has a multifaceted library for human behavior modelling. Simultaneously, information regarding the airport's security system operation was collected through expert assessments. For more accurate simulation of the passengers' flows entering the airport's security control area check-in zone was added to the simulation model.

The logic behind the digital twin (Fig. 10) of the daa Terminal 1 was developed based on the accepted passengers processing system at the investigated airport (Figs. 4, 5 and 6). The developed model consists of the following elements:

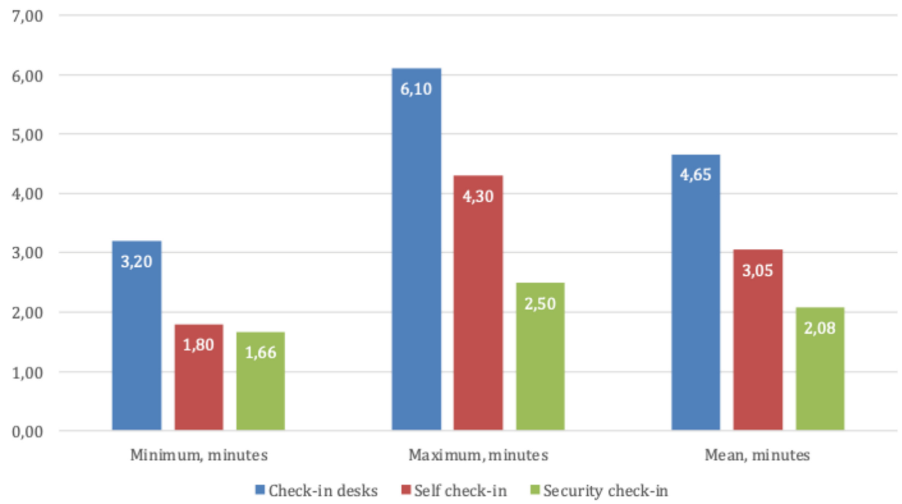


Fig. 7. Distribution of passengers' processing time at the airport's check-in and security areas.

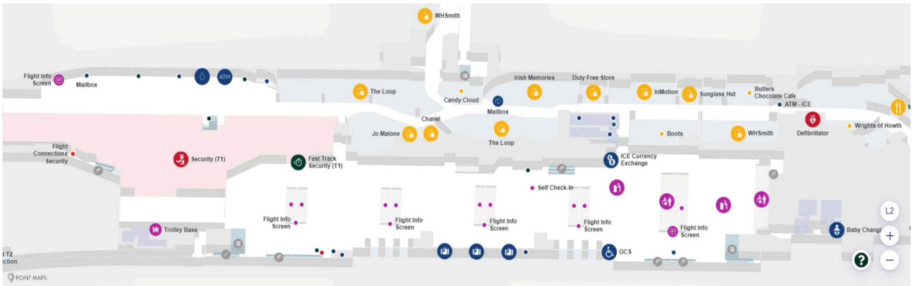


Fig. 8. Dublin airport Terminal 1 layout [20].

- 1 – «passFlow» - the block, which generates passengers. It is used as the starting point of the passengers flows with the passengers' arrival rate equals 572 persons per hour, which was determined during the analysis of 2023 Dublin Airport Annual Report [18];
- 2 – «typeCheckin» and «toCheckIn» - the block, which direct departing passengers to one of the check-in system, described in Fig. 4, with the given probability;
- 3 – «checkIn1», «checkIn2», «checkIn3», «checkIn4» - the block, that simulates passengers, which are processed at the traditional check-in counters.
- 4, 5 – «checkIn5», «checkIn6» - the block that simulates passengers, which are processed at the self-check-in counters;
- 6 – «timeMeasureStart» and «TimeMeasureEnd» - the pair of blocks, measuring the time a passenger spends at security check, including time in the queue and at the security checkpoint while processing;
- 7 – «securityCheck» - the block, which simulates passenger's servicing time at security check area;

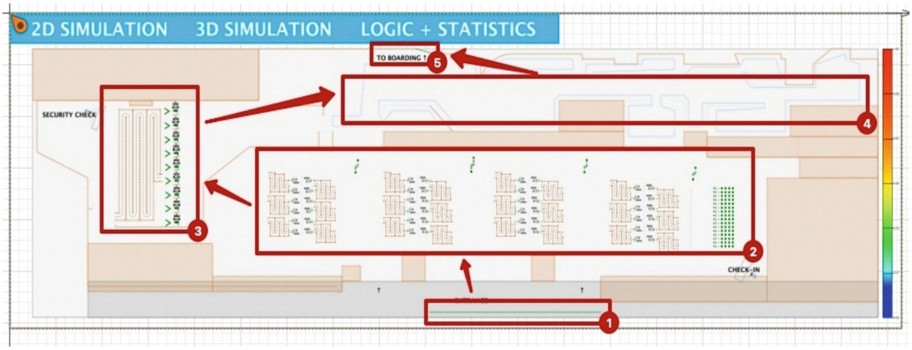


Fig. 9. Simulation model of the Dublin Airport Terminal 1, developed in the AnyLogic software: 1—the area, where passengers appear in the model; 2—the check-in area with three types of passengers check-in, assumed in the model (i.e. traditional check-in, self-check-in, and web check-in); 3—the airport security check area with a reactive strategy for the security checkpoints opening; 4—the area for other airport's procedures (i.e. concessions and holding zones); 5—the boarding area.

- 8 – «waitingFlight» - the block, simulating passengers waiting time at the airport's departure lounges and concessions;
- 9 – «toBoarding» - the block, directed passengers to a specified boarding gate;
- 10 – «pedSink block» - the block, which removes passengers from the system;
- 11 – a diagram, which shows the queue length at the airport security checkpoint;
- 12 – a histogram that represents the average time spent by passengers at the airport security check system.

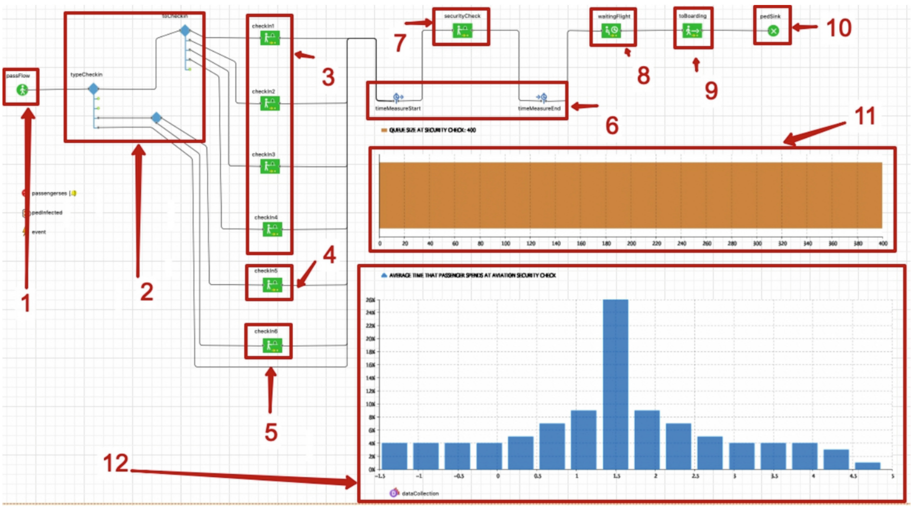


Fig. 10. The logic behind the developed simulation model of the Dublin Airport Terminal 1.

The reactive system for open service lines at the airport security area was used in the simulation model (Figs. 11 and 12). Such a system dynamically responds to the real-time conditions. When the queue length reaches a certain threshold, additional service lines are automatically opens to accommodate the increased demand, thereby reducing wait times and improving overall efficiency of the system. This approach ensures that resources are allocated effectively based on the actual passengers flow, optimizing the security screening process.

On startup:

```
servicesSecurity.setServiceSuspended(serviceLine, true);
servicesSecurity.setServiceSuspended(serviceLine1, true);
servicesSecurity.setServiceSuspended(serviceLine2, true);
servicesSecurity.setServiceSuspended(serviceLine3, true);
servicesSecurity.setServiceSuspended(serviceLine4, true);
servicesSecurity.setServiceSuspended(serviceLine5, true);
servicesSecurity.setServiceSuspended(serviceLine6, true);
```

Fig. 11. Coded in JavaScript suspension of the service lines at the airport security checkpoint at the start of the model simulation.

On enter:

```
if( self.queueSize(queueLine22) > 50 && serviceLine6.isSuspended() ){
    servicesSecurity.setServiceSuspended(serviceLine6, false);
}

if( self.queueSize(queueLine22) > 60 && serviceLine5.isSuspended() ){
    servicesSecurity.setServiceSuspended(serviceLine5, false);
}

if( self.queueSize(queueLine22) > 70 && serviceLine4.isSuspended() ){
    servicesSecurity.setServiceSuspended(serviceLine4, false);
}

if( self.queueSize(queueLine22) > 80 && serviceLine3.isSuspended() ){
    servicesSecurity.setServiceSuspended(serviceLine3, false);
}

if( self.queueSize(queueLine22) > 90 && serviceLine3.isSuspended() ){
    servicesSecurity.setServiceSuspended(serviceLine3, false);
}

if( self.queueSize(queueLine22) > 100 && serviceLine2.isSuspended() ){
    servicesSecurity.setServiceSuspended(serviceLine2, false);
}

if( self.queueSize(queueLine22) > 110 && serviceLine1.isSuspended() ){
    servicesSecurity.setServiceSuspended(serviceLine1, false);
}

if( self.queueSize(queueLine22) > 120 && serviceLine.isSuspended() ){
    servicesSecurity.setServiceSuspended(serviceLine, false);
}
```

Fig. 12. Coded in JavaScript gradual opening of the service lines at the airport security checkpoints during the model simulation.

Figure 13 illustrates the simulation of the developed in AnyLogic software 3D model of Dublin Airport Terminal 1.

The developed simulation model was further used for the conducting of five optimization experiments:

(1) analysis of delays at the airport security checkpoints;
(2) analysis of the airport security system alternatives;

(3) stress test of the optimal airport security system;
(4) assessment of the epidemiological safety at the airport;
(5) optimization of resources utilization at the airport security check lanes.

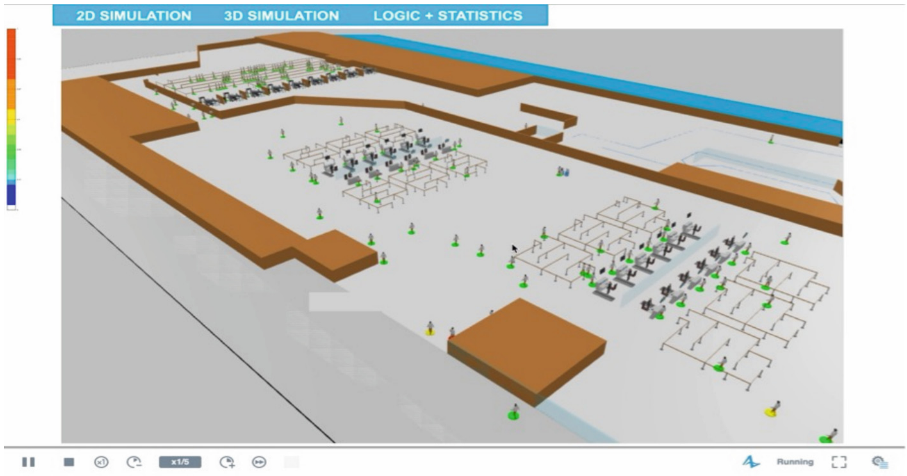


Fig. 13. 3D simulation of the developed daa Terminal 1 model in AnyLogic.

3 Findings and Discussions

For analyzing delays at the airport security checkpoints, the density map (with a critical value of 2 persons per 2 m^2) was created in AnyLogic during the first optimization experiment. It provides a visual representation of passengers' distribution and movement patterns within the terminal. The conducted simulation confirmed the existence of the problem of long queues formation at the aviation security checkpoints of the investigated airport (Fig. 14).

The following results about the time spent by passengers in the queues at aviation security check lines at the daa Terminal 1 were obtained: minimum time passenger spent at the security check – 13.6 min; maximum time passenger spent at the security check – 26.6 min; and the average spent time – 20.1 min. The data shows that 23% of passengers wait for the security screening more than 20 min (Fig. 15).

The second optimization experiment was done to analyze the perspectives of the alternative airport security systems application at daa, which are currently used at the leading airports around the world. Special attention was paid to the technical characteristics of these security systems and passenger's processing time in case of their usage (Table 1).

Conducting four different simulation experiments on the bases of the analyzed data regarding passengers processing time by different airport security systems (Table 1), it was found that the optimal alternative for daa Terminal 1 in terms of passengers processing time and queue length is the Rapiscan 620XR system (Fig. 16).

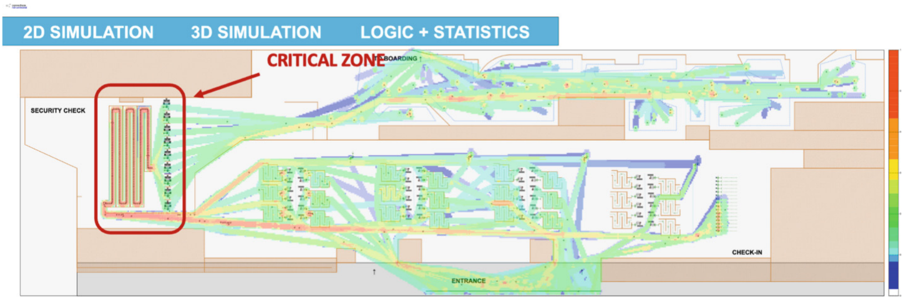


Fig. 14. Density map of the Dublin Airport Terminal 1.

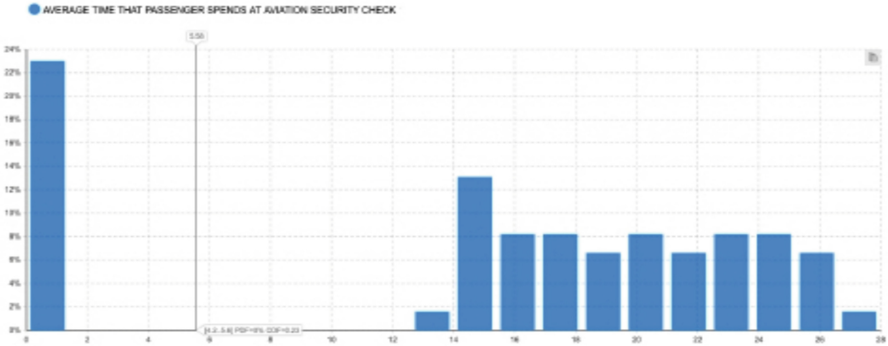


Fig. 15. Time a passenger spends at the daa T1 airport security checkpoint.

Table 1. Distribution of the security check time at the considered airport security systems.

Security system	Minimum, min	Maximum, min	Mean, min	Function in anylogic
L3 Communications PX6.4	1.66	2.5	2.08	Uniform (1.66, 2.5)
Rapiscan 620XR	0.94	1.33	0.635	Uniform (0.94, 1.33)
Smith Heimann HI-SCAN 6040i	2	3	2.5	Uniform (2, 3)
Autoclear 6040	1.66	2	0.933	Uniform (1.66, 2)

Source: Own elaboration of authors on the bases of [2]

The next third experiment was done to perform a stress test for establishment the maximum queue length for the selected alternative security system, where the waiting time in security lanes exceeds 30 min (Fig. 17). This stress test involved simulation of extreme conditions with a high volume of passengers in order to determine the point at which the system becomes overwhelmed. By identifying this threshold, we can better understand the system's capacity and the factors that contribute to excessive wait times, enabling us to make informed recommendations for the optimization of operations and resources allocation (Fig. 18).

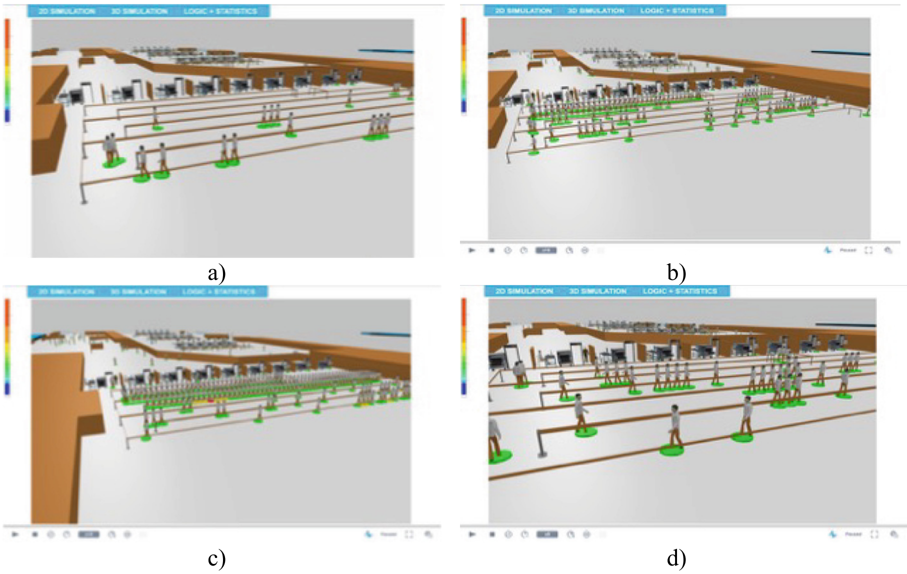


Fig. 16. 3D Simulation models of airport security systems alternatives: a) L3 Communications PX6; b) Rapiscan 620XR; c) Smith Heimann HI-SCAN 6040i; d) Autoclear 6040.

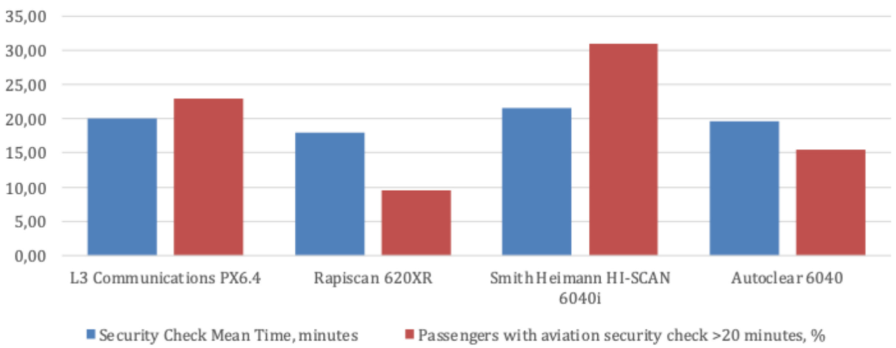


Fig. 17. Distribution of the passengers processing time at the airport security checkpoints, using different security systems.

The obtained results show that if passengers' traffic increases on 60% and more, then the average security screening time using the selected optimal screening system at the daa Terminal 1 per a passenger will exceed 30 min (Fig. 19).

In the post-Covid period the issue of epidemiological safety is very important for airport operators. That's why it was decided to conduct another optimization experiment

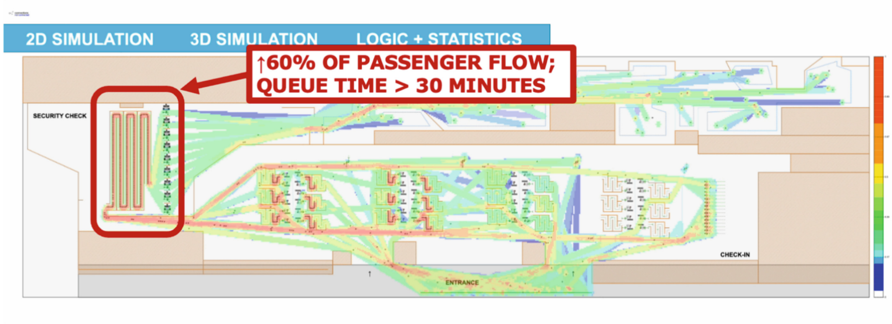


Fig. 18. Stress test of the selected optimal airport security system.

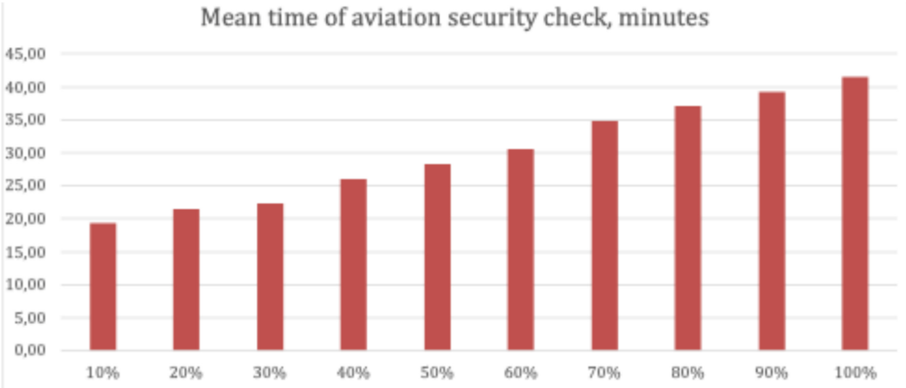
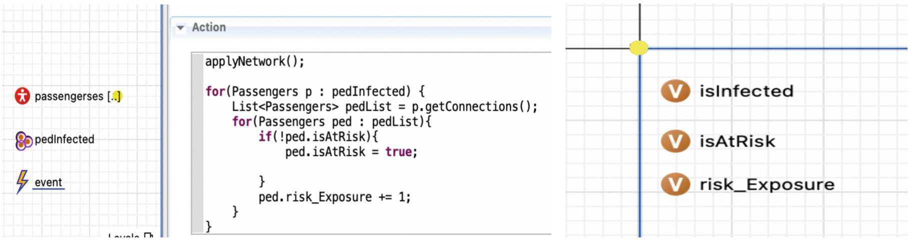


Fig. 19. Changing of the airport security check mean time with the increasing of passengers flow, minutes.

(experiment 4) to evaluate the epidemiological safety of the daa Terminal 1 and the impact of airport operations on it. To perform such analysis, a special code was developed in JavaScript (Fig. 20) and then implemented in the simulation model in AnyLogic. It was assumed in the research that airport passengers can be in one of the three states: non-infected (green on Fig. 21), at the risk of infection (yellow on Fig. 20), and infected (red on Fig. 21). At the start of the simulation, it was accepted that 1% of the passengers are infected. If infected passenger contacts with non-infected passengers at a distance less than 1.5 m for more than 2 s than that non-infected passenger becomes «at the risk of infection» state.

Provided algorithm calculates the number of passengers and records their state after exiting the model. The obtained results clearly demonstrate that 1% of infected passengers result in 12.7% of passengers being at the risk of infection.

The final optimization experiment (experiment 5) was done to examine the required number of resources at the security system of the investigated airport depending on the time of a day, using the data about daily flights distribution. The obtained results are presented in Figs. 22 and 23.



a) b)

Fig. 20. Developed in JavaScript code for infecting airport passengers at the investigated airport: a) a code for infecting airport passengers during a pandemic; b) variables in AnyLogic that control the passenger's state.

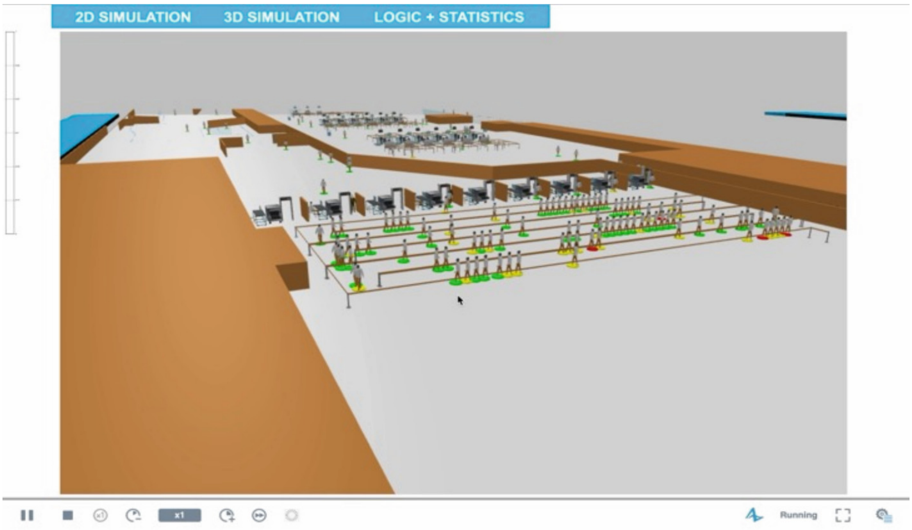
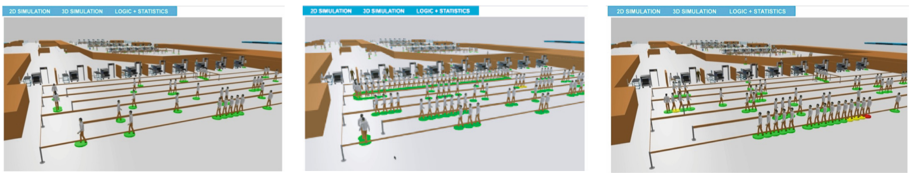


Fig. 21. Simulations of passengers' infection at the investigated airport.



a) b) c)

Fig. 22. Three simulation models for aviation security recourses utilization: a) morning model (6 am–1 pm); b) afternoon model (1 pm–6 pm); c) evening model (6 pm–11:59 pm).

The obtained results show that partial resources utilization (78%) is possible only in the mornings, while in the afternoons and evenings the selected optimal airport security system requires maximum functionality.

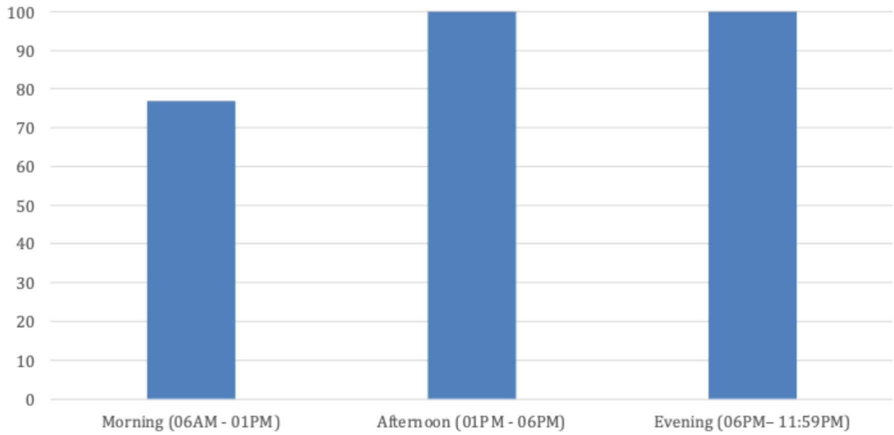


Fig. 23. Resource utilization at the airport security checkpoints during a day, %.

Overall, it can be concluded that the existing security screening system at the Dublin Airport T1 even when optimized is already operating "at the limit" and requires significant changes and new strategies.

The proposed methodology helps airport authority to analyze the efficiency of terminal operations, assess epidemiological safety and optimize resources utilization within the terminal building.

Despite the effectiveness of the proposed methodology, it has several limitations that would be addressed in future research. Firstly, the modelling was limited to Terminal 1 only, not the entire airport, which reduced the scope of the analysis. Secondly, separate processing of CIP and VIP passengers was not considered in the model, which could influence the results. Finally, the model did not consider the opening and closing of traditional check-in counters to optimize queue management at the security screening area.

4 Conclusions

This article presents algorithms for modelling and optimization of airport security systems, using simulation modelling techniques with the help of AnyLogic software. The developed algorithm was applied for modelling of the Dublin Airport Terminal 1 security system, which is currently experiencing delays at security checkpoints sometimes exceeding 20 min.

The results of the conducted research identified the main problems in queue management and resources utilization at the daa Terminal 1. The modeling showed that the existing security system is operating at the edge of its capabilities and requires significant changes. The optimization experiments and analysis showed that implementation of the new security system, such as Rapiscan 620XR, can reduce the average passenger's processing time at the airport security checkpoint to 0.635 min, which is on 20% faster compared to other alternative systems considered in the research. Additionally, it was found that efficiency of the security system resources management depends on the time of the day: in the morning hours (6 am–1 pm) resources utilization is at level of 78%, while during the afternoon and evening hours, the system operates at its full capacity.

Epidemiological analysis of the daa terminal 1 with the optimized security screening system Rapiscan 620XR shows that if 1% of the passenger flow would be infected, then 12.7% of passengers could be at the risk of infection while waiting in the security lanes at the airport.

In future research, it would be beneficial to focus on the comprehensive modelling of all airport terminals, considering separate processing of different categories of passengers, including CIP and VIP passengers. It would be also valuable to evaluate alternative simulation tools in addition to AnyLogic and examine various scenarios to compare their outcomes with the results discussed in the paper.

The proposed in the paper research approach will facilitate development of a more accurate and effective resources management for airport systems operation.

The research results can serve as a basis for future improvements in security systems at other international airports.

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