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OPTIMIZATION OF SECURITY LANES ALLOCATION FOR TRANSFER PASSENGERS AT HELSINKI AIRPORT

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The post-Covid pandemic ramp-up created new challenges for the industry and compiling stakeholders to adapt to new realities. Long waiting times not only jeopardize the flight schedules and canceled flights but also reflect an unsatisfactory customer experience. The aim of this thesis is to investigate the relationship between the number of security lanes allocated for transit passengers and the possibility of congestion during security control at Helsinki Airport. As subtopic researching methods of cost index and their possible practical implementation for security lanes allocation.

The author of this thesis aims to analyze research available, including secondary data from transfer security control at Helsinki airport. The author uses methods of quantitative analysis of secondary data obtained from transfer security points, in order to find correlations and trends. Two generic scenarios were created to explore the practical application of the cost index models, with further analysis.

The research results found direct correlations between the number of security lanes and congestion. However, anomalies require further analysis to establish their effect on the security control operations. A generic analysis of economic costs was conducted. The cost ratio method showed promise for future implementation. Analysis of security control operations found that transferring security control lanes between security control points can be a significant economic burden in the long term. The results of this research are contributing to seeking valuable insights that can be used as a ground for future strategies for balancing operational efficiency.

Keywords Aviation, Airport, Security control, Optimization, Passenger flow management
Pages 41 pages

Content

Figures

Tables

Appendices

Glossary

Airport Operator - the civilian or military agency, group, or individual which exercises control over the operations of the civil airport or military airfield.

Airport terminal – a building at an airport constructed to accommodate passengers' transfer between ground transportation and the facilities that allow them to board and disembark from an aircraft.

Airside – part of the airport beyond security control.

Approach - The phase of flight when a flight crew begins its descent to land.

Apron - the area of the Airport where the aircraft are parked, unloaded or loaded, refueled or boarded.

Block time - The overall duration of a flight, including the time from departure gate pushback ("off-blocks") to arrive at the destination gate ("on-blocks").

Border control - measures taken by governments to monitor and regulate the movement of people, animals, and goods across land, air, and maritime.

EASA - European Union Aviation Safety Agency**,** is responsible for ensuring safety and environmental protection in air transport in Europe.

ICAO - International Civil Aviation Organisation, is funded and directed by 193 national governments to support their diplomacy and cooperation in air transport as signatory states to the Chicago Convention (1944).

Landside – part of the airport before the security control.

NAA - The Agency of a sovereign state, or by agreement or statute, a group of sovereign states, which is given responsibility for determining and administering the regulatory regime.
Passenger Boarding Bridge - passageway which extends from an airport terminal gate to an airplane.

Passenger flow – the numerical value of passengers' throughflow through the security lane/control.

Runway - a paved strip of ground on a landing field for the landing and takeoff of aircraft.

Security control - is a combination of measures and human and material resources to safeguard civil aviation against acts of unlawful interference.

Security lane – a single unit of security control, including security officers and all necessary equipment for security screening.

Security Officer – trained personnel in charge of monitoring the safety and security of people and goods passing to airside.

Taxiway - taxiway is a path for aircraft at an airport connecting runways with aprons, hangars, terminals, and other facilities.

Transfer security control – security control checkpoint primarily used for non-Schengen transit passengers' security screening.

Transfer passengers – passengers arrived at Helsinki-Vantaa airport and changed their flight.

Introduction

The aviation industry plays an important role in the modern world. It enables for fast and efficient transport of passengers, and cargo, ensuring economic and business growth. Easy and accessible travel is vital for any country. The industry boosts tourism and improves contact between people, creating working places and bridging the gap between nations and cultures. It offers opportunities for business, tourism, and personal growth. All those aspects became a conventional part of life in modern society.

Aviation is a heavily regulated and competitive industry. The ground behind the regulations can be found in aviation history and the risks that are inherent in aircraft operations. Due to the international nature of the aviation sector, operations are conducted according to international standards and conventions. (Yadav & Nikraz, 2014)

Harmonization and implementation of standards require cooperation on different levels. The ICAO organization was founded in 1933, in order to promote the safe and orderly development of international civil aviation. (ICAO, n.d.) On the European Union level, EASA is responsible for ensuring safety and environmental protection in civil aviation. (European Union, n.d.). The National Aviation Authorities are constantly monitoring the implementation of the regulation and practices in order to comply with the standards. In Finland Traficom is the responsible body. (Traficom, 2023)
The airport business and regulatory environment have significantly changed during the last decade. Due to liberalization and privatization, modern airports are considered profit-making enterprises. This was the ground for operators to focus on the commercial aspects of their operation as well. Creating a unique environment, where harmonization between profitability and regulation implementations is vital for the operator. (Yadav & Nikraz, 2014)

The Covid-19 pandemic had a significant impact on the aviation industry. EUROCONTROL reported traffic losses of 62% in 2021 compared to 2019. Those figures recalculated as en-route revenue losses for the same period is 60%. (Aviation Intelligence Unit, 2022, a).

In 2021, the aviation industry experienced a ramp-up in passenger numbers and operations. This fact indicated a slow recovery from the pandemic. However, the recovery faced new challenges. Airlines, airport operators, and handling agents faced a shortage of staff after mass layoffs during the pandemic. The new tendency of fluctuating resource demand created new challenges in scheduling staff shifts, in order to comply with the peak hours demand. The surge

in passenger traffic was especially concentrated during peak periods, leading to increased pressure on airport facilities and personnel. The pandemic also caused operational losses and market instability, which compelled the industry to search for ways to optimize resource usage in the future. The tight labor market particularly affected airport operators, airlines, and ground handlers, presenting a significant challenge to scaling up in the current environment. These factors posed significant obstacles to European airports, with an ACI Europe survey predicting that they would result in 66% of flight delays and 16% of flight cancellations during the summer of 2022. (International Airport Review, 2022).
According to the latest EUROCONTROL report, 9.3 million flights were conducted in Europe in 2022. This reflects 83% of flights compared to 2019. The aviation ramp-up showed a tendency to slow down due to the war in Ukraine that started in February 2022. Closed Ukrainian airspace with restrictions in neighboring countries severely impacted traffic flows, as well as Russian airspace sanctions causing a major drop in eastward traffic. Raised inflation, energy prices forced airlines and operators to search for optimization, postponing long-awaited aviation sector recovery. (Aviation Intelligence Unit, 2022, b).

1.1 Research question

The author wants to investigate: “What is the relationship between the number of security lanes allocated for transit passengers and the possibility of congestion during security control at Helsinki Airport?” The research question is derived from a knowledge gap and the results of this study can be directly applicable to the company's operations. By identifying the optimal amount of security lanes, the airport operator can ensure the efficiency of the security control operation with cost optimizations. As part of the research, the author wants to study as a sub-question, searching for possible cost index models, which may be created in order to help with security lanes allocation. The research will be conducted based on secondary sources data. Researching relationships between different parameters allows for finding trends using methods of statistics.

1.2 Commissioning Company

Finavia is a Finnish state-owned public limited company. The Prime Minister's Office is responsible for the ownership. The company owns and ensures the operations of the airports’ network. Finavia’s airport network consists of 20 airports throughout Finland with Helsinki airport being the largest in the company’s network. (Finavia, n.d.a). Helsinki Airport construction started in 1950, 20 kilometers from Helsinki. The construction took place as a result of increased traffic at Malmi airport, as well as larger aircraft types operating during this time. Helsinki airport was opened for the Summer Olympics in 1952. (Finavia, n.d.b).

Based on the statistics, published by Finavia. The total passenger traffic at Helsinki airport increased from approx. 9,3 million passengers in 1998 to almost 22 million passengers in 2019. The overall number of passengers increased by almost 133,7% in 21 years. The covid pandemics' severe impact has been reflected in passenger traffic with a 41% decrease in passenger traffic, comparing 2022 and pre-covid 2019 data. (Finavia, n.d.c).

The airport has since been expanded several times during its history, the largest of which taking place in 2013. (Finavia, n.d.b). The main concept behind the development, was to ensure and improve customer experience. Modern concepts and ideas were implemented in the airport design. The "One roof concept" was used to accommodate more services while keeping the walking distances fast and efficient. "One terminal concept" made navigation inside the building easier and gave the customers more time to explore and enjoy the broad variety of services. A fast and efficient transition through the terminal is vital from the transfer passenger's perspective. During the planning phase, the fact that for some passengers, the airport would be their only contact with Finland was also considered. Finnish materials, designs, and philosophy were broadly used to ensure that each customer can explore and enjoy even a short stay in Finland. (Finavia, n.d.d).

According to Airports Council International (ACI), Helsinki airport is ranked 12th in Europe for the industry connectivity report and took first place in Northern Europe. Due to its location and optimized operations, the airport serves as a competitive air traffic hub for flights from Asia to Europe. (International Airport Review, 2017).

1.3 Research background

The basis for this thesis is to study available data, in order to find the potential correlation between the number of security lanes allocated for transit passengers and congestion during security control at Helsinki-Vantaa airport. The author wants to fill the knowledge gap and improve the tools for data-based decision-making.

In addition, the research for this thesis is done by analyzing available secondary data and identifying possible triggers and relationships between parameters. The author is aiming to find ways to optimize economic, staffing, and operational planning aspects. The study of the correlation between allocated resources and waiting time allows for the minimizing of resources allocated while obtaining optimal passenger flow. Optimization of the resources is emphasized in the post-pandemic and unstable political environment for the whole industry. The need for fast and scalable resource demand requires tools for planning and a better understanding of the insight process. The author aims to find tools for operational decision-making based on the results of this study. This research is providing a solid background for further improvement and optimization. The significance of the study can be implemented into operations with direct and beneficial reflection on economics and human resources.

1.4 Airport environment

The airport operation environment is a unique and complex sociotechnical system. The system includes discretionary and mandatory activities that are organized according to international standards and conventions. Discretionary activities include for example beverage, retail, and food services. They are accountable for 35% of revenue (considering non-aeronautical revenue). On the other hand, check-in, security control, and border control are considered to be mandatory terminal activities. Security control areas consist of queues and security lanes. Security lanes have belts, a walk-through metal detector, and an x-ray sensor. The equipment used for the security lanes may significantly vary depending on the airport, and locations of the lane. (Adin Mekic ‘, et al, 2021)

1.4.1 The Airside and Landside areas

The airport is a critical part of the air transport system. The airport facilities are designed in order to accommodate departing and arriving aircraft traffic and processing passengers, cargo, maintenance facilities, refueling services, and so on. The infrastructure of the airport used by arriving or departing aircraft includes runways, taxiways, aprons, gates, and hangars. The simplified sequence for arriving aircraft is shown in Figure 1. (Ashford et al., 2012)

Figure 1. Airport traffic sequence chart. (Author's own work, 2023)

Arriving traffic	**Departing traffic**
Approach	Gate or Stand
Runway	Apron
Taxiway	Taxiway
Apron	Runway
Gate or Stand	Departure

The airport area can be dived into landside and airside. The Landside is the portion of the airport before the security control. Airside respectively, after the security control. The primary function of an airport terminal is the physical linkage between the landside and the airside for departure air traffic. A terminal provides the processing capability to accommodate passenger and freight traffic between landside and aircraft. The processing shall be conducted according to established procedures, international standards, and regulations. A secondary function of the airport terminal is to accommodate check-in processes, security control, a variety of businesses, and services provided to customers. (Ashford et al., 2012)

1.4.2 Border control

Free movement is one of the fundamental principles of the European Union. The Schengen agreement is an agreement about common travel areas. The agreement was signed on 14 June 1985 in the town of Schengen in Luxembourg. This event led to common border checks being gradually removed and the creation of a border-free area. At the moment, the Schengen Area includes 26 out of the 27 member states of the EU. (European Council, n.d.).

The Schengen agreement guarantees the free movement principle due to the border-free policy. Allowing EU citizens, non-EU citizens, and tourists to travel without any special formalities and border checks around the Schengen area. (Migration and Home Affairs. n.d.).

The airport terminal shall accommodate the facilities and operational spaces for the examination process to fulfill the governmental requirements. (Ashford et al., 2012, p.223-224) Border control-related examination processes are mandatory for passengers arriving outside of the Schengen area or leaving the Schengen area.

1.5 Sustainability in aviation

In 2018 air transportation was responsible for 2% of overall CO2 emissions. According to the research, aviation impact is stronger, due to the height at which emissions are produced. Taking that into account, emissions shall be multiplied by 1,9 times. (ATAG, n.d.a)

The aviation sector made an agreement to minimize industry impact on the environment. This agreement was the first industry-wide document, ensuring cooperation and aiming toward sustainable operations. Climate action goals to archive net-zero carbon emissions by 2050 were declared in 2021. To achieve established goals coordination on an industry-wide level is required. Formulated key elements for future decarbonization are technological innovation, sustainable aviation fuels, operational improvements, and infostructure efficiencies. (ATAG, n.d.b) In the European Union, aviation accounted for 4,2% of all GDP in 2018. Europe is responsible for almost 25% of global air transportation. CO2 emissions reflect the volume of air transport and the overall air-traffic situation in Europe. (ATAG,n.d.c) Finland has a state-owned airport network comprising 20 airports operated by Finavia. Helsinki airport has archived carbon neutrality already in 2017. (Mikko Viinikainen, 2022).

2 Theoretical Framework

The post-pandemic ramp-up in the aviation sector created new challenges for the industry. A shortage of personnel and budget limitations created disruptions at the airports around Europe. long queues at the security controls affected delays, cancelations, and flight rearrangements. (International Airport Review, 2022).

Security lane allocation optimization has a direct operational and economic impact. The author wants to research the possible correlation between the number of security lanes allocated for transit passengers at Helsinki-Vantaa airport and possible congestion. The possible correlation will be examined by analyzing collected data from available sources. Researching relationships between different parameters allows for finding trends and using results for cost index model creation. Practical application of the cost index will reduce the number of security lanes allocated and minimize passengers' waiting time.

2.1 Robustness and Evolutionary Dynamic Optimisation of Airport Security Schedules

The problem of security lane allocation has a similarity with check-in desk allocation and can be used as background for future research. Darren M. Chitty, Shengxiang Yang, and Mario Gongora wrote a publication “Robustness and Evolutionary Dynamic Optimisation of Airport Security Schedules”. This paper has a solid background with a deep analysis of the airport security lane scheduling problem. The authors offer algorithms for more efficient allocation. However, the importance of passenger arrivals forecasts was emphasized in this work. Arrival passengers’ forecasts are too smooth compared to actual events. Problems of forecasting unforeseen events related to weather, delays, and any other operational factor are complicated to reflect in allocation. Improving passengers forecast could have a positive and direct effect on allocation planning. (Chitty, D. M., Yang, S., Gongora, M., 2017, P.3-8).

2.2 Systemic Agent-Based Modeling and Analysis of Passenger Discretionary Activities in Airport Terminals

Systemic Agent-Based Modeling and Analysis of Passenger Discretionary Activities in Airport Terminals publication published in 2021. The authors of the paper, Adin Mekic ́, Seyed Sahand

Mohammadi Ziabari, and Alexei Sharpanskykh, concentrate on the analysis of discretionary activities in an airport terminal and their relations with terminal processes. Under discretionary activities, the authors of the publication consider beverage, retail, and food services. According to their study, discretionary activities are accountable for 35% of revenue (considering non-aeronautical revenue). The study verifies the importance of discretionary activities' performance and emphasizes their relationship with mandatory activities. Security checkpoints and check-in shall be categorized as mandatory activities. The authors analyze terminal processes as a complex sociotechnical system and how processes reflect on passengers' decision-making. Agent-based Airport Terminal Operational Model (AATOM) was used to conduct the research. (Adin Mekic ‘, et al, 2021)

The importance of the Systemic Agent-Based Modeling and Analysis of Passenger Discretionary Activities in Airport Terminals study, within the framework of this research, cannot be underestimated. The research provided verification of the idea that the cost index model can be useful. Taking into account queuing time and the cost of the security lane the cost index can provide powerful tools for operational planning. (Adin Mekic ‘, et al, 2021)

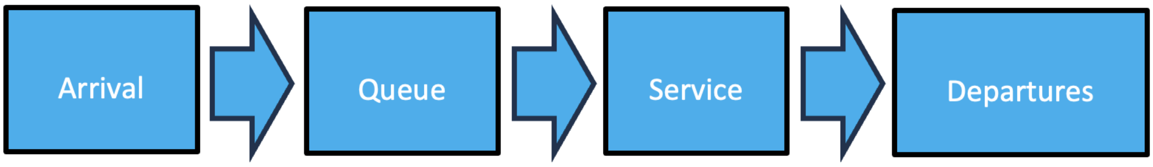
2.3 Probability, Statistics and Queing Theory

The author used the book Probability, Statistics and Queing Theory written by V. Sundarapandian in 2009. The book analyses the broad type of processes relevant to the framework of this research. Basic queuing models, covered in the book provided solid background for the study.

The queuing theory refers to the mathematical concept describing queues. The Theory found its application in the business decision-making process, for example for customer service resource allocation. Agner Krarup Erlang is the author of the queuing theory. The first study was published in 1909. The ground behind the theory was to analyze the congestion of telephone traffic. The theory provides tools for the analysis of queue systems. The parameters that theory covers are prediction queue lengths and waiting time. (Sundarapandian, 2009)

The queue system has characteristics like input (arrivals), queue, and service. The simple queueing model and its sequence are shown in Figure 2.

Figure 2. The queue system characteristics. (Author's own work, 2023)



The input or arrival refers to the characteristic rate of arrivals to join the system for future service. The queue discipline is an important parament, which affects how the whole system is formed. There are several disciplines usually used for queues analysis like First In First Out, Last In First Out, Selection for service In Random Order, and Priority in Selection. In the framework of this research, the only discipline to be covered is FIFO. FIFO stands for First In Forst Out or another name is First Come First Served. The system capacity refers to the maximum number of customers in the system. The system can be infinite or finite, but the author considers the queuing system as infinite in the framework of this thesis. (Sundarapandian, 2009)

2.4 Literature Review of Waiting Lines Theory and its Applications in Queuing Model

The publication is written about the waiting line theory, which is also known as Queuing Theory. The theory has strong practical applications in real-world scenarios, where queues are part of normal operations. The theory provides a mathematical approach to understanding and tools for the analysis of waiting lines. The importance of queuing analysis increases with the growing number of customers and in order to ensure the customer experience. Understanding the process, allows businesses to make data-based decision making. The authors of the publication discussed the aspect of the customer waiting cost and cost of service facility. (Shastrakar et al., 2018.)

The basic formula for total costs is:

$$TC_m = WC_m + FC_m$$

Where:

TC - expected total cost,

WC - expected waiting cost per period,

FC - expected facility cost.

(Shastrakar et al., 2018.)

The basic feature of the waiting systems is the classification of customer’s arrival. Several examples of the system classifications are single or multiple lines, finite or infinite, and many more. Service discipline, for a particular system, is the rule of how customers are selected for the system. Service disciplines are First-In First-Out (FIFO), Last-In First Out (LIFO), Service For Random Order (SRO), Priority Service. (PS). The nature of the customers is related to their behaviors, for example, are they willing to accept waiting or refuse it? Those parameters, help to describe the complexity of the waiting system. (Shastrakar et al., 2018.)

In conclusion, the role of the Queuing Theory cannot be underestimated in the modern business environment. The understanding and analysis of the queues, and waiting systems provide a strong ground for feather improvement of the service and customer experience.

3 Methodology

The research is based on the known knowledge gap related to transfer security control operations at Helsinki Airport. The research aims to analyze secondary data, collected from transfer security control at Helsinki-Vantaa airport and find possible correlations between the number of security lanes allocated and possible congestion related to it. The secondary data, obtained for this research, consists of 1-week metrics with a resolution of 1 minute. As secondary research, the author wants to find possible trends, new methods, and tools for the optimization of security control operations. The operations of security control are also linked to the customer experience; however, the author decided not to conduct any customer interviews and focus on the operational and economic aspects of operations. The results of this research can be used as the ground for new methods, which may be implemented in the future in order to ensure the efficiency of operative decision-making.

3.1 Limitations

The research is conducted on secondary data, obtained from XOVIS. The imported data sample is limited to a one-week operation of transfer security control from 8 MAY 2023 to 14 MAY 2023 (Monday to Sunday). The resolution of the data used is 1 minute. The author uses inferential statistics methods in order to find relationships between parameters and make inferences about the larger scale based on a sample of data. The primary parameters analyzed are the number of transfer passengers, waiting time, and the number of security lanes allocated. The generalization is used due to the complexity and scale of the studied phenomena.

3.2 Explanation of the selected research method

The author has selected the quantitative research method to study the secondary data sample obtained from available sources. Data has been collected by the automatic process and software at transfer security control for one week period. The resolution of the data is 1 minute. Compilation of data samples from several sources, including security control waiting time, number of passengers, and the actual number of security lanes allows for studying possible correlations. The examination of the one-week data sample ensures the variety of operations during the period and the quality of the obtained results.

With the settled research question: “How does the number of security lanes allocated for transit passengers correlate with possible congestion during security control in Helsinki airport?” quantitative research method allows us to accomplish the research and verify results.

3.3 Research design

The research aims to investigate correlations between security lanes allocated and possible congestion. The author aims to research available data from secondary sources with the purpose of further analysis and compilation of results. The primary source of data for this research is obtained from XOVIS software. The metrics obtained are the number of security lanes, the number of passengers, and the waiting time. Investigate key factors and their effect on the security control operations. For analyzing historical data samples, quantitative methods are used. The primary objective of this research is to study the possible correlation between the number of security lanes and congestion. The author wants to identify parameters and metrics that may contribute to congestion. Data analysis is performed in Microsoft Excel. The analysis does not include any personal information and complies with the privacy regulations. (Field, 2017, p.42.)

Based on the results of the primary research and utilizing the generic data, the author aims to create various scenarios. The objective for the generic scenarios is to study the economic foundation of the operations and implement the cost index model. The model could help with operational decision-making and planning purposes. Based on the research findings, the author has gathered recommendations for possible optimization. (Cost Effectiveness Analysis, n.d.)

3.4 The Logic of Inquiry

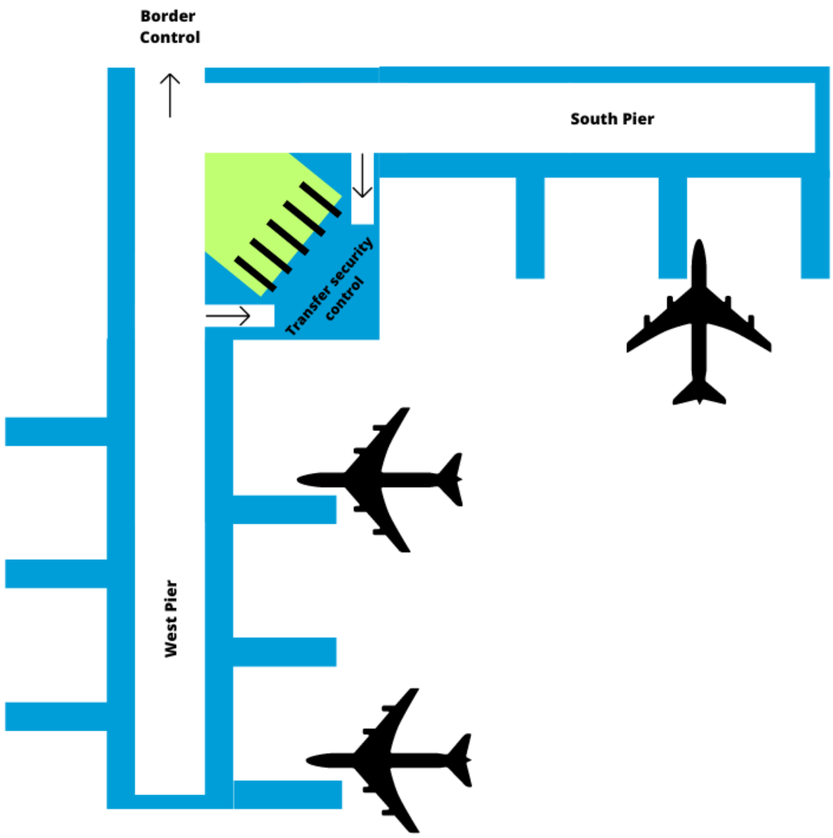
The author chose to use the quantitative methods. The ground for the chosen method is the nature of the research question, the complexity of the phenomena, and available secondary data. The methods chosen by the author are based generally on the type and quality of available data. Used methods allow to find possible trends and patterns. Based on the result of the research, new methods and tools can be created.

4 Analysis

The author conducted the research based on the chosen methodology and research methods. The airport layout, processes, and transfer passengers' paths need to be considered to obtain reliable results.

4.1 Transfer passengers' path

Figure 3. Layout of the non-Schengen area. (Author's own work, 2023)



In 2019, the West Pier part of the terminal was opened. The expansion allowed for new wide-body aircraft bridges. (Finavia 2020) The simplified passengers' path, arriving from the 3rd countries and not fulfilling the EU security control standards, consists of several stages. Arrival passengers proceed from the aircraft to the terminal through the passenger boarding bridge or are transported by apron passenger buses directly to the corresponding arrival door. Bus transportation is primarily used due to aircraft parking at a stand without a passenger boarding bridge. The overall simplified layout of the non-Schengen part of the Helsinki terminal is shown in Figure 3. Depending on the passenger's destination, they proceed to the west or south pier's corridor to the border control or transfer security control if they have a connecting flight. For effective directions in the terminal, guide signs are installed. During peak hours, terminal guides provide assistance, directing passengers to navigate through the terminal.

4.2 Data collection

The secondary data includes several numerical parameters. The parameters considered in the framework of this research are the number of transfer passengers, waiting time, and number of security lanes allocated. The relations between the parameter are explained in Table 1.

Table 1. Parameters. (Author's own work, 2023)

Name of parameter	**Type of Data**	**Target**	**Potential benefits**
Number of transfer passengers	Numerical value	The number of transfer passengers generally should be maximized. This is limited by the number of flights available, airport location, and operational limitations.	• Revenue generation • Competitive advantage • Economies of scale • Network connectivity
Waiting time	Numerical value	Waiting time should be kept at optimum.	• Customer satisfaction • Operational efficiency • Service quality.

Number of security lanes allocated	Numerical value	The number of security lanes allocated should be kept at an operational allowed minimum.	• Efficient queue management • Staffing optimization • Service quality.

4.2.1 Little's law

Little's Law is the concept for determining the overage number of items in a stationary queuing system. The theory has a direct application in the framework of this research. The basic formula for queuing is:

$$L = \lambda \times W$$

Where:

L – the average number of items in a queuing system

λ – the average number of items arriving at the system per unit of time

W – the average waiting time

This formula can be transformed to find the number of items arriving (λ):

$$\lambda = \frac{L}{W}$$

In order to find the average waiting time (W), the formula can be transformed:

$$W = \frac{L}{\lambda}$$

(Team, C. 2023).

In the framework of this research, the formula can be rephrased:

$$WT = \frac{NP}{n \times PF}$$

Where:

WT – expected waiting time in minutes

NP – number of transfer passengers

n – number of security lanes allocated

PF – expected passenger flow

4.2.2 The number of transfer passengers

The number of transfer passengers is the numerical value and its variable. This fact makes finding the optimization solution challenging. The total number of arriving passengers changes on a daily, weekly, monthly, and yearly basis. Passenger arrival times also fluctuate for various reasons, including flight delays, and technical issues, as well as weather. This parameter can be considered the primary factor which is taken into account when allocating the security lanes.

The secondary data was collected from XOVIS software. In the framework of this research, collected data represents a sample from 8 MAY 2023 to 14 MAY 2023 (Monday to Sunday) with an original resolution of 1 minute.

Figure 4. Total passenger numbers per day. (Author's own work, 2023)

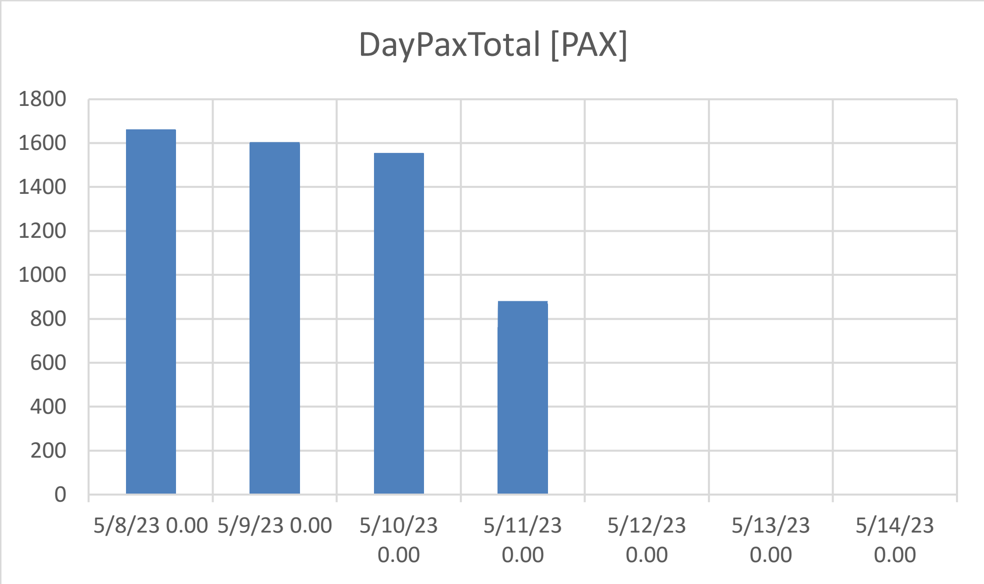
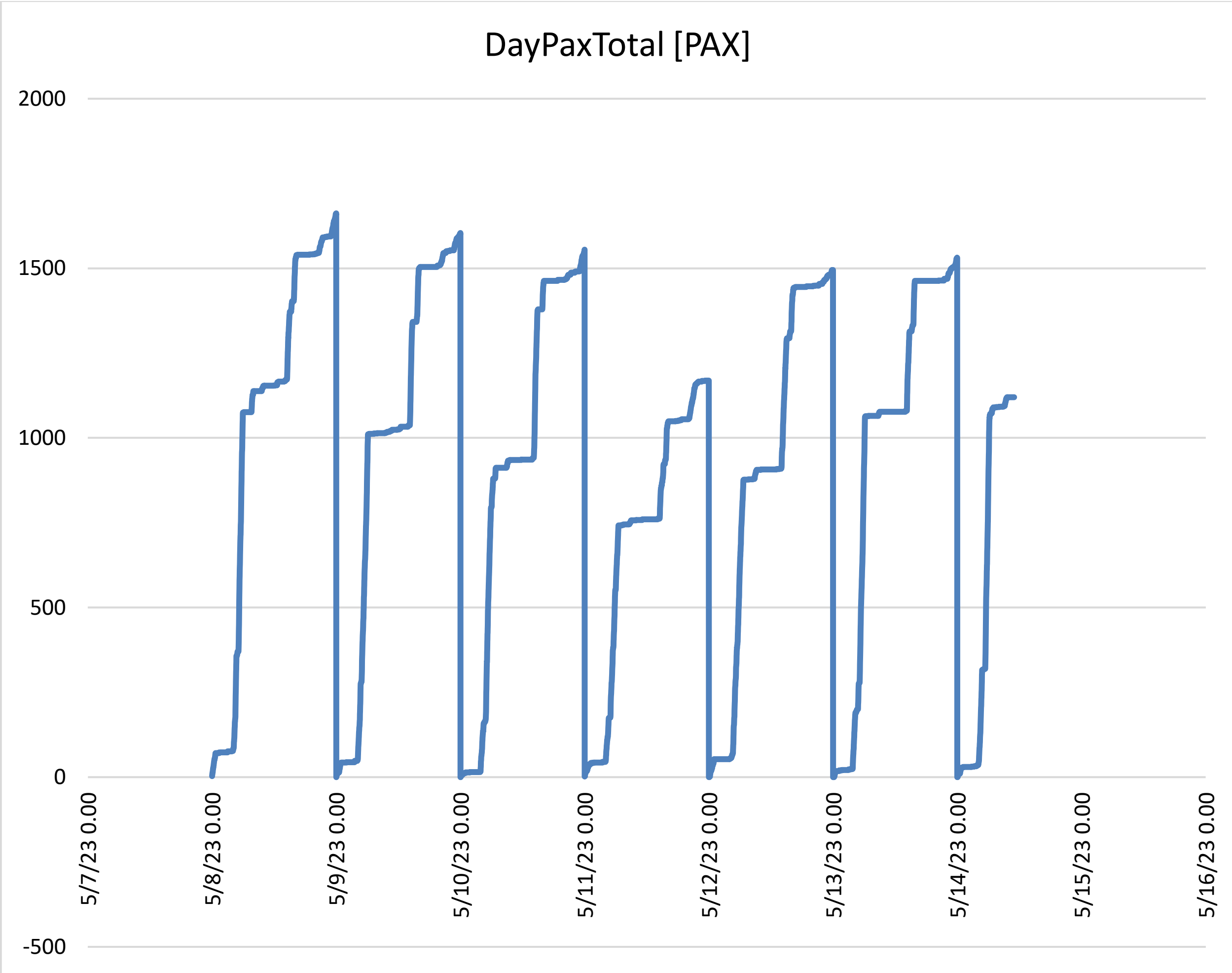


Figure 4 represents the total number of arriving transfer passengers on each day of the data sample. Based on the initial analysis, the author found an anomaly in data on 14 MAY. Part of the information is missed after the morning peak hour. The author decided to omit the data from 14 MAY due to insufficient and unreliable information.

Based on the collected data, the total number of arriving transfer passengers is different on each day of the sample week. The maximum number is on Monday 1662 pax (8.5.2023) with the minimum on Thursday 1169 pax (11.5.2023). The difference between the minimum and maximum is 493 passengers a 29,6% difference.

Figure 5. Daily Peak hours. (Author's own work, 2023)



In order to understand the daily fluctuation, Figure 5 represents the total transfer passengers, but as a trend in time for each day of the data sample. The representation shows the peak hours in the morning and afternoon, with some increased demand during the evening. The highest demand for security lanes is during morning and afternoon peak hours. From Figure 5 some fluctuation in the length and severity of peak hours can be found. In the framework of this study, the evening peak hours are omitted in order to simplify the case study.

4.2.3 Waiting time

The waiting time is a numerical value representing the time that passengers are waiting in the queue before entering the security control. This Key performance indicator directly affects customer satisfaction and service quality. According to “A Study on the Effects of Waiting Time for Airport Security Screening Service on Passengers' Emotional Responses and Airport Image", the perception of the long waiting time had a strong negative emotional response, perceived justice, and accessibility on passengers. (Kim et al., 2020)

Figure 6. Waiting time (seconds). (XOVIS,2023)

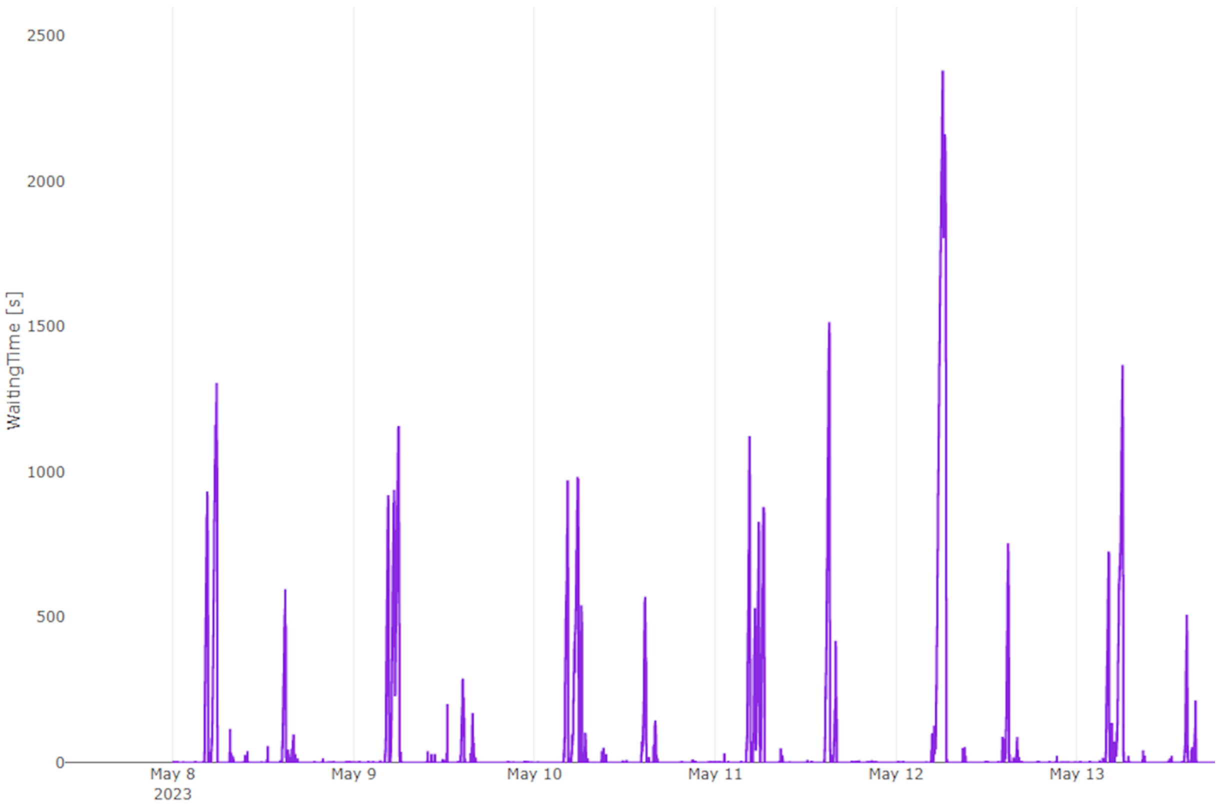


Table 2. Waiting time summery table. (Author's own work, 2023)

	8MAY		9MAY		10MAY		11MAY		12MAY		13MAY	
Peak hour	**Morning**	**Afternoon**	**Morning**	**Afternoon**	**Morning**	**Afternoon**	**Morning**	**Afternoon**	**Morning**	**Afternoon**	**Morning**	**Afternoon**
Maximum Waiting time in seconds	1032	593	1154	286	979	567	1102	1511	2376	751	1364	506
Maximum Waiting time in minutes	17,2	9,9	19,2	4,8	16,3	9,5	18,4	25,2	39,6	12,5	22,7	8,4

The overall representation of the waiting time for the data sample is effectively shown in Figure 6. (Chart is created in XOVIS). Figure 6 illustrates the waiting time peaks and their distribution over the studied data sample. The peaks of the chart represent where waiting time reaches its highest level. The indication of the highest waiting time peaks emphasizes the area of congestion and potential concern. In order to present data for easier analysis, table 2 contains the maximum waiting time for morning and afternoon peak hours. In the framework of this study, the evening peak hours are omitted. The anomaly on the chart can be clearly detected on 12 MAY. During the event, the morning peak hour's waiting time was 39,6 minutes. The anomaly will be further examined in the 4.3 data analysis part.

4.2.4 The number of security lanes

Figure 7. Summary of actual lanes allocation. (XOVIS,2023)

A security lane is a single unit of security control, including security officers and all necessary equipment for security screening. The number of security lanes allocated for transfer security control is aligned with the arriving flight schedules and the number of passengers. The actual number of security lanes allocated during the examined period is represented in Figure 7. Generally, the number of security lanes varies between 1 and 4. The primary parameter for the security lane passenger flow. The parameter is the target point representing the numerical value of passengers' throughflow through the security lane. There are many factors that may affect the passenger flow. In the framework of this research, the passenger flow will be considered constant to simplify the examination.

4.3 Data analysis

Table 3 represents the data sample for May 12 from period 04:40 to 06:40. The author divided the sample for the 15-minute time windows. Each time window has been coded with the letter for easy navigation from A to H.

Table 3. Overview of operation. (Author's own work, 2023)

15 minutes window	Total number PAX per 15 min	Waiting Time Minimum (Minutes)	Waiting Time Maximum (minutes)	Avarage Arrival rate PAX per minute	Avarage waiting time (Minutes)	Actual Number of Security lanes	Expected PAX per secuirty lanes
A	96	0,07	1,63	6,4	0,80	3	32,0
B	111	0,23	2,07	7,4	1,05	3	37,0
C	92	0,83	3,70	6,1	3,25	3	30,7
D	70	7,77	19,13	4,7	13,92	3	23,3
E	139	8,90	29,85	9,3	34,82	3	46,3
F	96	30,72	38,90	6,4	34,82	3	32,0
G	103	30,15	39,60	6,9	33,82	3	34,3
H	88	2,95	35,97	5,9	27,56	3	29,3

Based on the data from Table 3, we can see the effect of some various factors, that need to be further investigated in order to make more precise predictions. The rapid increase in waiting time between windows E and F might mean the creation of a bottleneck. This event created further delays and slowed down the overall process which caused the rapid increase in overall waiting time. The reasons behind the bottleneck creation stay unknown. The waiting time rapidly decreased in window H. That may mean the mitigation of the cause of the bottleneck.

4.4 Economic Foundations of Security Checkpoint Operations

4.4.1 Cost of waiting time

The concept of cost of waiting time is aiming to find the solution for the allocation of the optimum number of security lanes. The ground for the concept is that the cost of time is changing based on the target waiting time in the security control. The target waiting time needs to be optimized for efficient, but cost-effective passengers passing through the security control to their transfer flight. The overall impact of the waiting time on the operations and passengers is covered in Table 4.

Table 4. Impact of waiting time. (Author's own work, 2023)

	Impact on the operations	Impact on the passengers
Low waiting time	• High operational cost. • High staffing demand. • Potential low utilization of the security control resources. • Fast passenger's flow thought the security control.	• Minimum delays. • Stress-free experience. • Perception of degraded security measures.
Middle waiting time	• Optimal level of staffing. • Security lanes maintain balance between speed and passengers' flow.	• Slight inconvenience due to moderate waiting time. • Higher chance of missed flight for passengers with

	• High utilization of the security control resources. • May cause some delays during peak hours.	short connection time.
Long waiting time	• Major congestions and long queues are expected. • Potentially missed flights or severe delays. • Hight workload on the security control personnel.	• Emphasized frustration and stress feeling. • Missed connection flights. • Degraded overall customer experience.

The fact, that the security lane requires a certain number of security officers means that the cost of each lane can be considered as constant per unit. In the framework of this research, the security officers' wage add-ons, increased pay rates, and differences in wages depending on the role are omitted in order to simplify the calculations.

The total cost of the security control operations can be found by using the formula:

$$TC = UC \times n$$

Where:
TC – Expected Total cost per period,
UC - Unit cost for the security lane,
n – number of security lanes allocated.

When making the allocation decision, the number of security lanes allocated needs to be optimized with the number of arriving passengers and target waiting time. The minimum increment for allocation is n ± 1. Assuming that costs increase per unit of waiting time in expositional.

The relocation of security lanes is available between departure security control and transfer security control. Practically, that requires the relocation of security officers to another security point. This operation takes time, due to the long walking distance and required procedures of closing and opening a security lane. The time of relocation may vary, but in the framework of this research can be counted as 15 min per side. During the relocation, the security lane is out of operation, however, it is affecting the cost of operation.

4.4.2 Basic Relationship Between Waiting Time and Economic Costs

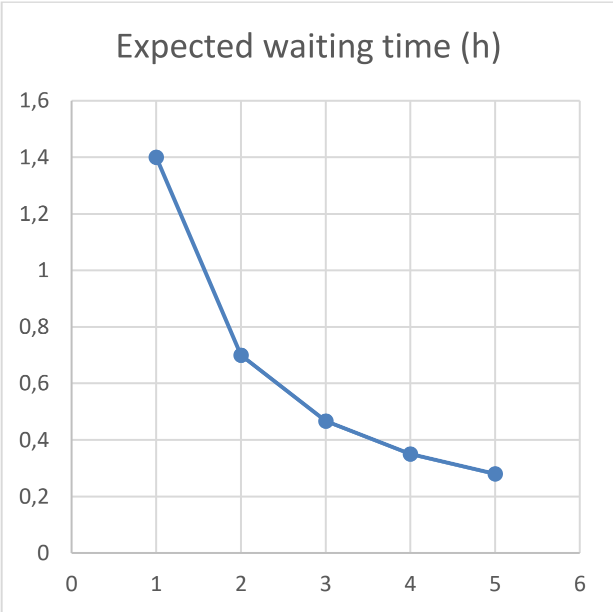
In order to, better represent the cost of the waiting time, the author created the generic table which provides a clear outlook of the relationship between waiting time and its effect on the economic costs. For a particular example, the number of arrival costs was taken as 350 passengers. Expected costs are calculated based on the number of security lanes with constant passenger flow. Figure 8 represents the relationship between number of the security lanes and waiting time based on the expected flow. Calculations don't take into consideration security lanes transferring or any other changes in the operational environment in order to simplify the calculations.

Table 5. Cost of waiting time. (Author's own work, 2023)

Constant variables		
Security officer wages/h	**30 €**	Wages don't take into account any additional extras related to the position. This number is only for reference and doesn't represent real life wages.
Security officers per lane	**7**	The number of security officers per security may vary in real life. This number is only for reference.
Exspected PAX flow	**250 pax/h**	Passenger Flow may vary significantly even during operations. This number was taken as constant and does not represent the real value.

Number of Arrival passangers	Number of the lanes	Expected waiting time (h)	Expected time (min)	Total cost per hour	Pax per minute	Expected cost per PAX.
350	1	1,4	84	210 €	4,2	0,60 €
	2	0,7	42	420 €	8,3	1,20 €
	3	0,47	28	630 €	12,5	1,80 €
	4	0,35	21	840 €	16,7	2,40 €
	5	0,28	16,8	1 050 €	20,8	3,00 €

Figure 8. Expected waiting time. (Author's own work, 2023)



Based on Table 5, the cost per passenger is increasing exponentially with the number of security lanes increased. Based on that generic data, the conclusion is that maintaining the correct proportion between the number of security lanes and waiting time should be able to optimize the economical aspect of the operations. Table 6 analyzes the change in expected costs and the change in expected time. By adding the cost ratio, the effect of the change can be examined precisely. The cost ratio formula looks next:

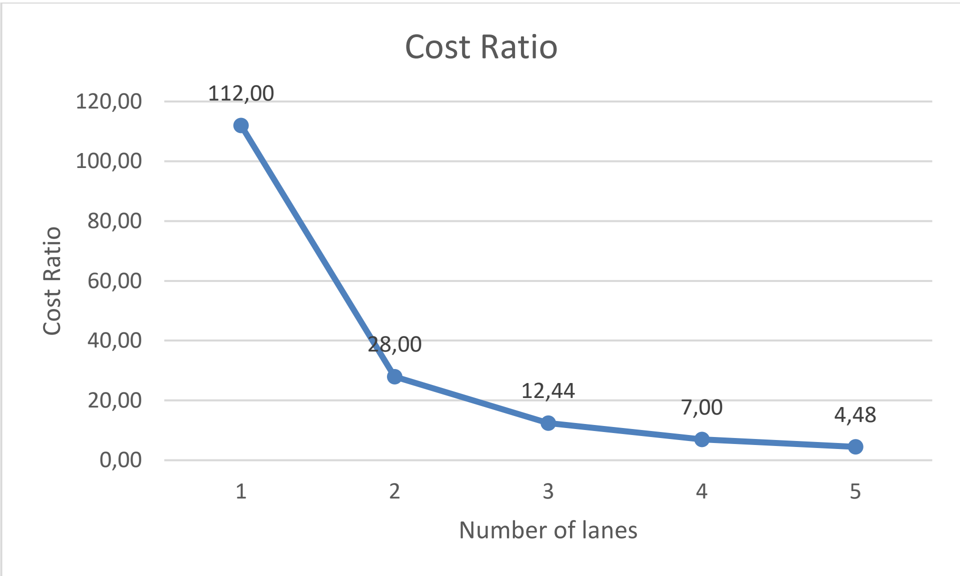
$$Cost\ Ratio\ = \frac{Expected\ waiting\ time}{Expected\ cost\ per\ PAX}$$

(Cost Effectiveness Analysis, n.d.)

Table 6. Change in parameters. (Author's own work, 2023)

Arrival passangers per hour	Number of the lanes	Expected time (min)	Expected cost per PAX	Change in Expected cost	Change in Expected time	Cost Ratio
350	1	84	0,60 €	-50%	100%	140,00
	2	42	1,20 €	0%	0%	35,00
	3	28	1,80 €	50%	-33%	15,56
	4	21	2,40 €	100%	-50%	8,75
	5	16,8	3,00 €	150%	-60%	5,60

Figure 9. Cost Ratio Chart. (Author's own work, 2023)



According to data represented in Figure 9, the change in cost ratio has a noticeable variation. The cost ratio fluctuates between 112 and 4.48 with an expected waiting time of 84 and 16,8 minutes accordingly. (Table 6.) The change in cost ratio trend has a remarkable drop at 2 security lanes or cost ratio 28. The change in the cost ratio between lanes 3, 4, and 5 is less significant. Due to that fact, the optimal waiting time target should be taken into account.

The possible practical application can be found in the cost ratio. By maintaining a certain cost ratio the required optimum balance between the waiting time and expected cost per passenger can be archived. This can be implemented for example, for planning purposes. Due to the complexity of the environment, aircraft origin, number of screening baggage, and a significant number of other factors will have a direct impact on real results. In the case of this study, those factors are omitted in order to simplify the calculations. In order to find the optimal cost ratio, more analysis is required.

Taking into consideration the transferring of security control personnel from one security point to another one can show another perceptive of the matter. For purposes of this study, moving personnel from one security point to another may take approximately 15 minutes. By adding the transfer cost, the obtained results are shown in Table 7.

Table 7. Generic transfer cost. (Author's own work, 2023)

Arrival passengers per hour	Number of the lanes	Expected time (min)	Total cost per hour	Additional transfer cost	Total cost per hour	Expected cost per PAX	Expected cost per PAX	Change in cost per PAX	Cost Ratio
350	1	84	210 €	**53 €**	263 €	0,75 €	0,60 €	**0,15 €**	112,00
	2	42	420 €	**105 €**	525 €	1,50 €	1,20 €	**0,30 €**	28,00
	3	28	630 €	**158 €**	788 €	2,25 €	1,80 €	**0,45 €**	12,44
	4	21	840 €	**210 €**	1 050 €	3,00 €	2,40 €	**0,60 €**	7,00
	5	16,8	1 050 €	**263 €**	1 313 €	3,75 €	3,00 €	**0,75 €**	4,48

Based on the calculations, the transfer of personnel may have a significant impact on the cost per passenger and directly affect the cost ratio of the security control operations. Taking into consideration, that transferring security lanes can happen multiple times per day in total that may reflect in significant increase in cost per passenger. This example shows the importance of planning and the need for minimization of transfers. Another approach to this matter could be ensuring the fast and efficient transfer of the security lanes between security points in order to maximize the utilization of available resources to maintain the optimum cost ratio.

By analyzing the results from Figure 9 and Tables 6 and 7 and summarize them accordingly. The results can be found in the table 8.

Table 8. Cost Ratio Compilation Table. (Author's own work, 2023)

Cost Ratio	Costs	Waiting time
High-Cost Ratio. (Table 7. **112 – 28)**	Costs are low and that means fewer security lanes allocated for particular moments.	The waiting time is opposite to the cost it significantly increases.
Optimum Cost Ratio (Middle) (Table 7. **12.44–7)**	Costs are maintained at optimum level. The number of security lanes close to optimum.	Waiting time correlates with demand for the number of transfer passengers and maintains an acceptable level.
Low-Cost Ratio (Table 7. **4,48)**	Costs are relatively high. The excessive number of security lanes is allocated.	Waiting time is further improved.

For easier understanding, the change in the cost ratio, expected waiting time, and Expected Cost per PAX can be also represented in percentages. The results are in Table 9 based on generic data from Table 7. The change represents the decrease from the previous value.

Table 9. Differential Analysis. (Author's own work, 2023)

Number of security lanes	Expected waiting time (minutes)	Change in %	Expected cost per PAX	Change in %	Cost ratio	Change in %
1	84		0,60€		112,00	
2	42	**-50%**	1,20€	**+ 100%**	28,00	**-75%**

3	28	**-33,3%**	1,80€	**+ 50%**	12,44	**-55%**
4	21	**-25%**	2,40€	**+ 33,3%**	7,00	**-43,6%**
5	16,8	**-20%**	3,00€	**+ 25%**	4,48	**-35,4 %**

Based on this analysis, changes in waiting time and costs are correlated with significant increases in cost and improvement of waiting time, but by further increasing the number of security lanes the change in waiting time is less significant. Eventually, the rise in cost is not followed by a significant improvement in waiting time.

4.4.3 Overview of the two case scenarios

The author created 2 generic examples with simplified calculations of the expected cost of operation of transfer security control. Examples are based on 2 shifting scenarios. The economic data do not represent the real costs and only reflect the generic examples and may significantly differ from the real numbers. For the scenarios, the different number of transfer passengers is used for calculation purposes. This simulates two different study cases. Initial allocation and service orders are based on the available passenger forecast. However, scenario 2 reflects the situation, when demand is higher than expected and additional security lanes are required in order to comply with demand.

4.4.4 Scenario 1

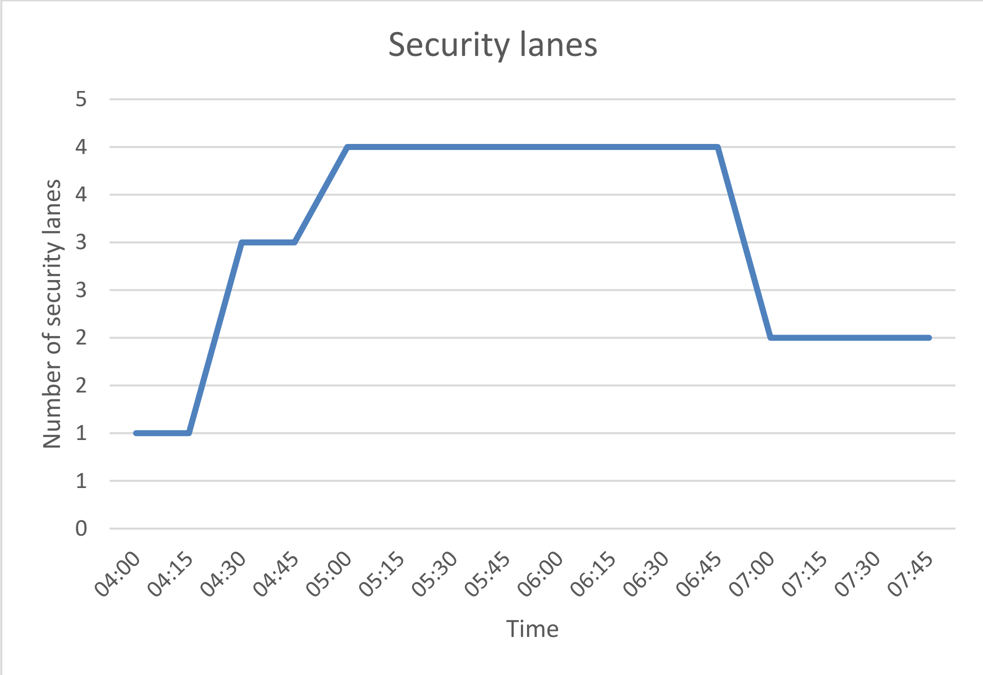
Scenario 1 is based on the passenger forecast. The number of security lanes scheduled is enough to maintain sufficient waiting time for the transfer passengers arriving during the security control opening slot. The security officers start their shifts at the transfer security control. Security lanes open according to the initial schedule. The is no need for relocation of security lanes between departure security control and transfer security control points. The overall shifting layout is shown in Figure 10. Table 10 represents calculations, of generic costs related to security control operations. The table shows a 4-hour operation with the number of passengers arriving per hour. The average waiting time in the security control was maintained at 21,75 minutes with an average Cost Ratio of 12.82. The overall layout of the security lanes is shown in Figure 10.

Table 10. Generic Scenario 1. (Author's own work, 2023)

Constant variables		
Security officer wages/h	**30 €**	Wages don't take into account any additional extras related to the position. This number is only for reference and doesn't represent real life wages.
Security officers per lane	**7**	The number of security officers per security may vary in real life. This number is only for reference.
Exspected PAX flow	**250 pax/h**	Passenger Flow may vary significantly even during operations. This number was taken as constant and does not represent the real value.

Time	Arrival passangers per hour	Security lanes	Expected waiting time (min)	Avarage waiting time	Expected cost per 15 minutes	Expected cost per hour	Transfer cost	Expected cost per PAX	Cost Ratio	Average Cost ratio(*100)
04:00	**150**	1	36	**24**	53 €	420 €		2,80 €	0,078	15,56
04:15		1	36		53 €				0,078	
04:30		3	12		158 €				0,233	
04:45		3	12		158 €				0,233	
05:00	**350**	4	21	**21**	210 €	840 €		2,40 €	0,114	11,43
05:15		4	21		210 €				0,114	
05:30		4	21		210 €				0,114	
05:45		4	21		210 €				0,114	
06:00	**400**	4	24	**24**	210 €	840 €		2,10 €	0,088	8,75
06:15		4	24		210 €				0,088	
06:30		4	24		210 €				0,088	
06:45		4	24		210 €				0,088	
07:00	**150**	2	18	**18**	105 €	420 €		2,80 €	0,156	15,56
07:15		2	18		105 €				0,156	
07:30		2	18		105 €				0,156	
07:45		2	18		105 €				0,156	
Totals:	**1050**		**Average waiting time**	**21,75**		**2 520 €**	**Average cost**	**2,53 €**	**Average Cost Ratio**	**12,82**

Figure 10. Security lanes Layout (Scenario 1). (Author's own work, 2023)



4.4.5 Scenario 2

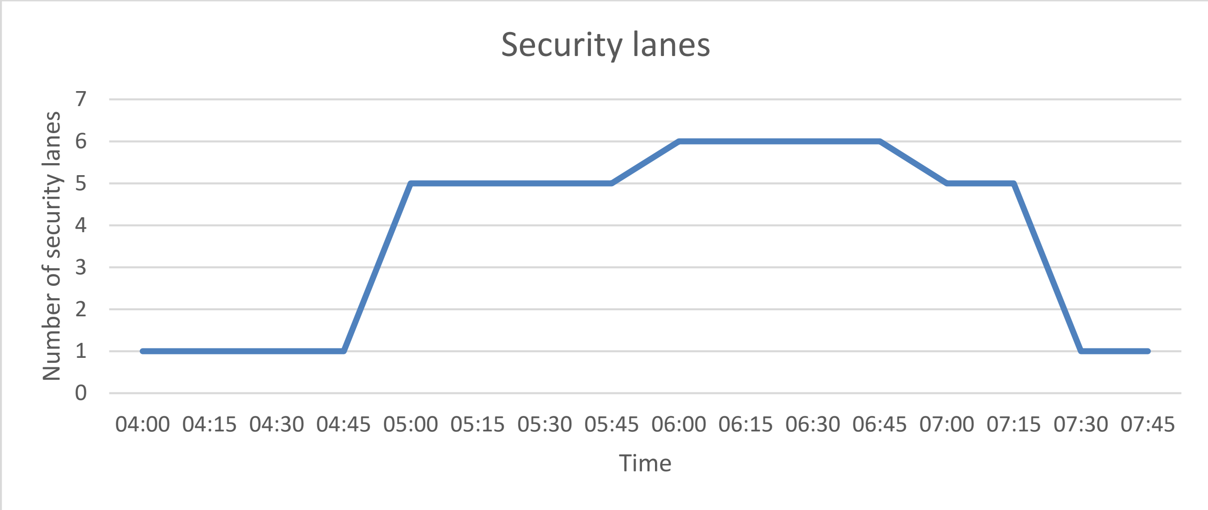
Scenario 2 is based on the passenger forecast; however, the actual number of security lanes needs to be modified in order to comply with the demand. Some security officers start their shifts at the transfer security control, but some personnel will be transferred from the departure security control. The relocation of several security lanes between departure security control and transfer security control points takes approximately 15 minutes. The overall shifting layout, with the transfer of the security lanes, is shown in Figure 11. The transfer cost in Table 11 reflects the estimated cost of transferring the security lane. This metric assumes the fact, that security officers are on the shift during the transfer time and getting paid. The reality of transferring the security lane, however, can be different, and changes in that parameter can increase or decrease. This depends on the length of the transfer, number of the security officers, and some other variable factors.

Table 11. Generic Scenario 2. (Author's own work, 2023)

Constant variables		
Security officer wages/h	**30 €**	Wages don't take into account any additional extras related to the position. This number is only for reference and doesn't represent real life wages.
Security officers per lane	**7**	The number of security officers per security may vary in real life. This number is only for reference.
Exspected PAX flow	**250 pax/h**	Passenger Flow may vary significantly even during operations. This number was taken as constant and does not represent the real value.

Time	Arrival passangers per hour	Security lanes	Expected waiting time (min)	Avarage waiting time	Expected cost per 15 minutes	Expected cost per hour	Transfer cost	Expected cost per PAX	Cost Ratio	Avarage Cost ratio(*100)
04:00	**250**	1	60	**60**	53 €	210 €	0 €	0,84 €	0,014	1,40
04:15		1	60		53 €				0,014	
04:30		1	60		53 €				0,014	
04:45		1	60		53 €				0,014	
05:00	**400**	5	19,2	**19,2**	263 €	1 103 €	53 €	2,76 €	0,144	14,36
05:15		5	19,2		263 €				0,144	
05:30		5	19,2		263 €				0,144	
05:45		5	19,2		263 €				0,144	
06:00	**400**	6	16	**16**	315 €	1 273 €	13 €	3,18 €	0,199	19,89
06:15		6	16		315 €				0,199	
06:30		6	16		315 €				0,199	
06:45		6	16		315 €				0,199	
07:00	**150**	5	7,2	**21,6**	263 €	630 €	0 €	4,20 €	0,583	35,00
07:15		5	7,2		263 €				0,583	
07:30		1	36		53 €				0,117	
07:45		1	36		53 €				0,117	
Totals:	**1200**		**Avarage waiting time**	**29,2**		**3 216 €**	**Avarage cost:**	**2,74 €**	**Avarage Cost Ratio**	**17,66**

Figure 11. Security lanes Layout (Scenario 2). (Author's own work, 2023)



In this scenario, the transfer of the security officers from one security point to the transfer security point takes 15 minutes. During this time, the security lane is out of operation at both security points. That eventually reflects in overall decreased performance in both security points and creates a fluctuation in the Cost Ratio.

4.4.6 Analysis of the scenarios

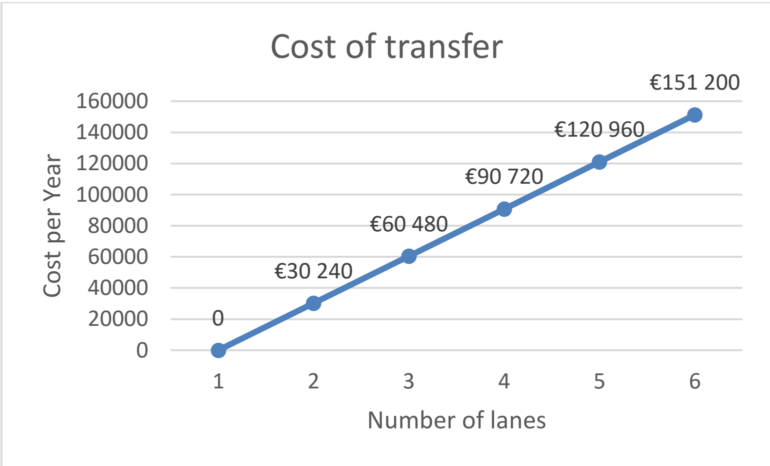
Two different study case scenarios show the way of implementation of the cost ratio method. The Cost Ratio fluctuates according to waiting time and cost per passenger. Metrics linked with the number of security lanes allocated which correspond to the number of passengers arriving per hour. The cost ratio allows us to see the correlation between different metrics. Making adjustment of the security lanes easier. However, the real-life application of this method requires tools, which will allow for the calculation of the cost ratio with possible simulation.

Another important aspect is the transferring of security lanes, which was covered in case two. The case showed that the transfer of security personnel has its own economic cost. The Transfer Cost reflected in Table 11 can be considered minor and does not affect the economic situation overall. If this cost is recalculated for a long time, it may reflect in significant economic burden. In Table 12, the author calculated the estimated cost for the transfer of security lanes on week, month and year bases. Calculations are based on generic data and use the same constant values as in previous study cases. For calculation simplification, the next data was used, 2 transfers per day and 6 transfers per week.

Table 12. Estimated cost compilation table. (Author's own work, 2023)

Number of the lanes	Transfers cost (15 min)	Transfer cost per week	Transfer cost per month	Transfer cost per Year
1	53 €	630 €	2 520 €	**30 240 €**
2	105 €	1 260 €	5 040 €	**60 480 €**
3	158 €	1 890 €	7 560 €	**90 720 €**
4	210 €	2 520 €	10 080 €	**120 960 €**
5	263 €	3 150 €	12 600 €	**151 200 €**

Figure 12. Cost of transfer Chart. (Author's own work, 2023)



Based on the results obtained, transfer cost may have a significant impact on security control point operations. (Figure 12.) In order to understand the effect of security lanes transferring, more data and research is required. The scenario was created only to show one of the possible trends and does not reflect the real costs in Helsinki airport. Based on this examination, the conclusion is that the transfer cost may directly result in increased cost per passenger and cost ratio.

5 Results

The author initially planned to research the possible correlation between the number of security lanes allocated for transit passengers at Helsinki airport and possible congestion. Researching relationships between different parameters may allow for finding trends and using results for cost index model creation.

In order to answer the research question, the author used analysis of the secondary data, based on initial research, can conclude that the number of security lanes allocated in the transfer security point directly impacts the efficiency of the security point. This fact correlates with possible congestion when the security control capacity is below the required demand. High waiting time in the security control, also significantly affects the passenger experience. The prolonged waiting time at the security checkpoint can result in flight delays, missed connections, and overall unsatisfactory passenger experience. The complexity of the issue cannot be underestimated. There are many factors, that may affect directly or indirectly possible congestion as well. Various factors need to be studied more precisely in order to find the possible correlation and their direct impact and methods of mitigations. However, the number of security lanes can be considered as a primary factor ensuring the initial security control process. The number of security lanes influences the capacity of the security control, but on the other hand, increases the cost related to security control operations. The number of security lanes shall be balanced with optimal economic perspective. In order to simplify operational decision-making, new methods of allocation can be implemented.

In the framework of this research, the initial secondary data was used in order to examine parameters, the number of transfer passengers, waiting time, and number of security lanes. Based on this data, the correlation between the number of security lanes allocated and congestion can be found. However, some various factors may significantly change the expected waiting time. Some examples of those anomalies are technical malfunctions, fluctuation in arrival passenger numbers, aircraft origin airport, a number of security screened baggage, and many more. The author of this research, examined on bottleneck example found in the provided secondary data (4.3 Data Analysis). However, the real cause of the phenomena is left unknown and can be mitigated in the framework of this research.

The author also examined the economic foundation of the security control process. The generic data was used in order to study possible trends and better understand the overall background of this foundation. The potential optimization possibilities will require more precise data and deep examination to find links between different metrics. The author found the use of Cost

Ratio as one of the possible methods for future implementation in planning. These simple methods could allow for easy and efficient decision-making. The cost ratio targets can be created for different scenarios. The benefit of this method is to include many economic factors, which could be hard to take into account during the operative decision-making process. The author used a simplified version of the Cost Ratio method for two generic study scenarios. Based on the results, provided by study cases, the method can be implemented however, requires future study and analysis. Taking into account, operative security lanes transfers, the author found a trend that may cause a significant economic burden. The assumption is based on the fact, that transfer of the security lanes, requires time, due to the distances between security points and the opening and closer of security lanes-related procedures. This aspect could be studied further in order to find the real-life effect of this trend.

6 Conclusions

In conclusion, the research initially aimed to study the potential correlation between the number of security lanes allocated at transfer security control and possible congestion. This research was based on a known knowledge gap related to security control operations at Helsinki Airport. The research topic is complex and demanding. Due to the complexity of the operations and operational environment, the analysis of the metrics and their correlations was limited to several parameters. The focus of this research was to study the secondary data and generic economic data in order to find possible correlations and trends.

The analyses started with the research on the industry situation in post-covid times. The examination of available resources showed the whole industry's challenges. Overall issues are generally related to personnel shortages and new trends, like passenger traffic fluctuation and post-Covid aviation economic recovery. The author obtained the secondary data, from the transfer security control at Helsinki airport. The data provided a sample of one-week operations with a resolution of 1 minute. Based on that data, quantitative methods were used for analysis. The metrics like waiting time, number of transfer passengers, and number of security lanes allocated were examined. The author found a direct correlation between the number of security lanes and possible congestion. The examined metrics directly affect the security control capacity. However, it is important to recognize that various factors may affect the security control operations. Those factors may have a direct or indirect impact on the operations. The effect of those factors was omitted and requires more research in order to find the correlations and mitigation strategies. The number of security lanes remains the primary factor of the security point capacity.

The author wanted to find balance and new approaches to operational efficiency and the economic perspective. The fact that increased number of security lanes created higher operational costs. The economic foundation of security control operations was studied by utilizing generic data, in order to identify trends and new methods of operative decision-making. In the framework of this research, the author introduced the Cost Ratio method. This method allows to linking of several different metrics and gives a direct and easily understandable numerical representation of security control capacity. The application of this method was tested on two generic scenarios. Based on the results, this method can be used as a new approach and tool for decision-making. However, the author wants to emphasize the importance of further research and studies before final conclusions can be made. Practical implementation of those methods would require new digital tools in order to ensure easy practical application.

7 Recommendations

As the result of this research, the author found several possible recommendations, that may improve the efficiency of decision-making and ensure security control operations. This research emphasizes the importance of established target metrics. In order to obtain the required balance between operational efficiency and economic aspects. One example of metrics could be the target waiting time. This may help to calculate the required number of security lanes. Waiting time could be related to passenger experience or expected transfer time for the passengers. This aspect can also take into account discretionary activities. According to Systemic Agent-Based Modeling and Analysis of Passenger Discretionary Activities in Airport Terminals publication, discretionary activities are accountable for 35% of revenue. (Adin Mekic ‘, et al, 2021)

Implementation and future research of the Cost Ratio method can be beneficial. This method could allow for more flexible operations of security control and balance between different parameters in the required manner. Implementation of tools, allowing the calculation of Cost Ratio will make operative decision-making easier and within required economic frames.

Based on this study, the conclusion is that transferring the security lanes of one security point to another may significantly increase the cost per passenger. Taking that into consideration, the importance of planning is emphasized. Allocating the security lanes in such a manner, that security personnel’s shifts start from the transfer security control can be considered. In order to ensure proper planning, the passenger forecast and setting precise parameters such as cost ratio may be considered. Another aspect that may improve the situation could be to ensure a fast and efficient transfer of personnel. Due to the long distance between the security control points, the use of golf car or kick scooters can help to improve the efficiency of the transferring process.

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Appendix 1. Data Management Plan

The data management plan is settled for handling and systematizing data used for this research. The primary data used for analysis is a secondary source obtained from the XOVIS software. The Data represents a week sample with a 1-minute resolution. Metrics represented in the data sample are the actual number of security lanes, the number of transfer passengers, and waiting time. The data sample doesn’t consist of any personal data, however, the data used for the analysis is related to the airport operations. Due to the source and the nature of operations, the data is considered to be sensitive data. The data is stored on two memory sticks in the CSV (Comma-Separated Values) and Excel tables (.xlsx) formats. The formats used are compatible with the tools used for the analysis. The author started with data cleaning and pre-processing, in order to, systematizing available information. This step involved searching for missing data, standardizing the data layout, and creating a small data sample for the analysis. The processed data is stored separately from the raw data. Data analysis was performed using Microsoft Excel. Organized and processed data was analyzed using the methods of quantitative analysis. The ownership of research results and data is in accordance with the thesis agreement. The author decided not to utilize the research data for the future. The data will be securely stored for one year.