Striving towards a shorter security queue

A stated choice experiment on the timeslot reservation system at Schiphol Amsterdam Airport

Engineering and Policy Analysis

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TU Delft

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by

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Project Duration:	September, 2024 - February, 2025
Faculty:	Technology, Policy and Management

Cover: TelNEX 2024. *Wachtrijen*. TelNEX. Retrieved September, 2024, from https://telnex.nl/vaste-telefonie/functies/wachtrijen/.

TU Delft

Preface

Before starting my master thesis, I was looking for a subject that interests me. I already wrote another thesis for another master program that I did last year, but I wanted to get a topic which highly interests me, so that I would be motivated for a long period. In the end, I found this topic after I won the business case of Schiphol Group at the Techniek Bedrijven event. I am very grateful to be able to graduate at such a company, as I had the opportunity to write a thesis on an interesting subject, while also having the opportunity to see how things work at Schiphol. Now at the end of my thesis, I can proudly say that I pushed myself to the limit to produce this thesis. However, this thesis was not possible without some people. Therefore, I would like to take the opportunity to express my gratitude to a few people.

I want to sincerely thank my committee, as this thesis would not have been possible without their help. A special shout-out goes to Eric Molin, the chair of my committee, for always being there for me and supporting me during my project. His expertise and understanding of choice modelling really guided me through this research. To Alexander Verbraeck, thank you for taking the time at the end of my project, in which I wanted to integrate a simulation study. You have helped me to create a small, but effective model. Moreover, I want to thank Martijn van Boven for your supervision from the perspective of Schiphol. You guided me trough the maze of Schiphol and was always available for help. It really amazed me how someone could be so helpful to other people. I have learned a lot from you, thank you! In addition, I would like to thank my family and girlfriend for their unconditional support and their advice during my research. Furthermore, I would like my roommates and other friends who have helped me trough this challenging period. Finally, I would like to thank Mart Vloet and Wessel Donkervoort, as you two know my whole thesis, without even reading one letter of my report. Being able to write a thesis together with friends who are also writing their thesis was very valuable for me. Now, my student period and, therefore, my time at the TU Delft is over, and I am very grateful for everything I learned here and for the great time I had.

T.J. Hillenaar
Delft, February 2025

Summary

This thesis researches passenger preferences regarding the security time slot reservation system at Schiphol Airport. This study is motivated by the fact that time slots are currently used less than expected by Schiphol, while time slots aught to be one of the solutions for the rising number of passengers, which cause more pressure on several systems at the airport, including the security checkpoint.

The main goal of this thesis is: ”to investigate passengers’ preferences of a security time slot reservation system at Schiphol Airport. Additionally, the study aims to identify the optimal balance between travellers with and without a time slot for the security check point to ensure system effectiveness.” Through a survey that includes both a Stated Preference Analysis and a Factor Analysis, passenger preferences are researched. In addition, a discrete event simulation is done in order to explore possible scenarios for time slot usage.

The research shows that passengers who book a time slot tend to have a more favourable view of the system than those who do not have a reservation. While having time slots brings more certainty to catch your flight, it can also limit flexibility, which some travellers see as a downside. Stress levels vary between these two groups, with those using time slots reporting less stress because they know what to expect due to time slots. However, people who are not familiar with the time slot system often remain sceptical, underlining the need for better awareness to change these perceptions.

When it comes to passenger preferences, the time between security checks and departure plays a crucial role in deciding whether to reserve a time slot. The study indicates that passengers find the most value when this time is less than 100 minutes, with the benefits decreasing as this time increases. Cost sensitivity is another important factor, as passengers react strongly when a previously free service becomes a paid one. On the other hand, their sensitivity is less strong for potential price increases. A similar trend is seen with saved waiting time, where the first few minutes saved are more valuable than larger time savings. Business travellers and passengers travelling with children tend to be less cost-sensitive, likely due to company support or a focus on convenience. Moreover, Schengen passengers are more likely to book time slots when the time between security and departure is short, while non-Schengen passengers have a less strong preferences towards short time slots.

The scenario analysis indicates that adding more security lanes can help reduce waiting times, but this effect is less strong when queues are already short. The study also finds that having dedicated security lanes for time slot passengers is not very efficient unless a large number of passengers are using them. Instead, a mixed strategy (with other types of lanes, such as priority class) is suggested to enhance efficiency. Additionally, peak shaving, which involves spreading out passengers across different time slots, is shown to be an effective method for managing queue lengths and improving overall flow.

Keywords: Discrete choice experiment, MNL model, Stated preferences, willingness-to-pay, Airport, Security Time Slots, Peak Shaving, factor analysis, Discrete event simulation

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Nomenclature

Abbreviations

Abbreviation	Definition
DCE	Discrete Choice Event
DES	Discrete Event Simulation
MNL model	multinomial logit model
RP	Revealed preference
RQ	Research question
SF	Security Filter
SP	Stated Preference
WTP	Willingness to pay

1 Introduction

In the years before Covid-19, Schiphol Amsterdam Airport had a continuous growth regarding the number of departing passengers (CBS 2024a). Covid-19 had a major impact on the airport, which reduced the number of passengers drastically. However, the yearly report of 2023 shows that Schiphol Airport is recovering as the recent number of passengers is almost similar to the pre-COVID period (Royal Schiphol Group 2023).

More passengers increase pressure on the already suppressed airport system. Before the COVID-19 pandemic, long queues in front of the security checkpoints were already a struggle for airports, as one in every seven travellers missed a flight due to long security queues (Stoller 2018). Before COVID-19, Schiphol was already warned by several instances that their pool of security employees was too small (Stil 2023). Due to COVID-19, Schiphol had problems keeping their financial budget healthy, which caused many airport employees to be fired, including security staff members. Many of these ex-security employees got a new job in a different sector, which made it challenging for airports to hire new staff after the COVID-19 passenger dip (Schouten 2022). This, in combination with the already small pool of security employees, caused massive waiting times in front of the security check. At one point, queues became so long that they extended all the way outside with a waiting time longer than 3 hours (Schelfaut 2022). The situation worsened so badly that the military police almost had to intervene (Bakker 2022).

Obviously, queues at airports are not only an issue for airports, but especially for passengers. Passengers experience delays, missed flights, and increased stress due to long waiting times (BBC 2022, Rosenow et al. 2020). Exceptional long queues during the COVID-19 pandemic increased these passenger complaints massively.

After this queuing debacle, Royal Schiphol Group agreed that the system was not functioning efficiently, which resulted in the implementation of an added queuing system: The security time slot reservation system (Royal Schiphol Group 2022).

1.1. The Security Time Slot Reservation System

The security time slot reservation system enables passengers to select a time slot in which they would like to go through the security checkpoint. Before the time slot system, the security queue was split up into four different queues: a queue for economy class passengers, a priority lane, a privium member queue, and a lane dedicated to disabled people (PRM). The original idea for the time slot system was a dedicated lane for passengers with a time slot reservation (i.e. a 5th lane). However, the current system allows passengers with a time slot reservation to join the priority class queue. This priority class queue is usually shorter than economy class queues (Royal Schiphol Group 2022). Nowadays, a reservation for a time slot lasts 15 minutes. However, passengers could have delayed arrivals due to unforeseen circumstances. Therefore, a buffer of 15 minutes is implemented in which passengers are still allowed to join the queue. Schiphol created a time slot tool in which several time slots are presented to passengers. The shortest time slot is 1 hour before departure, and the latest time slot is 2-3 hours before departure (2 hours for Schengen flights, 3 hours for non-Schengen flights). In between, time slots will differ 15 minutes from each other; for instance: a time slot between 09:00-09:15 will be followed by a time slot between 09:15-09:30.

The mixture of priority passengers with 'time slot passengers' (consisting of passengers with different reservation times) creates a challenge for the airport: Who is allowed to go first? The following policy is made by Schiphol: Normally, a first-come first-serve system is used in the priority/time slot queue. However, time slot passengers gain priority (i.e. skipping the line) whenever passengers are about to miss their time slot.

The phenomenon of time slots for security queues is not a new system, as Flughafen Frankfurt am Main did a pilot study in 2018 (Frankfurt Airport 2024). From this moment onwards, other airports followed and also implemented a time slot system.

However, airports used time slots for different purposes than Schiphol does nowadays. Previously, other airports implemented a time slot system only to reduce passengers' anxieties. Back in April 2023, Schiphol was the first airport that used time slots multi-purposely as it was also used to reduce security queues. For instance: other airports create an equal number of time slots for each period, while Schiphol calculates the number of time slots to influence passenger flows. Managing passenger flows to create less demand during peak hours is called peak shaving.

1.2. System Capabilities and Advantages

The time slot system has the potential to solve multiple issues for both the airport and passengers. First of all, Schiphol uses an algorithm to calculate the number of available time slots for each period for each security filter. This enables Schiphol to manage passenger flow more efficiently, as fewer time slots are available during rush hours and more time slots during off-peak hours (peak shaving). Peak shaving distributes passengers during a peak over a period before and after the peak. Thus, a broader, less high passenger peak is being created. This newly created peak benefits passengers, as the average waiting time decreases. Peak shaving also benefits the airport, as the occupancy rate of resources at Schiphol increases, due to less idle time.

In addition, the time slot system gives Schiphol more control over the passenger flow in front of the security check as passengers' arrival behaviour is more predictable under the time slot system (Calder 2022).

Passengers could benefit from the time slot system, as it could solve their increased stress levels. As mentioned before, passengers suffer from travel anxiety, lost productivity, and missed flights due to longer waiting times (Rosenow et al. 2020). The time slot system helps to reduce the impact of these issues in two different ways: The system leads to lower average waiting times and the system gives more certainty to catch a flight.

1.3. Motivation for the Research

Despite the known advantages of the timeslot system, there are still some uncertainties that Schiphol wants to learn more about. More information about these uncertainties is necessary in order to make further improvements of the system. Currently, Schiphol is putting a lot of effort into researching potential improvements of the time slot reservation system. An example of a potential improvement is is the possibility to expand the service with an included luggage check-in time slot. Expanding the service with a luggage check-in time slot would benefit both passengers and Schiphol.

Passengers would benefit from an included luggage check-in time slot, because this makes it easier for passengers to make a planning for the trip. Currently, passengers have a dedicated arrival time for the security check point, but not for luggage check-in. Therefore, passengers with check-in luggage still have uncertainties within the airport process, as they do not know how long the queue in front of the luggage check-in desk will be. Including the luggage check-in in the time slot reservation service will offer less uncertainty for passengers with check-in luggage.

Expanding the system could also benefit Schiphol, as more passengers might be interested to book a security time slot. As stated above, the current time slot reservation is less attractive to passengers with check-in luggage, as they still have uncertainty about waiting time in their airport process. Whenever the service can create less uncertainty in a larger part of the airport process, the service becomes more attractive to passengers to use. More users of the time slot reservation system benefits Schiphol, because it becomes easier to reach the reach the goals of the system. For instance, peak shaving becomes more powerful whenever more passengers are positioned outside of the peak.

The uncertainty of this expenditure for Schiphol lies in the fact that these benefits are based upon estimation. Schiphol does not precisely know how much passengers value the time slot system. More specific, Schiphol does not know why passengers would use/ignore the possibility to reserve a time slot. This uncertainty is also an uncertainty for other potential extensions of the service. It must be stated that these uncertainties are not the only challenge for potential improvements of the system. For instance, time slots for luggage check-in must be aligned with airlines in order to work. However, gaining more knowledge about passenger preferences gives Schiphol more information about the decision to continue or stop with a potential extension.

Finally, the time slot tool is relatively new, which means that it is not a known tool for all passengers. Currently, it is not possible for Schiphol to send emails to passengers in order to make them aware of time slots. In some cases, airlines have send an email to passengers, but this is not a common occurrence. Therefore, it is interesting for Schiphol to gain more information about the awareness of the time slot tool, to understand whether more action is necessary.

Concluding, Schiphol believes that the time slot reservation system still contains room for improvements. More knowledge about passenger preferences can help Schiphol to decide whether to continue with extensions of the system of to stop with them, due to lack of support.

1.4. Knowledge Gaps

Currently, the exact system implemented by Schiphol has not been researched due to the combination of the pioneering role of Schiphol for the usage of time slots and a relatively new system (April 2023). Several aspects of the system have been researched individually (Chapter 3), but the combination used by Schiphol has never been researched. Only one article researches this kind of time slot system (Cao et al. 2024), but passengers receive assigned time slots in this study. In contrast, the time slot system used by Schiphol enables passengers to choose their time slot. Therefore, several knowledge gaps still exist.

First of all, it is unclear to Schiphol why passengers choose to use (or ignore) the time slot system. During the busiest weeks of the summer peak , only 20% of all passengers use the time slot system, which is less than expected before. These passengers reserved approximately 29% of the available time slots. This means that 71% of the time slot capacity has not been used. Ideally, Schiphol realises a 100% usage of time slots (under the condition that the capacity of time slots is based upon the goal to apply peak shaving and not on the goal to realise 100% use rate). Collecting more information about driving factors could improve the number of passengers that use the time slot system.

Moreover, it is unclear to Schiphol when passengers would prefer to reserve a time slot, rather than going to the security without a time slot reservation. Thus, Schiphol wants to know the distribution of passengers regarding necessary waiting time to cause time slot reservations. This is important knowledge for Schiphol to gain, as this information could explain when the time slot service is effective or not.

In addition, information about the willingness to pay for less waiting time in security queues is currently missing. Schiphol is indifferent regarding charging money for time slot services in the future. More information could be used to create strong policy regarding pricing for time slots.

Furthermore, it is currently unclear how the time slot queue effects the security checkpoint system and how this could evolve in the future with different reserving ratios.

1.5. Research Questions

In order to solve the knowledge gaps described above, a main research goal for this study has been formulated:

”The goal of this research is to investigate passengers' preferences of a security time slot reservation system at Schiphol Airport. Additionally, the study aims to identify efficient security lane strategies for different ratios of passengers with/without a time slot to ensure system effectiveness in the future.”

This research goal can be defined with five research questions:

1. *“What are the driving factors for passengers to use/ignore the security time slot reservation system and how do these factors differ over groups, clustered by (socio)demographic characteristics?”*

   This research question is answered by a factor analysis. Within the factor analysis, statements will be shown to the respondents. These statements need to be answered on a five-point scale from Fully-disagree towards fully agree.

2. *“What is the awareness of passengers regarding the time slot reservation system and how does awareness influence the attitude towards time slots?”*

   This research questions is also answered by a factor analysis. The outcomes of the statements will be analysed for passengers who knew that time slots exist and passengers who did not know that time slots exist.

3. *”What are consumers' preferences regarding time slot alternatives, including the attributes of the attribute and the context of travelling?”*

   This question will be answered by a stated preference (SP) analysis. A revealed preference analysis could also be applied to answer such a research question. However, sp is used as this allows to explore hypothetical scenarios, such as paid time slots. In addition, the data available at Schiphol regarding time slots includes bias, due to human error. Normally, security employees should scan the QR code of the reserved time slots before allowing passengers to enter the queue. In reality, these QR codes do not always get scanned (sometimes only 30% of the reserved time slots is being scanned). Therefore, a sp dataset is more reliable and creates more possibilities for scenario exploration.

Within the sp analysis, several questions will be asked in which respondents need to choose between two available time slots. Respondents are also allowed to make no reservation and ignore both time slots. The findings from this analysis are validated by the responses from respondents to questions that focus on isolated attributes.

4. *"What is the Willingness To Pay (WTP) of passengers for a security time slot reservation?"*

   This question will also be answered by applying stated preference. In detail, passenger profiles will be made which all have different WTP for specific scenarios of possible time slots. This way, WTP behaviour of the passenger profiles can be analysed.

5. *"Considering the maximum waiting time of passengers and the occupation rate of security checkpoints, how must the security system at Schiphol be arranged to handle different scenarios of ratios between passengers with/without a time slot."*

   This question will be answered by applying discrete event simulation (DES). The software Simio is used to rebuild security system of Schiphol to analyze potential solutions.

Concluding, in order to answer RQ 1 untill RQ4, a survey will be constructed which includes both the Factor Analysis and Stated Preference method. In addition, a Discrete Event Simulation will be done with the software of Simio to answer RQ5.

1.6. Societal relevance

Air travel is a crucial component of modern society, facilitating economic growth, international connectivity, and personal mobility. However, one of the key challenges for both passengers and airports is the unpredictability and inefficiency of security checkpoint queues. According to Schiphol (2024), people experience the most stress during the security check (including the queue before the check). The time slot tool aims to reduce unpredictability at the security check point of Schiphol. Therefore, the time slot tool could lead to potential societal benefits. This research analyses the current usage of the time slot system and explores scenarios in which the time slot system works efficiently. In my Master program of Engineering and Policy Analysis, I have been researching complex sociotechnical systems, such as the security queuing system at airports. This research aims to generate benefits for society, which aligns perfectly with the goals of the master's program.

1.7. Report Structure

Thus, this research focuses on the usage of time slot reservations at airport security checkpoints. First, an overview of airport processes is given in chapter 2. Then, a literature review is done in chapter 3. Afterwards, an elaboration on the methods and tools that will be used is provided in chapter 4 and 5. The chapters 6 until 10 will present results and creates interpretations which can be used to answer the research questions. Next, a discussion is done in which the obtained results are reflected upon and limitations, possible future research and implications are discussed. The last chapter includes the conclusions of this research, which answer the research questions.

2

Airport Processes description

This chapter describes the processes that a passenger goes through, while catching a flight, until the security checkpoint. Illustrating these processes creates a better understanding of the challenges faced by passengers regarding security time slots.

2.1. Processes at Airport until Security Check

The security checkpoint (including the queue) is not the only step in the process of flying. This section describes the processes before entering the queue in front of the security checkpoint. Figure 2.1 includes a flowchart with every airport step within the process of flying, from transport towards the airport until departure. As this thesis focusses on the time slot system for the security check point queue, the steps before the security check will be elaborated.

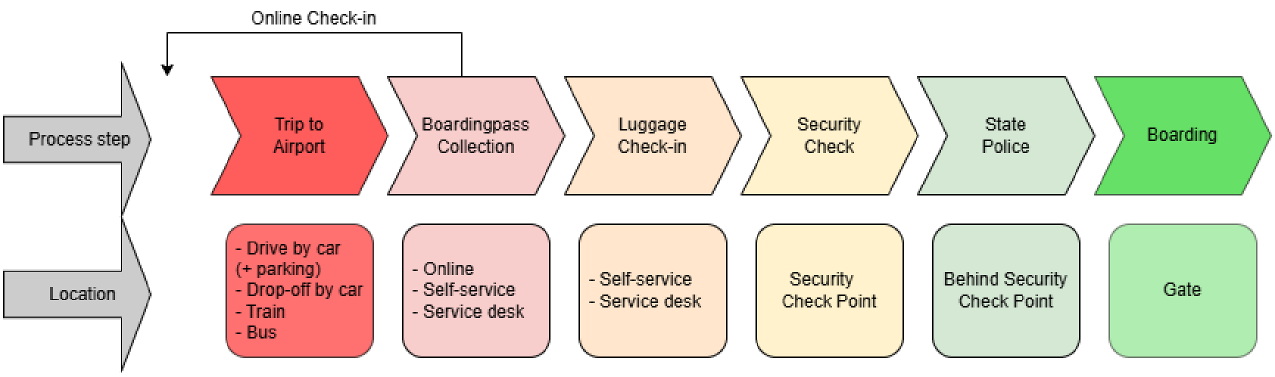

Figure 2.1: Flowchart airport processes

2.1.1. Transport Access Mode

The first relatable step starts already at home, as passengers have to decide how to travel towards Schiphol. For instance, travel time is not the only driver for the access mode selection, as costs, or other variables, could also play an important role.

The transport mode towards the airport influences the arrival pattern due to differences in travel time and possibilities for delay. Travelling by car is often faster than travelling by public transport, but traffic could cause major delays during rush hours. In addition, road accidents could occur outside the window of rush hours as well, potentially causing massive delays. After arriving at the airport, passengers need to park their cars and walk to the terminal which takes time as well (this takes in case of Schiphol more than the time it takes to walk after arrival by train).

Public transport is a transport mode that is being used often towards Schiphol, especially travelling by train. A major advantage of travelling by public transport is the ability to plan your trip in more detail. A train departs from a station at a specific time. Obviously, trains could get delayed as well, but 95% of all train movements in The Netherlands are more or less on time. However, whenever a train connection has a failure (for instance a track switch failure), it is often very difficult to reach that destination without having to take a detour which causes a lot of delay.

Concluding, passengers could select different kinds of transport modes and each of these modes has different travel behaviours. Not only does the travel time differ, but the causes of possible delays differ as well. Due to delays, passengers arrive later at the airport than expected. Passengers often have an expected arrival time at the airport which depends on their type of passenger (section 2.2). Whenever a passenger does not calculate much room for error in its arrival time, the ability to be in time for the time slot of the security checkpoint becomes rather difficult. However, passengers could also arrive too early at the airport, whenever they have no delay during the trip to the airport, but expected to have some. This is also a negative impact on the time slot reservation system, because early passengers are not allowed to enter the queue. This uncertainty could lead to passengers ignoring the time slot service.

2.1.2. Ticket Check-in

After arriving at the airport, people need to get their boarding pass. This process has been optimized often, as online check-in (i.e. online boarding pass) is possible for the majority of flights. However, some flights cannot be checked in online, and some passengers do not use the online check-in tool. These passengers need to check-in at a check-in desk at the airport. There are multiple options for check-in desks. People could use a self-service unit or passengers could go to an airline service desk to receive a boarding pass. Checking in at a self-service unit or a service desk takes more time at the airport (compared to online check-in which passengers can do before going to the airport), especially when many other passengers have to use them as well.

Some airlines enables passengers to get a boarding pass and to drop their luggage at the same service desk, both not all airlines offer this service.

2.1.3. Luggage Check-in

After finishing the ticket check-in procedure, some passengers need to check in their luggage as well. In addition, the luggage check-in differs among airlines, as some airlines offer self-service drop-off and others still use luggage check-in at service desks. Usually, the self-service luggage drop-off takes less time than the luggage check-in at the service desks, due to an automated process. Service desks often check in per flight, which means that people on later flights need to wait until every one of a flight before them has been checked in. Whenever a passenger of a later flight arrives earlier at the airport, it needs to wait until the luggage service desk will help him/her. During rush hours, queues in front of the luggage check-in could be long and challenging to predict for passengers.

As can be imagined, these three processes before the security checkpoint make it challenging for passengers to predict their time slot at the security check. Sometimes, passengers arrive later than expected at the security check, due to delays in one (or more) of these three processes. Whenever passengers did not calculate room for error in their arrival schedule, this would cause missed security time slots. As a result, these passengers need to join the regular queue due to a missed time slot. In some cases, this would lead to a missed flight.

On the other hand, people could anticipate potential delays and travel to the airport earlier than necessary for their time slot. Whenever these passengers do not experience any delays, they end up too early for their time slot. Some passengers will use this time to relax and drink a cup of coffee. Other passengers prefer to join the regular queue in that case, which can be defined as a 'missed time slot'.

Concluding, it can be challenging for passengers to reach their time slot, due to possible delays in the processes before the security checkpoint. Schiphol captures data about the number of passengers that reaches its time slot. According tot data, only 30% of the time slots are scanned within the time slot period (buffer time included). However, the data contains bias and is assumed to reflect a too low use-rate (Royal Schiphol Group 2023). The data is gained by human actions as Schiphol staff have to scan the QR code of the time slot passenger in order to create data. In reality, not every QR code is getting scanned, due to human error. Therefore, the number of scanned QR codes does not represent the actual number of time slots used.

2.2. Design of the security checkpoint

At Schiphol, there are four security check filters. Each of them has a slightly different structure, but the overall system is identical. The main difference between security checkpoints depends on the destination of the gates behind the security. Whenever a destination is within the Schengen area (majority of countries within Europe), military police do not check the passports of passengers. Therefore, the security checkpoint structure differs, as there is no need for space for them. For non-Schengen flights, dedicated security checkpoints (including the military police) are used. The military police is located behind the security checkpoints. To give an example of a security filter, security filter 1 is shown in Figure 2.2

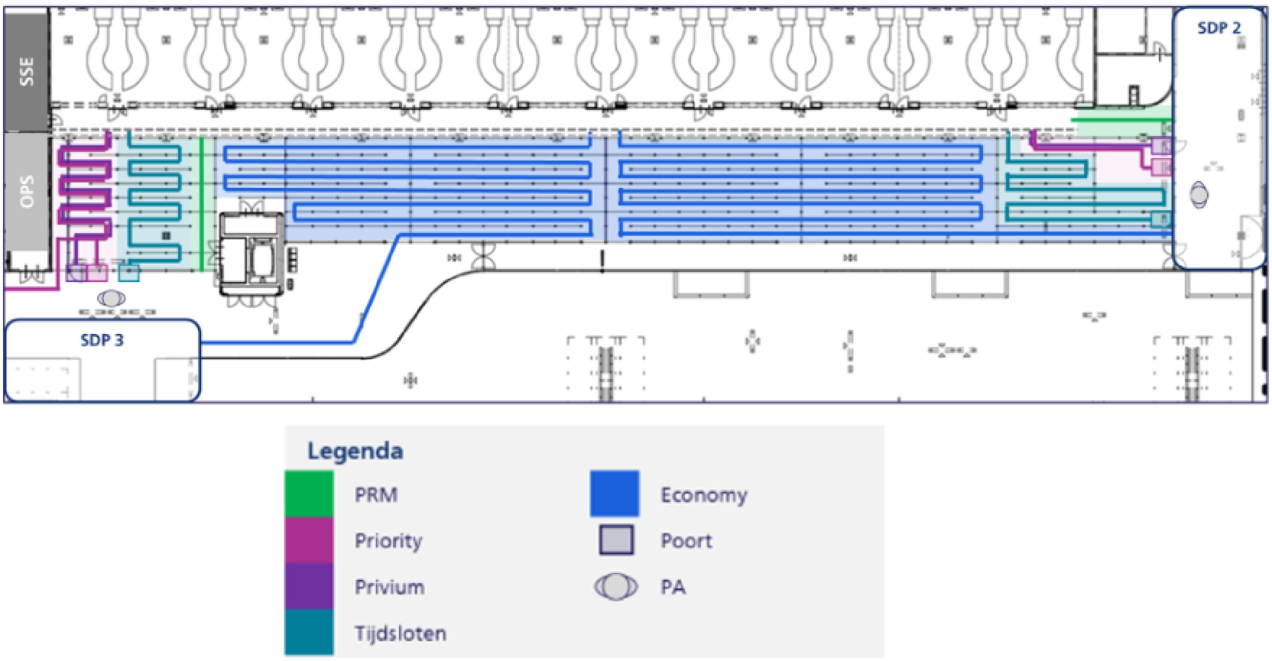

Figure 2.2: Map of security filter 1 at Schiphol

As stated before, Schiphol has four different security filters. To generate a clear overview of a security filter, a conceptual design is made (figure 2.3), based upon figure 2.2. This conceptual design is not an exact replica of an actual security checkpoint at Schiphol, but it must be seen as a general principle that can be applied to the security checkpoints of Schiphol.

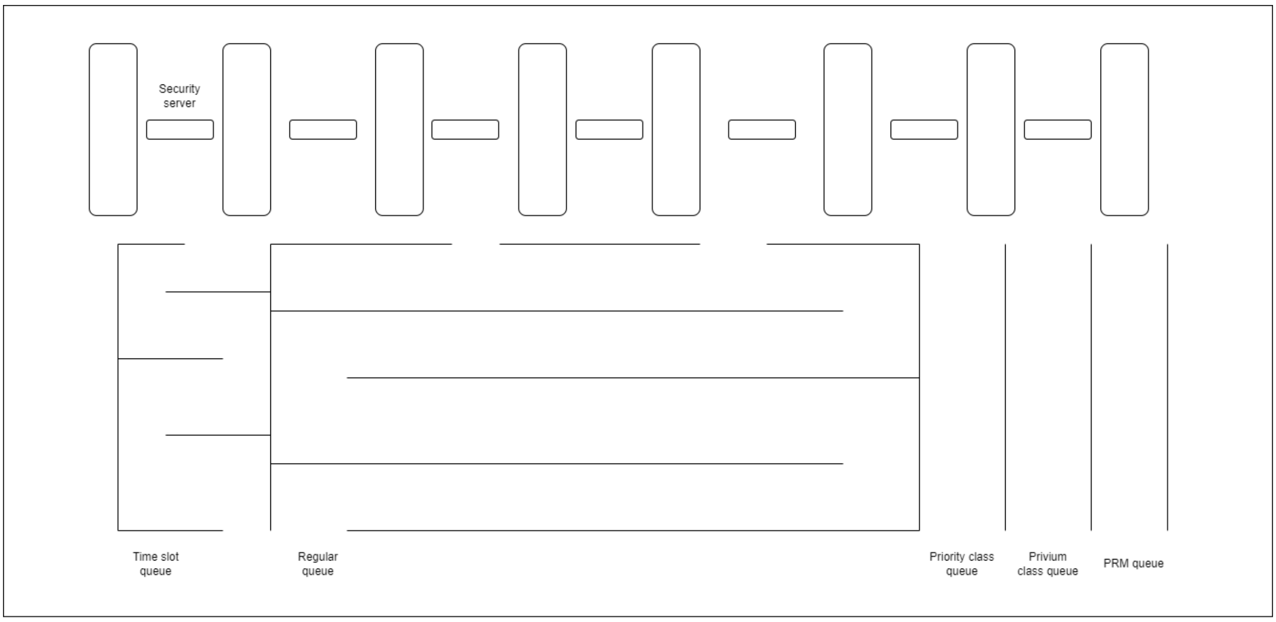

Figure 2.3: Conceptual design of a security checkpoint at Schiphol

As can be seen in figure 2.3, the system contains two main parts: the set of security servers and the queues in front of them. There are five different queues, one for time slot passengers, one regular queue, one for priority class passengers, one for privium members, and one for disabled passengers (PRM). Each of the queues is bundled into dedicated security servers. Therefore, passengers from different lines will not be mixed after being assigned to a queue.

Within the time slot queue, passengers with different time slots will be mixed. This is caused due to the fact that passengers can enter the queue 15 minutes before and after the time slot. Passengers will keep their position in the queue, so a first-in-first-out (fifo) system is applied.

It is important to mention that the system of figure 2.2 and 2.3 is not the currently used system at Schiphol, as the current system combines the queues for time slot passengers and priority class passengers. However, the time slot system is designed to have a dedicated queue. Therefore, this system will be used during this research.

2.3. Additional Specifications

This section is made to create some system clarifications. First of all, until now, there have been no known cases of missed flights due to a poorly timed time slot. Every time slot presented by Schiphol ensures passengers to catch their flight, as long as no unforeseen events occur.

In addition, in case of a paid time slot in the future, Schiphol states that it is very difficult to refund passengers whenever they are too late for their time slot. As stated before, passengers could be delayed in one (or more) of the processes before the security checkpoint. However, the cause of this delay could be due to force majeure or due to failure of the passenger. It is almost impossible for Schiphol to decide whether a passenger deserves the right to be refunded. Currently, more than 70% of all time slot passengers join the queue in a time frame between 10 minutes before the time slot and 9 minutes after the time slot. This number will likely rise when the tool becomes a paid tool.

Moreover, at the entrance of the time slot queue, a Schiphol employee stands in order to serve time slot passengers. This employee scans the QR code of the time slot reservations and allows passengers to join the queue as long as they come within their time slot. Whenever passengers come too early, they can decide to wait for their time slot or join the regular queue. If passengers come too late, they are asked to join the regular queue.

3 Literature Review

Within this research, Scopus and Google Scholar are used in order to find relevant literature. Multiple search strings are used, as the subjects of the literature review are not commonly used in one research. The search strings are defined as follows:

1. ”Queue” AND ”Queuing Theory” AND (”Reservation system” OR ”passenger reassignment” OR ”security checkpoint” OR ”First-come first-serve” OR ”passenger reassignment”)
2. ”Peak shaving” AND (”Energy management” OR ”airport” OR ”security checkpoint”
3. ”Morning commute problem” AND ”Queuing theory”
4. ”Hospital” AND (”patient reassignment” OR ”reservation system”)

3.1. Queuing Theory

Queuing theory systems exist out of several important elements, including the customer arrival process. The customer arrival process can include variability in terms of inter-arrival times. Another key factor is customer behavior, distinguishing between patient and impatient customers. Service times may also play a role, as they can either be dependent or independent of certain variables, such as the queue length.

Moreover, the service discipline refers to whether customers are served individually or in batches. Finally, the system's structure includes service capacity, which may involve a single server or a group of servers, and the waiting room capacity, which could impose limits on the number of customers who can wait (Adan and Resing 2002).

Kendall introduced a notation to classify different queuing models. This notation is composed of three parts (a/b/c). The first element refers to the distribution of inter-arrival times, the second indicates the service time distribution, and the third specifies the number of servers. The distributions can be either general (G) or memoryless (M, exponential) (Kendall 1951).

Variations of the M/G/1 model exist, such as systems with setup times, unreliable machines, group arrivals, and the M/G/c/c queue, where customers are turned away if all servers are occupied (Adan and Resing 2002).

In terms of performance metrics, several factors are crucial for analysing a queuing system. These include the average waiting time per customer, the overall sojourn time (waiting time plus service time), and the distribution of the number of customers in the system, either including or excluding those already being served. Other measures include the total workload in the system (the sum of the service time of waiting customers and the remaining service time for customers currently being served) and the distribution of server busy periods (the duration of time that a server is continuously active) (Adan and Resing 2002).

Typical systems facing queuing problems can be found in various domains. For instance, in production lines where objects move along and tasks are performed at varying rates. Within these production lines, there may be penalties for storing unfinished products. Adjusting labour distribution can help minimize these storage costs. Similarly in traffic, where vehicles experience bottlenecks, where appropriate signal timing adjustments can reduce delays. In healthcare, patients may face delays when trying to enter a hospital with limited capacity (Newell 1982).

The complexity of modelling these queuing systems often originates from the fact that repeating experiments under identical conditions rarely form the same results. To predict future behavior, stochastic models are typically applied, estimating probabilities based on repeated observations.

However, in many real-world applications, such as queuing systems, the observed stream of objects can not always be simplified to a simple stochastic model. It is often necessary to perform multiple experiments to accurately research the system's behavior under various circumstances, rather than relying only on hypothetical models (Couillet and Debbah 2017).

Finally, queuing theory has made significant developments in addressing three key issues: behavioral aspects (dealing with uncertainty in input data and differentiating between transient and steady-state behavior), statistical aspects (involving the study of empirical data and hypothesis testing), and operational aspects (the practical challenges of real-world queuing systems) (Bhat 1969). Each queuing system consists of fundamental components: the input process (usually random customer arrivals), the service mechanism (defining the number of servers and the duration of service), the queue discipline (for instance: ”first-come, first-served”), and the number of queues, which could be multiple queues for different servers (Bhat 1969).

3.2. Peak Shaving

The number of departing passengers varies from time to time in a day at airports. However, broadening the scope toward the yearly number of flights creates a trend line, which has an upward character (CBS 2024a). Covid-19 did lower the number of flights drastically, but the number of flights is recovering towards pre-Covid numbers. This upward trend of flights at Schiphol results in a larger volume of passengers (transfer passengers excluded) (Sky 2024). As a result, peak demands rise as well, which causes more pressure on security checkpoints. Therefore, meeting time-varying demand, especially in peak periods, possesses a key challenge to security checkpoints (Uddin et al. 2018).

The number of passengers per day is important for demand planning, but every passenger has other arrival behaviour as well (Skorupski and Wierzbińska 2015). Some passengers like to go very early to the airport in order to have a large buffer. Other passengers prefer to go just in time, as they want to be as efficient as possible. This means that passengers from different flights could be mixed, even though departure times could differ. This creates a complex passenger flow which is challenging to forecast.

One of the tools Schiphol applies to meet demand is called 'Peak Shaving'. Peak Shaving is a process of making the load curve flatten by reducing the peak amount of load and shifting it to times of lower load (Nourai et al. 2008). The term originates in the Energy Industry, in which peak shaving is important due to restricted network capacity (Mishra and Palanisamy 2018). Traditionally, the benefits of Peak Shaving can be divided into three categories:

- Benefits for the Grid Operator
- Benefits for the End-User
- Carbon Emission Reduction

Two of these three categories are applicable to airports: ”Benefits for the Grid Operator” becomes ”Benefits for the airport”. ”Benefits for the End-User” becomes ”Benefits for the passengers”. The category ”Carbon Emission Reduction” is applicable in the energy industry, but not to airports. Within the energy industry, diesel generators are used to increase energy supply. These diesel generators cause carbon emissions. Realizing more security capacity at airports has nothing to do with carbon emissions, which is the reason why this category does not apply to airports.

3.2.1. Benefits for the Airport

The following paragraphs elaborate on several factors that can be significantly improved by applying peak load shaving in the system.

First of all, the operating costs of the security checkpoint could be reduced by applying peak shaving. To create spare capacity, Schiphol has a buffer team of security employees, besides regular planned teams, which can be used in times of unforeseen high demand peaks. However, This buffer team of security employees is a flex team with higher hiring costs. Therefore, hiring buffer teams has additional costs compared to the ’regular’ security employees, which means that operational costs increase by using buffer employees.

Secondly, the productivity of security employees can be improved by applying peak shaving. Data shows that a higher workload (due to higher demand) improves the productivity of security employees, while the number of errors stays relatively low. Within this case, productivity is the number of passengers that can be handled per time period (Commission 2021). Peak shaving shifts passengers from (too) high-demand periods towards low-demand periods. This way, the demand curve becomes more flat. This benefits for two reasons: First, the capacity will not be overloaded (causing queues). Secondly, the average workload increases, due to more passengers in low-demand periods, causing higher productivity of security employees.

Thirdly, the occupancy rate of security plants will improve by applying peak shaving. The occupancy rate can be defined as: $\frac{T_a}{T_t}$ (Enoma et al. 2009). Where Ta is ”Time active” and Tt is ”Total Time”. Previously, periods with low demand could include idle security checkpoints, as the capacity of the security checkpoints is larger than demand. This negatively impacts the airport, as idle security checkpoints create a lower occupancy rate, which creates unnecessary operational costs. As explained before, peak shaving flattens the demand curve, which ensures more passengers during low-demand periods, resulting in a higher occupancy rate.

In order to visualize the impact of time slots on the passenger flow at the security checkpoint, figure 3.1 is shown.

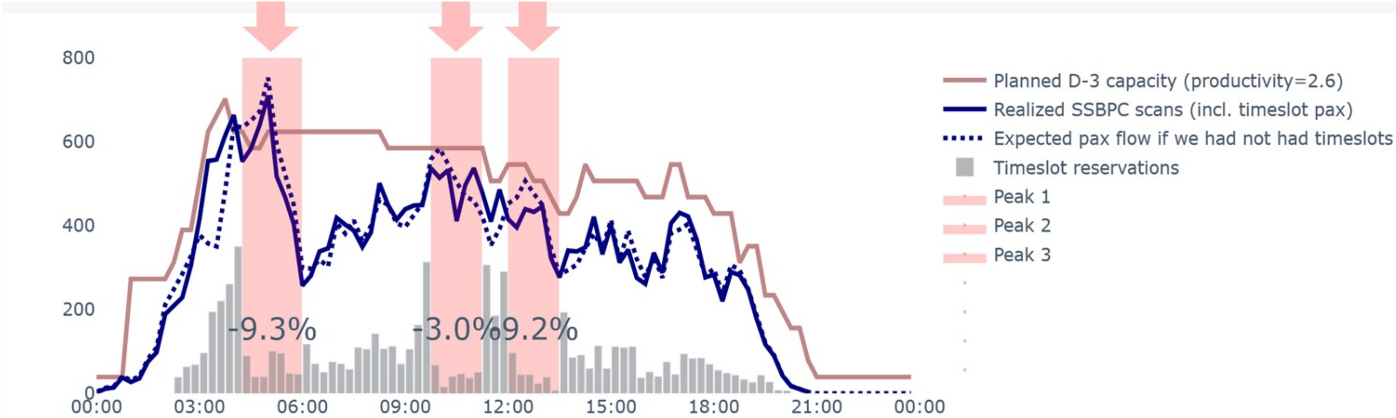

Figure 3.1: Impact of time slots at the passenger flow

As can be seen in figure 3.1, a difference between expected passenger flow and realized passenger flow is caused due to the implementation of time slots. The red line shows the capacity at the security checkpoint, which has not been adjusted after implementing time slots. As long as the passenger flow is smaller than the capacity of the security checkpoint, relatively small queues should be formed (assuming that the productivity of the security employees stays equal after implementing time slots), which results in lower average waiting times (Balsamo et al. 2003).

3.2.2. Benefits for the Passengers

As stated in the introduction, passengers in the security queue suffer from several issues such as travel anxiety, lost productivity, and missed flights (Cao et al. 2024). All of these issues can be caused by long average waiting times (note: long waiting times are often not the only cause for these issues). Schiphol also studied the stress level of passengers during the whole process of flying. This starts at home while booking a ticket and ends at the airport while boarding to the airplane. The different stress levels are shown in figure 3.2.

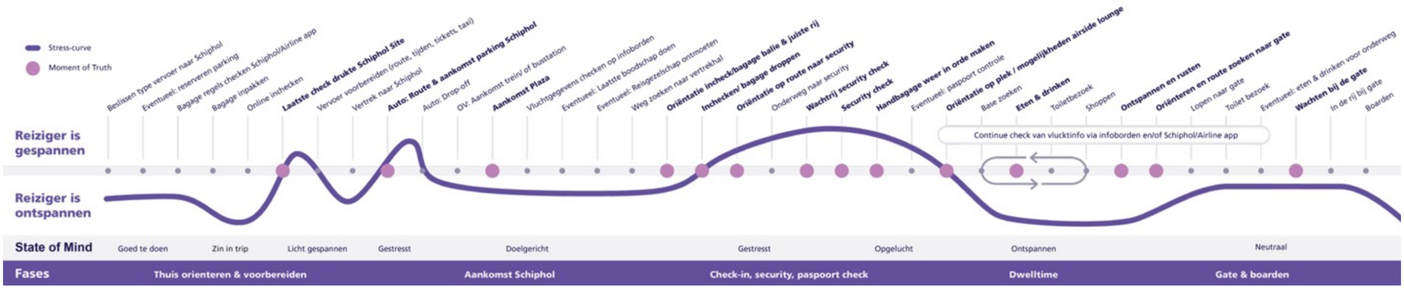

Figure 3.2: Stress level passengers during whole flying process

Figure 3.2 confirms the claim of Cao et al. that passengers suffer from travel anxieties while standing in the security queue, as the queue for the security and the security check itself are the most stressful events of flying. Therefore, (newly) implemented support tools for passengers that focus on security events could benefit passengers a lot.

As interpreted with figure 3.1, the time slot tool of Schiphol reduces the average waiting times of passengers in the security queue (one of the main sources of several anxieties faced). Therefore, this tool could potentially lower several anxieties faced by passengers.

3.3. Comparison to Commute Problem

Daganzo's work on the time-dependent commute problem introduces the concept of managing traffic flow through bottlenecks, or "hot spots" where N users must pass through a bottleneck exhibiting three main characteristics: a fixed, time-independent capacity (μ) expressed in vehicles per unit time, a first-in-first-out (FIFO) service principle, and a system behaviour that aligns well with the fluid model of queuing theory (Daganzo and Garcia 2000). The user population may have different origins and destinations, but the travel time to the bottleneck remains constant for each individual.

Daganzo highlights a key difference from traditional economic literature, which typically considers the timing of departure from home and arrival at the destination. Instead, this study focuses on the timing of arrival at and departure from the bottleneck, which is an inverse approach. One major challenge with time-dependent tolling, according to Daganzo, is that vehicles would adjust their schedules to avoid queuing delays, but would incur a monetary penalty instead. Essentially, commuters would experience no net benefit, except for potential indirect gains from revenue collection. This creates a need for alternative strategies that could generate Pareto improvements (Daganzo and Garcia 2000).

A theoretical solution proposed to eliminate queuing involves classifying commuters by short time slices (e.g., each minute during rush hour) and assigning class-specific tolls. These tolls would be zero for departures within the assigned time slice and prohibitively high for departures outside of it. This system mimics an appointment-based approach for bottleneck usage (Daganzo and Garcia 2000).

Another solution for managing congestion is the implementation of a cap-and-trade system, similar to those used in pollution control and emission regulation (Winch and Dales 1969). In this system, a limited number of cars are allowed to enter the road during a specific time slot. Once the capacity for a time slot is reached, no more vehicles can enter unless they purchase a slot from another driver, or they wait for the next available slot.

Traveller behaviour in such systems is typically modelled as a trade-off between anticipated travel delay and schedule costs (Mahmassani and Herman 1984). The overall pattern of the morning rush hour can be seen as a Nash equilibrium, where commuters aim to minimize their total costs by adjusting departure times and routes (Hendrickson and Kocur 1981).

3.4. Usage of Time Slots in Hospitals

The implementation of hospital reservation systems is motivated by several key factors. Firstly, reducing waiting times for patients is an important goal, as long waiting times can lead to dissatisfaction and decreased trust in healthcare services. In addition, improving patient satisfaction is an important goal, to establish a more positive experience within healthcare (Q. Wang, Ma, Mao, Song, Xiao, Zhao, Yuan, and Hu 2024).

Improving the speed and organization of medical tests is another important reason for using these systems. A smoother process helps make sure that tests are done on time. Also, using these technologies could encourage hospitals to keep up with new advancements, allowing them to provide smarter and more efficient services (Jebamani et al. 2022).

In addition, making the best use of hospital resources is important, as these systems help manage equipment and staff more effectively (Q. Wang, Ma, Mao, Song, Xiao, Zhao, Yuan, H. Wang, et al. 2022). Improving the Hospital Information System (HIS) is also essential because adding reservation systems helps organize and coordinate patient services more efficiently.

However, introducing reservation systems in hospitals can also bring challenges. One major difficulty is that many patients are used to traditional ways of making appointments and may resist change (Q. Wang, Ma, Mao, Song, Xiao, Zhao, Yuan, and Hu 2024). Additionally, learning how to use new technology can be difficult for some patients, making it harder for them to use the system properly (Zhang et al. 2023).

Concerns about privacy are another challenge, as patients may worry about data security and the risk of their personal information being exposed, which can make them less willing to use the system. Additionally, if hospital staff do not provide enough support, patients may feel confused and struggle to navigate the new system (Jebamani et al. 2022).

Finally, technical issues, such as inadequate access to technology or internet connectivity, can lower the user experience (Q. Wang, Ma, Mao, Song, Xiao, Zhao, Yuan, and Hu 2024).

3.5. Convergence of Subjects

The time slot system introduced by Schiphol can be seen as a combination of both peak shaving and the queuing theory. Reassignment of demand in front of the bottleneck has been researched before, with the commute problem and queues in hospitals. Therefore, lessons can be learned from pros and cons described in the sections above. However, Schiphol applies a slightly different system than the system used in hospitals and the commuting problem. The main difference is that passengers at airports have different arrival behaviour. This, in combination with flights departing at different times, creates a challenging queuing problem as it is difficult to forecast the demand in front of the bottleneck at a specific time period. Time slots are created in such a way that few time slots are available in rush hour moments, while many time slots are open in low-demand periods. In addition, passengers at airports differ from hospital patients, as hospital patient are often older (CBS 2024b), while airport passengers are often younger (Statista 2024). Concluding, one can use the pros and cons of both the commuting problem and hospital systems, but should not presume exactly the same effects on the airport security queue system.

In order to visualize the relations between the four elements described in this chapter, figure 3.3 is shown below.

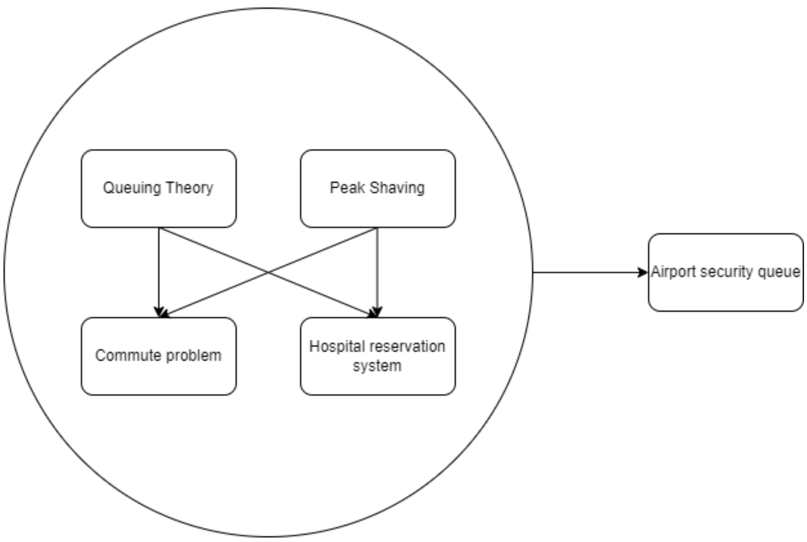

Figure 3.3: Context diagram literature

4 Methodology - Survey Design

Within this research, two different methods are applied to answer the research questions. This chapter explains the methodology used to construct the survey used in this research. Within this survey, both a stated-preference and a factor analysis are present.

The first nine sections of this chapter focus on the construction, execution and analysis of the stated preference research. Then, section 10 shows the structure of the survey and section 11 explains the construction of the factor analysis.

4.1. Setup Stated Preference (SP) experiment

Stated-preference methods can be used to reveal preferences, priorities, and the relative importance of individual features (Hauber et al. 2016). Within stated preference methods, discrete choice experiments (DCE) are a commonly used method, as DCEs can determine which factors influence an individual's choices (Rose and Bliemer 2009). These influencing factors are called attributes. To perform a discrete choice experiment, it is important to define the attributes included and their levels. (Stobierski 2020). An alternative is a hypothetical scenario formed by these attributes. Each attribute will have one level in an alternative. Two or more alternatives together form a choice set (Hauber et al. 2016). Finally, an experimental design is formed by generating specific combinations of attributes and levels (Johnson et al. 2013). This experimental design can be spread to respondents. who evaluate these choice questions.

While creating a DCE, a process including developing, testing and optimizing is applied. It is important to execute this process properly, as it is important for the success of the experiment, including the validity of the results (Kløjgaard et al. 2012). To create a qualitatively good setup, the process has been divided into 7 steps (Rose and Bliemer 2014, Kløjgaard et al. 2012):

1. Decide whether to use labelled or unlabelled experiments
2. Determine the attributes included in the experiment
3. Determine the levels of the attributes
4. Decide which experimental design to use
5. Creating the choice tasks

6. perform a pilot study
7. Execute the main study

Next sections will elaborate the decisions made in the setup of the DCE.

4.2. Labelled or Unlabelled experiment

Within DCEs, one can decide whether to use labelled or unlabelled choice sets. Considering the research questions of this research, unlabelled experiments are used in this research.

Unlabelled experiments are usually applied in more abstract or general situations where the emphasis is on the characteristics of the choices, instead of the particular options themselves. People are not always familiar with time slots, which makes it more interesting to analyse a generalised experiment. In addition, unlabelled experiments are useful when one is interested in the willingness to pay for certain attributes (Rose and Bliemer 2014).

4.3. Included attributes

Selecting attributes for the research is very important in the process of creating a survey, as it becomes more likely to obtain valuable results when the selection process of attributes is executed properly. To select the attributes in the research, a second literature review is executed (appendix A). This literature review focuses on related stated preference research. A matrix is formed in which the attributes used in the reviewed studies are shown. The overview formed by this table is used to indicate interesting attributes for the survey of this research. A combination of attributes that have been used in relatable research and attributes that interests Schiphol will be selected in the research.

Table 4.1: Attributes obtained from previous research that influence the time slot reservation, (Thorhauge et al. 2016, Kalakou and Moura 2021 , Silva et al. 2022)

Attribute	Thorhauge et al (2016)	Kalakou & Moura (2021)	da Silva et al (2022)	Schiphol (2024)
Flight departure time	X	X		X
Travel Time	x			
Travel time variability	x			
Travel Cost	x			X
Arrival time (at airport)		X		X
Number of passengers travelling with		X		X
Familiarity with the airport building		X		
Queue time			X	X
Process time			X	
Reservation costs				X
Luggage Check-in Option				X

As stated before, overlapping attributes with the interests of Schiphol will be taken as attributes for this research. However, not every overlapping factor can be used as an attribute in the research. Together with Schiphol, the decision has been made to select the following three attributes:

- Saved waiting time in the security queue
- Time between security (time slot) and departure of flight
- Time slot costs

Although the luggage check-in option is interesting for Schiphol to find out, it has not been used in this stated preference research. Luggage check-in is excluded, as it is currently unclear whether this is even possible at Schiphol. Integration of Luggage-check-in in the time slot tool is very challenging, as luggage check-in is done by many different airlines and check-in operators. In order to integrate luggage check-in into the time slot tool, agreements with all these companies should be made, which takes a lot of time and effort. Therefore, Schiphol is currently doing research towards this topic and does not (yet) know whether it is even realistic to integrate this in the tool. Due to this uncertainty, the decision has been made to only integrate attributes that are realistic to integrate in the time slot tool, which means that the luggage check-in option is excluded from the stated preference analysis.

However, it still is interesting to get information about passengers views on the option of luggage check-in. Therefore, it is integrated as a statement in the factor analysis.

The combination of these three elements give Schiphol the best insight in passengers' preferences towards time slot. These attributes are defined as:

Table 4.2: Definition of Included Attributes

Attribute	Explanation
Expected saved waiting time (minutes)	The predicted time savings in minutes when using the time slot queue compared to the economy class queue, according to Schiphol estimates.
Time before departure (hours)	The time between arriving at the security checkpoint (before joining the queue) and the departure of the flight.
Time slot costs (€)	The costs for reserving a time slot.

Factors that are not selected to be integrated as attributes might still be relevant for the research in another function. This research also applies contexts (section 4.5) and some factors in table 4.2 could also function as an context. For instance, the factor ”number of passengers travelling with” could be used as a context variable.

4.4. Included levels

After selecting the relevant attributes, the attribute levels need to be established. The level of an attribute must be of a range which ensures that a trade-off exists between attributes (Szinay et al. 2021). This means that one will lose a bit of attribute A to gain more of attribute B. It is important to include a wide enough range for the levels because there is a risk that participants would ignore the attributes when the differences are too small (Lancsar and Louviere 2008).

This research only uses quantitative levels, because quantitative levels enable the researcher to study changes in specific numbers related to a certain attribute influence people's decisions. This helps to figure out concepts like marginal utility (Kløjgaard et al. 2012). Table 4.3 shows the set of levels used for every attribute.

Table 4.3: Levels for all included attributes

Attribute	Level 1	Level 2	Level 3
Expected saved waiting time (minutes)	0 minutes	30 minutes	60 minutes
Time before departure (hours)	1 hour	2 hours	3 hours
Time slot costs (€)	€0,00	€2,50	€5,00

At the time of spreading the survey, there was almost no information about the potential waiting time saved by time slots in comparison to the regular queue. In addition, it was not clear how passengers react on potential saved waiting time. Therefore, the decision has been made to create a broad range for this level, as it is easier to interpolate than to extrapolate (Molin 2024).

The first level for Time before departure was relatively easy pick, as it corresponds with the time slot system used in reality. 1 Hour is the shortest period between time slots and the departure of the dedicated flight. The maximum level of this attribute was also clear, is the longest period between a time slot for the security and the departure of the flight is 3 hours (non-Schengen). The same choice sets will be distributed in Schengen and non-Schengen area, so the maximum level is 3 hours. In order to keep the levels easy to interpret for respondents, only a third option in between is used (2 hours) and not a 4th or a 5th.

The attribute first level of the Costs attribute is obvious, as this is the free option (current situation of time slots). The two other options were more challenging. A small pilot has been done by Transavia for paid slots at luggage check-in. Very few people wanted to make a reservation, despite the relative cheap price (approximately €7). Obviously, this service is not an exact identical system comparison, but it is likely that passengers are not willing to pay a lot more for time slots for the security check point. On the other hand, the difference between levels should not be too small, as this would be too challenging for passengers to interpret (Louviere et al. 2000). Therefore, a maximum of €5.00 is selected with one level in between of €2.50. This creates a relatively low value for high costs, but also creates enough difference between the levels to enable respondents to interpret them properly.

4.5. Experimental Design

This research applies a fractional factorial design for the DCE, specifically a orthogonal design. An orthogonal design is used, as orthogonal designs include no correlation between attributes (Younes et al. 2014). Therefore, estimating separate parameters included in the research is possible (Rose and Bliemer 2009). Depending on the number of attributes and the number of levels per attribute, a specific orthogonal design will be chosen from previously created orthogonal designs by mathematicians (Molin 2024).

In detail, a basic plan has been applied, which are orthogonal fractional factorial designs. The main argument for this design is to generate a smaller number of choice sets. It is not desirable to create interaction effects with two attributes, which makes fractional factorial designs suitable.

Within this research, 3 attributes with 3 levels are included. Therefore, basic plan 2 is suitable for constructing the scenarios. Basic plan 2 has the following structure:

BASIC PLAN 2: 3^4; 2^4; 9 trials

1	2	3	4	1	2	3	4
0	0	0	0	0	0	0	0
0	1	1	2	0	1	1	0
0	2	2	1	0	0	0	1
1	0	1	1	1	0	1	1
1	1	2	0	1	1	0	0
1	2	0	2	1	0	0	0
2	0	2	2	0	0	0	0
2	1	0	1	0	1	0	1
2	2	1	0	0	0	1	0

Figure 4.1: Basic Plan 2 structure

The attributes with 3 levels can be found at the left columns of the basic plan. This will form the basic principle for creating the scenarios. Each row represents a combination (alternative) for which there is no correlation between the attributes.

Next, choice sets can be formed by a combination of two alternatives. A sequential construction has been applied to construct choice sets. Sequential construction includes randomly paired alternatives (Molin 2024). One could explain this pairing the following: Alternatives generated by the basic plan are divided into two groups, each containing all available alternatives. A choice set is then created by combining one randomly selected alternative from each group. This process is visualized in figure 4.2 below.

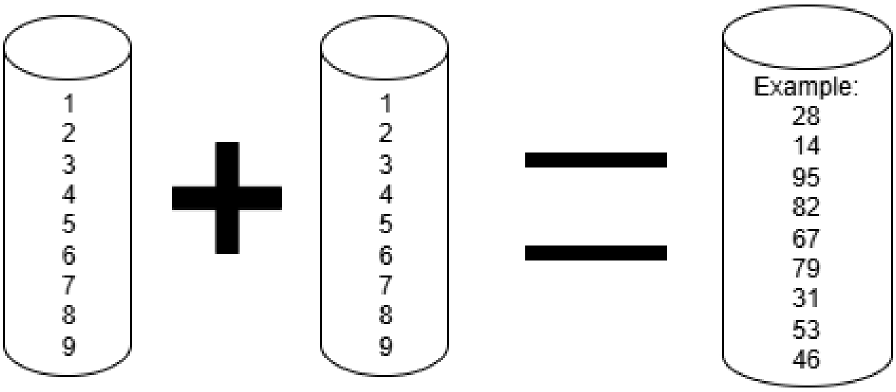

Figure 4.2: Sequential drawing process

An example of a choice set can be seen in the table below.

Table 4.4: Example of a (dominated) Choice Set

Attribute	Time Slot A	Time Slot B
Waiting Time (minutes)	5 minutes	15 minutes
Time before departure (hours)	2 hours	2 hours
Time Slot Costs (€)	€2.50	€0.00

However, the process of construction choice set is not yet completed. As can be seen in table 4.4, dominant choice sets could be formed. In this research, each choice set offers a choice between two alternatives. A dominant alternative can be described as an option within a choice set that is clearly superior to all other options based on the levels of attributes presented. This means that, regardless of individual preferences, the dominant alternative objectively outperforms the others across all attributes (Rose and Bliemer 2009). Therefore, choice sets with a dominant alternative should be avoided while constructing choice sets.

In order to do so, dominant combinations have been identified. If a dominant choice set is included in the set of choice sets, the process should be repeated, as removing a single choice set from the total of nine is not an option. This cannot be done due to the orthogonality constraint: removing one choice set will lose orthogonality, as not all levels of the attributes are equally represented.

The final set of choice sets used in the research can be found in appendix B. The correlation matrix of these choice sets are also shown in appendix B

4.6. Contexts within survey

An additional element will be added to the survey, as each respondent receives a context in which the respondent needs to answer the questions in the survey. The distribution of contexts to passengers is revealed, so each passenger receives a context for the type of trip that the passenger is making (exception: people who are currently travelling as non-business passengers but have experience as a business traveller). Revealed contexts are used, because this makes it easier for passengers to interpret the context, which lowers bias in the results as passengers can answer the stated preference questions with the context they are currently travelling with.

Time slots are available for all economy class passengers. However, within economy class passengers, there is a huge variety of types. This could be due to different socio-demographic characteristics (age, gender etc.), but there could also be differences in trip purpose or other flight-related characteristics. Therefore, contexts are added to the DCE, as it is interesting to research whether time slot related preferences differ for different type of passengers.

This survey includes contexts, as it is expected that the contexts of passengers could influence their preferences. By creating these contexts, different compositions can be made for several types of passengers. By doing so, the attitude towards time slots for each type of passengers can be studied. In addition, context influences can be studied individually, for instance the impact between Schengen and Non-Schengen flights. The information obtained from the contexts can be used by Schiphol as input to create a strategy for targetting potential time slot users.

This research applies three elements for each context:

- Flight within Schengen vs Flight outside of Schengen
- Business vs non-business passengers
- Flying Alone vs flying with adults vs flying with Children

Schiphol divided its security filters into two parts: 2 security filters for Schengen flights and 2 filters for non-Schengen flights. This automatically creates a differentiation in context used in this survey: people who fly within the Schengen area will get a Schengen context and vice versa.

The assumption has been made that business passengers travel either alone or with other adults, not with children. Non-business passengers have all three different options to travel with. All possible combinations of contexts are made within these assumptions. An overview of the contexts constructed is shown below in table 4.5.

Table 4.5: Constructed Contexts

Context variable	Context 1	Context 2	Context 3	Context 4	Context 5
Purpose	Business	Business	Non-Business	Non-Business	Non-Business
Travel Company	Alone	Adults	Children	Adults	Alone

These 5 contexts will be spread among passengers who fly within Schengen and passengers who fly within non-Schengen. This creates a total of 10 different contexts.

Within the survey software, a tool has been enabled in which specific contexts are assigned to answers of respondents. This means that only a business passenger can receive a business context. This decision has been made, as not every leisure passenger has had a business passenger trip, which makes it challenging to pretend to be one. Before spreading the survey, the expectation was that business passengers were more challenging to convince to join the survey. Therefore, non-business passengers were asked whether they have ever had a business flight in economy class before. Passengers who have experience from previous business trips will also receive a business context. Figure 4.3 visualized the context distribution among respondents.

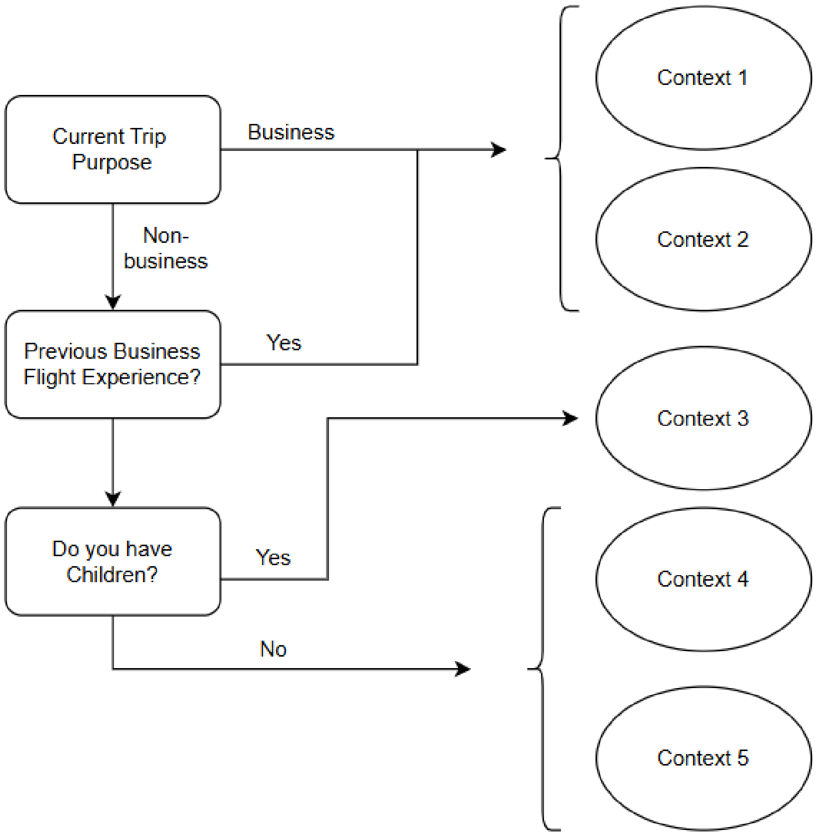

Figure 4.3: Distribution contexts among respondents

4.7. Pilot study

Before the main study, a pilot study was executed to find out whether the survey was clear for the respondents (Rose and Bliemer 2014). Respondents in the pilot study have the possibility to give feedback and explain what part of the survey were unclear. This feedback is used to iterate the survey design.

Prior to the main study, a pilot study has been executed in order to find out whether the survey is clear for the respondents (Rose and Bliemer 2014). The pilot survey has been spread among approximately 30 potential respondents (people who have flown via Schiphol). Afterwards, feedback was collected and implemented. Finally, the survey is ready to be spread among a large group of respondents.

4.8. Execution Survey

After completion of the survey, the main research is executed. The answers of the respondents will be collected and formed into a database. This database is cleaned in order to prevent poor data quality entering the results section. While spreading a survey, one should be aware of several factors which might have influence on the results. This section describes these factors and explains how these factors were handled.

4.8.1. Respondents Composition in Sample

As stated before, different kinds of passengers can be defined at airports and each type of passenger behaves differently. One can split passengers into often applied demographic factors, such as gender, age, cultural background etc. In addition, it is also possible to split passengers at airports into other types, based on their travel behaviour. Important characteristics of passengers could for instance be:

- Business vs non-business passengers
- Frequent flyers vs sporadic flyers
- Full-service flight passengers vs low-cost flight passengers
- Etc.

While conducting the second literature research, a selection of important characteristics of passenger will be made, which is going to be part of the survey. These characteristics could either be analysed individually (as introduction question), or a combination of characteristics could be used to form passenger types (context).

The targetted respondent composition of this sample must represent the passenger population of Schiphol. This includes passenger characteristics, but also time periods in which the survey is distributed. In order to achieve representative passenger characteristics in the sample, the survey is spread towards all passengers (18+) located at gates of Schiphol. This way, the sample is likely to be more representative, as no distinction is made between passengers. Obviously, the main goal is to gain a fully representative sample, but this is challenging as it depends on the location, time and willingness of passengers to fill in the survey. Therefore, another goal is to collect enough respondents per passengers composition, so that future analyses can be done without having to deal with too few respondents. In the following subsections, respondent quantities, location of the survey distribution and the time of survey distribution is elaborated in more detail.

4.8.2. Number of respondents

A sufficient number of respondents in the sample is necessary to create trustworthy results. However, the necessary size of the sample depends on the design of the DCE. In order to have a clear goal of the minimum number of respondents necessary, the following rule of thumb has been used (Orme 2010).

$$\frac{N \cdot t \cdot a}{c} \geq 500 \tag{4.1}$$

Where:

- N is the number of respondents
- t is the number of tasks (=9)
- a is the number of alternatives per task (not including the none alternative) (=2)
- c is the largest number of levels for any of the attributes (=3)

The result of this equation is a total number of 83 respondents.

Within this calculation, contexts variables are not included. Therefore, the goal is to gain at least 83 respondents for each context. The context with most levels (3) is the context of ”Travel Company”. Therefore, the survey must at least have 249 respondents. However, more respondents will increase the statistical power of analyses and reduces the risk of too few respondents for a specific context.

4.8.3. Location Survey Spreading

The survey will be distributed among passengers who are waiting at their gates at Schiphol. This way, passengers are more likely to answer the survey, as they are could be bored while waiting. In addition, spreading the survey at this location does not effect airport processes (such as creating congestion at places where this is not wanted). Another positive fact for this distribution location is the fact that Schengen and non-Schengen passengers are separated at the gates. This way, it is easier to track the contexts distributed.

However, survey distribution at the gates also has disadvantages, as the location in which people answer the survey is not equal to the location at which people reserve time slots. Schiphol enables passengers to reserve a time slot 3 days before their flight, which means that passengers are likely to make a reservation at home (or at least: not at the airport). This could influence results of the analysis, because people might answer the survey different due to experiences in previous airport processes that day. For instance, someone who just had to wait for 15 minutes at the security is likely to have a more positive attitude towards time slots than before going to the airport. On the other hand, people who had no waiting time at all, due to a quiet period at the security check point might underestimate the value of time slots (related to their estimated valuation before going to the airport). Despite the fact that some form of bias is created by the distribution location, the data obtained at the gates is still viable to use, as it can give impressions about the preferences of passengers.

4.8.4. Period of Survey Spreading

Before distributing the survey at Schiphol, as planning was made for the times and dates that the survey would be distributed. It is important to gather data in different times, as passengers might have different preferences due to other time periods of travelling. The survey has been spread between 07:00 and 22:00, so that the majority of possible departure times are covered. This way, more representative data can be collected.

In addition, the dates of spreading were also planned in order to catch different kind of passenger compositions. In a 'regular' week, a relatively larger part of the passenger population is business passengers. During the Christmas Holiday, non-business passengers will dominate the passenger population. The survey has been spread in both periods in order to gather enough passengers for each context.

4.9. Analysis of DCE

This research applies a Multinomial Logit Model to interpret dataset obtained from the survey. First, the Random Utility Theory will be elaborated, as it forms the foundation for the Multinomial Logit Model (MNL).

4.9.1. Random Utility Maximization Theory

As explained in the introduction of this section, the interpretation methods used in this research are based on the Random Utility Maximization (RUM) theory. According to this theory, people make choices that maximize their obtained utility. The obtained utility consists of a systematic utility and an error term. This error term captures utility besides the rational choice of a respondent. The equation of the RUM is the following:

$$U_{i,j,k} = V_{i,j,k} + \varepsilon_{i,j,k} \tag{4.2}$$

$V_{i,j,k}$ is a function of attribute levels and their weights. Therefore, substituting these element in the RUM equation forms the following rewritten version:

$$U_{i,j,k} = \beta \cdot X_{i,j,k} + \varepsilon_{i,j,k} \tag{4.3}$$

4.9.2. Multinomial Logit Model (MNL)

The MNL model suggests that the utility obtained of each alternative presented comes from a combination of the attributes of the options, weighted by coefficients that show how important each attribute is (Louviere et al. 2000). This model reflects the idea that individuals will pick the option they believe has the highest utility, and this choice is expressed in probabilistic terms. In addition, this model assumes that whenever someone prefers alternative X over Y, this preference still exists whenever an extra alternative is added.

Coefficients of attributes cannot be interpret, without including the levels of that attribute. Only a combination of coefficients and levels can show the relative importance towards other attributes.

Within the MNL model it is possible to have more than one parameter for an attribute, as not only the linear parameter can be interpret. It is, for instance, also possible to interpret quadratic (or even higher magnitudes) and interaction effects (Rose and Bliemer 2009). The standard formula of the MNL model is shown in equation 4.4.

$$V_{ij} = \beta \cdot X_{ij} \tag{4.4}$$

After obtaining the total amount of utility for a specific calculated scenario, it is possible to calculate the chance that someone would choose a specific alternative. This chance can be calculated by equation 4.5.

$$P_{ij} = \frac{e^{V_{ij}}}{\sum_{k=1}^{J} e^{V_{ik}}} \tag{4.5}$$

4.10. Survey Structure

To begin this section, the survey structure will be elaborated. The survey that has been distributed includes:

1. General introduction of survey
2. Introduction questions (9)
3. Explanation stated preference research
4. Explanation assigned context
5. Stated preference questions (9)
6. Factor Analysis statements (14)
7. Final questions (5)

Next sections are structured in such a way that they represent the order in which the survey has been designed.

4.11. Statement Questions

The factor analysis statements have been constructed by discussing potential advantages and downsides of the time slot reservation system with employees of Schiphol. In addition, some statements were added that are not necessarily focussed on the time slot system, such as statements regarding waiting time and a statement about interest in innovative products. Within the survey, respondents have to rate each statement with a value between 1 and 5. The values represent the following answers:

1. Fully Disagree
2. Disagree
3. Indifferent
4. Agree
5. Fully Agree

Below, the statements are categorized per focus.

1. Planning Preferences
These statements focus on how passengers value planning their airport process.

1. I prefer to go through security earlier than recommended for my flight.
2. I dislike time slots, as a dedicated time slot for the security check gives me less flexibility for other steps in my airport process (travel to the airport, luggage check-in, etc.).
3. I like security time slots, as they enable me to plan my whole trip (travel to the airport, luggage check-in, security check, walk to the gate) in more detail.
4. I prefer to join the security whenever I want, rather than a dedicated time slot.

2. Perceptions of Time Slots
These statements researches attitudes toward the time slot system.

1. I (expect to) find it too much effort to reserve a time slot.
2. The time slots available do not align with my preferred travel times (real life, not the time slots shown in the experiment).
3. I would prefer time slots which also include luggage check-in.
4. (I expect that) Time slots do not save me significant time in the security queue.
5. I find the certainty of passing through the security checkpoint within a specific time provided by a time slot very important.
6. Time slots are also useful during quiet times, not only during peak travel times.

3. Awareness
These statements explore passengers' knowledge of the time slot system.

1. I think the time slot tool is a well-known service from Schiphol among passengers.
2. I would recommend time slots to other travellers.

4. Stress and Convenience
These statements determine how the time slot system affects stress levels.

1. I don't mind waiting, as long as I expect to do so.
2. I believe that a reserved time slot for the security checkpoint lowers my stress levels.
3. I find waiting in queues at the airport very annoying.

5. Innovation
This statement explores openness to adopting new tools.

1. I am interested in trying new tools to lower waiting times, such as the time slot reservation system.

5

Methodology - Discrete Event Simulation

Within this research, discrete event simulation (DES) is applied to research the queuing system of time slots passengers. Thus, this part of the research is focussed on answering RQ 5. First, the general modelling setup is elaborated. Afterwards, the experimental setup is shown.

5.1. Relation with previously described study

Managing airport security queues effectively is really important for making sure passengers have a good experience and that everything runs smoothly. As explained in chapter 2 (section 2.2), time slots currently have no dedicated queue, but they are likely to get one in the near future. Creating a dedicated line for passengers who have reserved a time slot could help speed up the security process, lessen crowding, and make things more predictable. This is especially true whenever more passengers have time slot reservations, as a large crowd of time slot passengers would deregulate the current system. Currently, it is unclear how a system with a dedicated line for time slot passengers would function as it relies on different changing factors, like when passengers arrive, how long the lines are, how many time slot reservations are made etc. By researching this topic, Schiphol receives more information about the (yet unknown) security design with a dedicated time slot queue. This enables Schiphol to prepare more properly for the transition later. In addition, Schiphol is able to make adjustments more quickly after implementation of the system, as they have more information about influencing factors within the system.

Concluding, previously described research in chapter 4 focusses on the preferences of passengers regarding time slots. This gives information to Schiphol which can be used to create more attractive time slots for passengers. The simulation part of the research is the follow-up research, as it researches how the design of the security check point should be shaped in the future. This future will be explored under multiple scenarios, for instance one in which many passengers (more than 40% of the passengers) makes a time slot reservation, but also one in which the number of time slot reservations is comparable to the current situation.

5.2. Simulation as a research method

The security checkpoint system, described in chapter 2, could be seen as a complex system due to many variables, constraints, and interdependencies. In addition, some characteristics are stochastic, such as arrival times, equipment failures, service durations etc. DES is a well-suited modelling technique to include probability distributions for these events, which results in a more realistic model. Whenever a model is completed, DES enables the modeller to test several scenarios to obtain results within the spectrum of both best-case and worse-case scenarios. Within this research, DES is very interesting as the impact of the results of the DCE on the security checkpoint system can be tested (Robinson 2005).

In order to specify the DES set-up for this research, the frameworks of Chwif et al. 2013 and Robinson 2008 are combined into one process of creating a (conceptual) model. This framework consists out of four main steps:

1. Understanding the problem situation
2. Determine the modelling objectives
3. Identifying the model outputs (responses)
4. Identifying the model inputs (potential experimental factors)
5. Determining the model content (scope and level of detail), identifying any assumptions and simplifications
6. Model verification and validation

The first step is already done, as the problem situation is already discussed in section 5.1. The next steps will be covered by upcoming sections.

5.3. Modelling objectives

In order to define the model objectives, two elements should be identified. First, the general research objective is elaborated. Afterwards, potential modelling complexities are discussed, which could influence the research objective.

Research Objective: The main goal of this simulation research is to identify how factors within the system (such as the ratio between passengers with/without a reservation) influence the system and, more specifically, how big their influence is. This research will be done under different scenarios to gain more robust results. The security design of figure 2.3 is used as a starting point of the simulation model.

As explained in more detail in section 5.9, the model simulates a Friday at Schiphol in a regular week. The research objective of this simulation model adds information to the research objective of the stated preference analysis. As explained in section 4.8, the survey is distributed in both a 'regular' time period and a more crowded time period during the Christmas Holiday. This simulation model is representative for a busy day in a regular time period. Therefore, the model is not suitable for very quiet days or very busy days. However, some interpretations of this simulation model might also be useful for these days, as they can be extracted to other type of days at Schiphol.

Complexities: While this simulation study includes a relatively simple queuing case, three main complexities can be identified

First of all, a complexity of the model lies in the arrival pattern of passengers. It is challenging to predict how many passengers arrive at a specific time at the security check point. This is not only due to the fact that behaviour of people is challenging to predict, but it is also due to the influence of the number of flights that is departing at a certain time period. More flights leads to more passengers in the period before that flight. The combination of passenger behaviour and flight schedules makes this prediction very complex.

In addition, it is also challenging to make an estimation about the ratio of passengers with/without a time slot. This model complexity is caused by the first complexity. As it is challenging to predict general behaviour, it becomes even more challenging to estimate the ratio between passengers with/without time slots. However, this information is necessary to estimate the impact on the system.

Finally, another complexity of the model is the lane allocation strategy of security employees. Currently at Schiphol, security employees are located at the end of the queue and assign passengers to a security lane. This is based upon experience of the security employee, which makes this process a subjective element, as passengers get assigned by estimations of the security employee. This subjective process cannot be integrated in the simulation model, as the model uses a rigid decision strategy. However, assigning passengers to a security lane is an important aspect of the system.

5.4. Modelling Responses (model output)

Model responses are the key performance indicators (KPI's), that are obtained after running a simulation model. These KPI's show how the system behaves and performs under specific scenarios (Banks et al. 2010). There are two main KPI's which will be extracted from the simulation model.

First, the maximum waiting time is used as a KPI. The decision has been made to use maximum waiting time instead of the average waiting time, which was also possible to extract from the simulation model. The average waiting time is focusses on the waiting time of a whole day. However, average waiting time could be misleading, for instance when there is a huge queue at one period of the day, while the rest of the day has almost no waiting time. The average waiting time would be very low, while the system performs very bad in the system overload during the peak period. The maximum waiting time shows how the system performs at the busiest period of the day. This means that this KPI is focussed on a whole day, rather than just specific peak periods during the day. A busy period can be defined as a period in which the capacity of the security check point is lower than the number of passengers that want to go trough the system during that period. This means that the busiest period of the day is not necessarily the period in which the most passengers goes trough the system, as it also depends on the capacity of the security check point. Concluding, this KPI aims to optimize the simulation model to enhance passenger experiences, keeping the maximum waiting time as low as possible.

Second, The occupancy rate of security lanes is used as a KPI. This KPI enables one to review the performance of security lanes. Whenever the first KPI is the only one to be reviewed, Schiphol would open all security lanes during the day in order to keep maximum waiting times as low as possible. Obviously, this does not make sense, as it is not necessary to realise maximum security capacity in a very quiet period. As a matter of fact, opening security lanes costs Schiphol money, due to hiring of security employees and other operating costs. Concluding, this KPI aims to optimize the simulation model to enhance efficiencies of security lanes, thus keeping the average occupancies of security lanes as high as possible. Therefore, this KPI counterbalances the other KPI, as the maximum waiting time is focusses on passenger benefits and the average occupancy rates of security lanes is focussed on efficiency, thus minimizing costs for Schiphol.

5.5. Experimental Factors (model input)

The simulation model includes three important input variables that affect the KPIs. These variables are chosen to represent different scenarios for the security check point of Schiphol.

A key factor in the model is the ratio between passengers with and without a security time slot. This ratio has a direct impact on the length of both types of queues. By changing this ratio, the model looks at how various numbers of time slot users influence the performance of the system and the experience of the passengers. This gives information for possible future scenario in which the time slot tool may (or may not) be more popular than now, which affects the number of passengers with a time slot.

The second input decides how many security lanes are open at any moment during the day. The number of lanes in use is really important for queue management because it affects how quickly travellers can get processed. By changing this input, the model can test out how different operational plans influence both KPIs.

The third input factor considers how work schedules differ among various security lanes. Some lanes are open all day long, while others only operate during peak periods. This factor helps to analyse how the availability of lanes affects both KPIs.

5.6. Model Explanation

The process description of a simulation normally exists out of two main components: a schematic layout and model assumptions. The basis of the schematic layout is already presented in chapter 2, in which airport processes and the security filter are elaborated. However, some details still need to be clarified.

First of all, all passengers arrive at the same location in the model. Only after a general arrival, passengers get separated. This decision has been made, as this is also true for the majority of security filters at Schiphol.

Next, the model uses split queues, which means that there is a queue for passengers with a time slot and a queue for passengers without a time slot.

Furthermore, all passengers leave the model at the same location. Thus, passengers are combined after going through the security check to leave the model at the same location. This is also true in reality, as the security filter has one main exit for all passengers.

Moreover, all security lanes have work-schedules. Work-schedules differ between security lanes, which means that the capacity fluctuates over the day. Every security lane has its own work-schedule.

Finally, Passengers get assigned to a security lane by security employees. This means that passengers line up according to their category, and then they proceed to a security lane assigned to them by the security personnel.

In order to create an overview of the security system, figure 5.1 shows an IDEF-0 figure on the highest aggregation level.

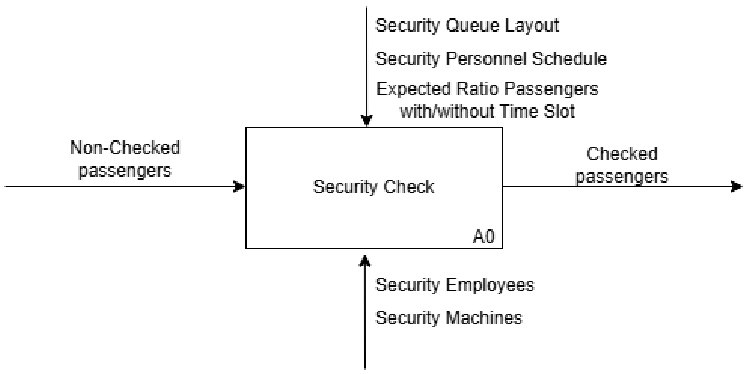

Figure 5.1: Overview of the security system

The full complexity of real-world processes cannot completely be captured in models. Therefore, certain simplifications and assumptions have been made while constructing the simulation model. Some of these assumptions were already discussed in detail in previous sections. However, they are summarized in this section for more clarity.

Table 5.1: Model assumptions

Assumption	Explanation
Passenger type	Only passengers within economy class are integrated in the model, which means passengers with or without a security time slot. Therefore, Privium, Priority and PRM passengers are not integrated in the model.
Passenger Arrival	The arrival pattern of passengers in the model is based upon data per time periods of 15 min. In order to spread passengers over these 15 mins, a distribution is made. Therefore, the arrival pattern consists out of many distributions within a time range of 15 mins. This means that the arrival pattern in the model slightly differs from the arrival pattern in reality, but the effect is rather small.
Malfunction of machines	Within the model, probabilities that security machines get broken are not included.
Groups of passengers	Normally, groups of passengers travelling together arrive at the same time at the security check point. Within the model, these passenger groups are not integrated as only the total number of passengers per hour is incorporated. Therefore, passenger flows on a larger scale are still comparable.
Security lane allocation	In the model, passengers can get assigned to dedicated security lanes for each type of queue. In reality, security lanes are not dedicated to specific types of lanes. However, some lanes are heavily dominated by a type of lane. Therefore, this assumption only has limited influence on the simulation results.
Work-schedules of security lanes	As stated before, all security lanes have a work-schedule. This work-schedule is based upon the input data. This is further elaborated in appendix G.
Security Lane Flow (1)	Within the model, 5 passengers can be processed in the security lane independently. In reality, these passengers do depend on each other, as a slow (inexperienced) passenger can hold other (more quickly) passengers behind this person.
Security Lane Flow (2)	In reality, passengers stand in a short line (approximately 0-5 passengers) at the security lane after being assigned by security employees. Within the model, this extra queue is simplified, by integrating this waiting time in the total processing time of the security lane.

Now that the principles of the model are elaborated, the model can be build. The decision has been made to build the model in Simio software. Figure 5.2 is a screenshot of the model in Simio.

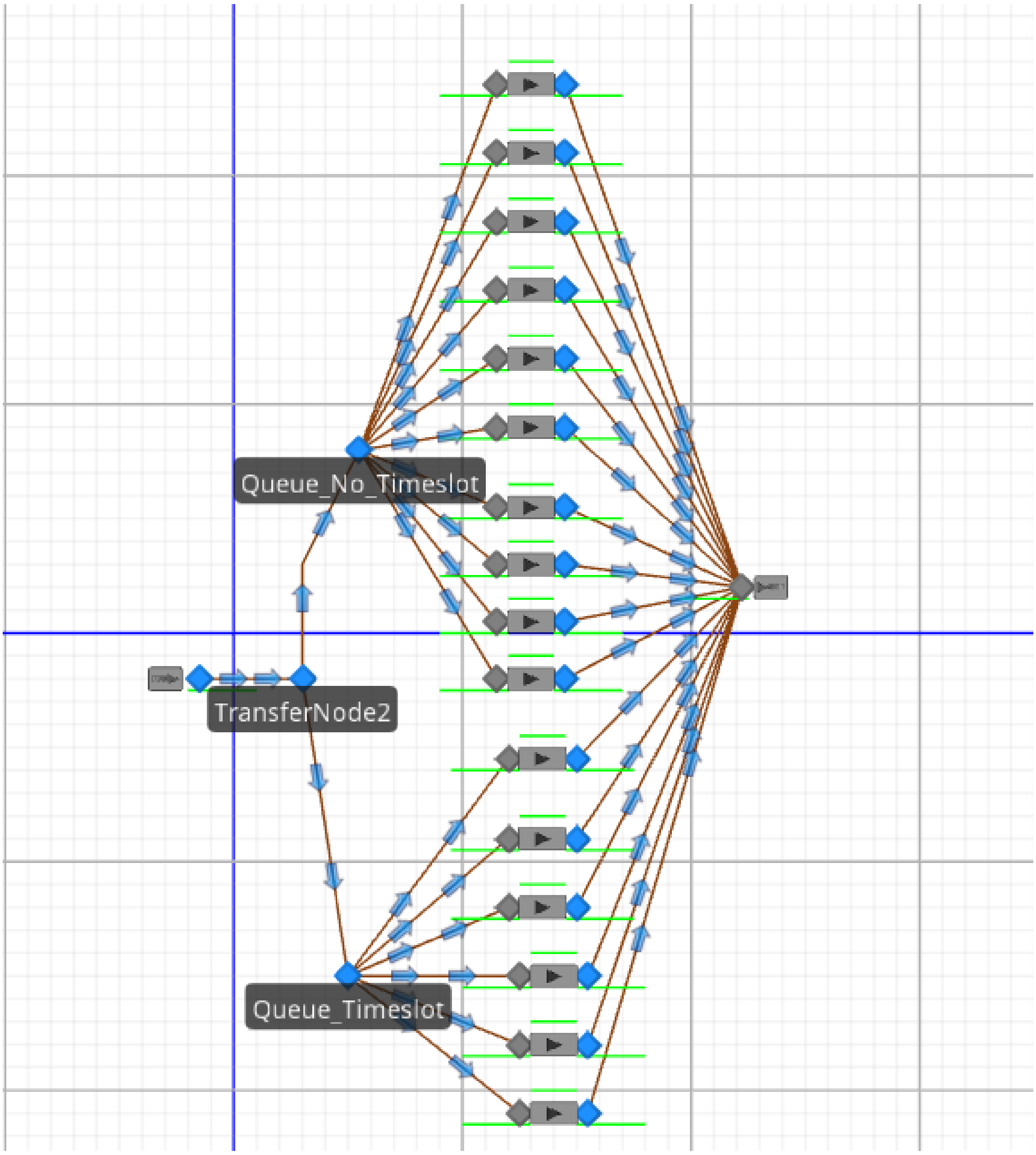

Figure 5.2: Overview of the simulation model

5.7. Input Data

Before using the model, input data needs to be defined. A combination of two different data sources will be used as input data in the model. First all, results from the DCE will be implemented in the model. In addition, data supplied by Schiphol will complete the input dataset. Table 5.2 explains input variables and their values. However, some variables are part of the scenarios which are being created. Therefore, these variables will have the value "scenario". Motivations for the applied distributions are given in appendix G.

Table 5.2: Input Data Overview

Input variable	Explanation	Input value
Composition of passenger types	Passengers will be split up in passengers with/without a time slot. This variable defines the ratio between these two types of passengers.	Scenario
Process time security machines	This variable includes the time that it takes for a passenger to go trough the security check. This includes getting ready for the check (putting everything in the plastic trays).	Random.Triangular(2,3,5) (Schiphol data)
Capacity of security machines	The maximum number of passengers that can be checked at one security lane at the same time.	5 (Schiphol data)
Queue capacities	The maximum number of passengers that can enter the queue	Infinity
Queue Discipline	The organisation of the queue. This queue includes the FIFO (First In, First Out) system.	-
Number of (operating) security machines	The number of security machines that are mobilised by security staff.	Scenario
Passenger arrival rate	Arrival pattern of the passengers.	Arrival table (figure 5.3) (Schiphol data)

In order to give a clear insight in the arrival pattern of passengers at the security check point, figure 5.3 shows an arrival pattern of Friday 31 January. This data is obtained in front of the security check point at Schiphol, so it represents the number of passengers that arrive at the security. This data has been used as Fridays are busy days at the airport, which is most interesting for the research. Within the Simio model, the arrival table is distributed with a Johnson SB (bounded distribution) to make sure that passenger arrivals are distributed instead of bundled arrivals at the time periods of the arrival table. This process is further elaborated in appendix G.

Figure 5.3: Overview of the arrival pattern of passengers

The work-schedules of the security lanes are based upon the security capacity that is offered by Schiphol data. A more detailed description of the creation of the work-schedules is given in appendix G.

Table 5.3: Work-schedule security lanes

	Whole day (07:00-21:30)	Morning peak (07:00-11:00)	Mid-day peak (11:00-14:30)	Afternoon peak (16:00-18:00)	Night peak (19:00-21:30)
No Time slot Lane 1	X				
No Time Slot Lane 2	X				
No Time slot Lane 3	X				
No Time slot Lane 4		X	X	X	X
No Time slot Lane 5		X	X	X	X
No Time slot Lane 6		X	X	X	X
No Time slot Lane 7		X		X	X
No Time slot Lane 8		X		X	X
No Time slot Lane 9		X			X
No Time slot Lane 10		X			
Time Slot Lane 1	X				
Time Slot Lane 2	X				
Time Slot Lane 3		X	X	X	X
Time Slot Lane 4		X		X	X
Time Slot Lane 5	X				
Time Slot Lane 6		X		X	X

5.8. Model Validation & Verification

This section exists out of two parts. First, the model will be verified by verification. Then, the model will be validated.

Verification: The model has been checked at several different parts of the model. This includes entry of only 1 passenger in the model, entry of 1000 passengers etc. There has been a check on the throughput of these passengers. In addition, the process of passenger composition has been checked by looking at passenger type ratios. Furthermore, the work-schedules of the security lanes have been checked. No mistakes are found, which means that every passenger that entered the model also left the model, the passenger composition process works properly and the work-schedules are working. A more detailed verification process is described in appendix G.

Validation: Within this research, operational validation is used to validate the simulation model. Operational validation includes a comparison between model outcomes with real-world data (Sargent et al. 2016). This comparison gives information about the performance of the model. Within this validation, a realistic number of passengers has been added to the model. Then, occurring lines in the queue are spotted at times that were expected. Therefore, the validation shows that the model performs well. A more detailed validation process is described in appendix G.

5.9. Experimental setup

Finally, an experimental setup for a Simio model is made. An experimental setup is essential for systematically exploring different scenarios, optimizing system performance, and gaining insights into how various factors affect the system.

The main focus of the experiments is to change the ratio between passengers with/without a time slot reservation. The range of ratios is between 10% and 40% of time slot users. This way, possible future scenarios of time slot usage can be explored. Obviously, differentiations in the ratio effect the number of passengers that goes trough the security lanes of either the time slot queue or the non- time slot queue. Therefore, The number of security lanes that is used in each scenario differs as well, so that the impact of the ratio can be tested under multiple scenarios of open/closed security lanes.

As mentioned in the research question, two main variables will be used in the experiments to interpret results: average occupation of security machines and maximum waiting time of passengers. The decision for maximum waiting time is chosen, as the majority of passengers experience low waiting times. Therefore, the average waiting time will be low.

As explained in the section about input data, multiple input data variables include uncertainty. Therefore, replications are used in experiments to counteract the uncertainty. Within this experimental setup, each scenario will include 10 replications. Boxplots shown in appendix G show that relatively small differences are present, therefore 10 replications is sufficient for this model.

A simulation model normally needs a warm-up period, as the model starts with an empty system (Kolahi 2011). However, this model does not need a warm-up period, as the model simulates a whole day. Therefore, the model starts empty and also finishes empty. A warm-up period would decrease the quality of the model, as you would simulate only parts of the day instead of a whole day.

The run length of the model is one operational day at Schiphol at Friday 31 January 2025. The security filters open around 07:00 and close around 21:30 (Schiphol 2025). However, this is not the case for all security lanes, as some lanes have other opening and closing times.

As stated before, the set of security lanes differs over the scenarios. There are two types of differentiations within these sets: differentiations in overall number of open security lanes and differentiations in different type of open security lanes. The second differentiation is based upon the different work-schedules of the security lanes. The set-up of the experiments is as follows:

Table 5.4: Set-up Simulation Experiments

Experiment Name	Ratio	Opened Non-Time slot security lanes	Opened Time Slot Security Lanes
Low ratio with high capacity	10%	1 until 10	1 until 3
Low ratio with medium capacity	10%	1 until 9	1 and 2
Low ratio with low capacity	10%	1 until 8	1
Above average ratio with high capacity	20%	1 until 10	1 until 3
Above average ratio with medium capacity	20%	1 until 9	1 and 2
Above average ratio with low capacity	20%	1 until 8	1 and 2
High ratio with high capacity	30%	1 until 9	1 until 3, and 5
High ratio with medium capacity	30%	1 until 8	1 until 4
High ratio with low capacity	30%	1, 2, 4 until 9	1 until 3
Exceptionally high ratio with high capacity	40%	1 until 7	1 until 6
Exceptionally high ratio with low capacity	40%	1, 2, 4 until 7	1 until 5

As an addition to the experiments described above, the effect of peakshaving is tested. This is done by applying peakshaving to the input data. Just as used in the experiments, the percentage of peakshaving is between 10% and 40%. How peakshaving is executed precisely is elaborated in appendix G. Each peakshaving effect is tested for one scenario in the experiments described above. The experiment with the longest expected waiting times is used (lowest capacities), as this experiment is able to show the potential of peak shaving. This is an overview of the experiments used per peak shaving coefficient:

- 10% peakshaving: experiment ”Low ratio with low capacity”
- 20% peakshaving: experiment ”Above average ratio with low capacity”
- 30% peakshaving: experiment ”High ratio with low capacity”
- 40% peakshaving: experiment ”Exceptionally high ratio with low capacity”

6

Descriptive Statistics of Sample

This chapter examines the descriptive statistics of the sample collected by distributing the survey. Section 6.1 explains how the data has been cleaned, section 6.2 interprets the socio-demographic characteristics of the sample, section 6.3 interprets the trip related characteristics of respondents in the sample, section 6.4 explains the mode choice split and section 6.5 interprets the statements that are answered in the survey. In short, this chapter provides answers for RQ1 and RQ2.

6.1. Data Preparation

The survey has been spread between December 17th and December 23th at the gates of Schiphol Airport. In total, 1306 respondents have opened the survey, from which 853 (65%) have completed the full survey. The survey has been build in such a way, that the response was send automatically 1 hour after entry of the survey. Therefore, it was not necessary to delete duration-time related outliers, as these were already handled by only allowing fully completed survey responses. In addition, 8 respondents were left out, because they were younger than 18.

Besides the check for unfinished surveys, it is important to check indicate whether there are unreliable responses in the finished surveys. Within this research, unreliable responses are answers that do not correspond with the 'real' behaviour of the respondent. Obviously, this is challenging to find, as the survey has been spread among a large number of people. However, one way to find unreliable responses is to check whether people have non-trading behaviour. Non-trading behaviour is the phenomenon in which respondents chose the same answer for all the DCE questions. Within the data set, non-trading behaviour did almost not exist, except for the option of non reserving a time slot. However, it does not necessarily mean that a respondents is having non-trading behaviour, whenever someone choose to ignore timeslots for every DCE question. Someone could, for instance, simply dislike the time slot tool and never want to reserve one, regardless of the context or the scenario. Therefore, answers for other questions in the survey were checked for candidates of non-trading behaviour. Especially the question "have you reserved a time slot for this trip" was useful to check whether respondents showed non-trading behaviour, as it is unlikely that someone with a reserved time slot in reality would never reserve a time slot according to the DCE. In total, 9 cases of non-trading behaviour were detected and, therefore, deleted out of the data set.

Concluding, the final data set includes the answers of 836 respondents.

6.2. Socio-demographic Composition

Within this survey, respondents are asked to fill in socio-demographic questions. The information of these socio-demographic characteristics can be used to gain knowledge about the composition of the group respondent sample. In order to do so, the respondent sample will be compared to the population of passengers at Schiphol. This information about the population is offered by Schiphol. Information about the respondent sample is shown in table 6.1. It is important to mention that respondents had the possibility to refuse to answer these questions, as they are not necessarily important for the main research of this study. Sometimes, socio-demographic questions puts respondents off whenever they are forced. To prevent this from happening, the option ”No answer” is added.

However, not all demographic characteristics of the respondent sample could be compared to the population of passengers at Schiphol, as Schiphol does not have all the data. Information about age and gender is available, but education level and income not. Therefore, data of the Central Bureau of Statistics (CBS) and Ministry of Infrastructure and Water Management (I&W)is also used to compare the sample with the population. As data from CBS is used to compare income levels, the variable ”income” has been shaped towards the same standards of the data of CBS. This means that income categories have been determined as: low-income: €0-€30.000, middle-income: €30.000-€70.000 and high-income: €70.000+ (CBS 2023).

Table 6.1: Socio-demographic characteristics of the sample

Characteristic	Option	Frequency	Percentage
Age	Youth (18-25)	224	26.8%
	Young adults (26-40)	268	32.0%
	Middle-aged adults (41-65)	267	31.9%
	Elderly adults (65+)	30	3.6%
	No answer	47	5.6%
Gender	Male	420	50.2%
	Female	394	47.1%
	Non-binary	8	1.0%
	No answer	11	1.3%
Highest Education Degree	Secondary school	100	12.0%
	Secondary vocational education	60	7.2%
	Applied science Bachelors degree	97	11.6%
	Applied science Masters degree	52	6.2%
	University Bachelors degree	201	24.0%
	University Masters degree	219	26.2%
	University PhD degree	72	8.6%
	No answer	32	3.8%
Income	Low-income	242	28.9%
	Middle-income	224	26.8%
	High-income	189	22.6%
	No answer	178	21.3%

Comparing the sample composition of ’age’ with the population at Schiphol, it becomes clear that this survey lacks elderly adults (65+). This can be caused by the fact that the survey has been spread in an online environment, which could scare older adults, but could also be caused by the time in which the survey has been spread. This was during the Christmas Holiday, which is (in general) not a period of time in which many elderly passengers are travelling (Eurostat 2024).

The composition of 'gender' seems to have an equal distribution in the sample, compared with the population at Schiphol. The number of non-binary passengers is relatively low, but this is also the case in the population.

The composition of 'Highest education degree' has a peak at university degrees. Combined, passengers with a university Bachelors or Masters are more than 50% of the sample. This is very high, but seems to be comparable to the population (Ministerie van Infrastructuur en Waterstaat 2024).

Last, the composition of 'income' shows a relative flat distribution. However, this can include bias, as many students (age: 18-25) are part of the survey and students do not work full time. The data of CBS only includes working people, which makes it difficult to compare the sample with the population In addition, a relatively large part of the respondents did not want to answer this question. This makes it challenging to create in-debt information about this composition. However, it is noticeable that almost 23% of the respondents in the sample has a high-income level, which is above average compared to the population (16%). In fact, this difference is not necessarily a problem, as this could be explained by the fact that people with low-income fly less often than people with a high-income (Ministerie van Infrastructuur en Waterstaat 2024).

6.3. Trip Related characteristics

Besides socio-demographic questions, respondents have also answered trip related questions. These questions are necessary to create a passenger profile for each respondent. As explained earlier in chapter **??**, respondents receive a context based upon their passenger profile. The sample will also bo compared to the population at Schiphol for the trip related characteristics to make sure the data of the sample is representative.

It is important to mention that transfer passengers have been treated different than other types of passengers in some analyses. Obviously, transfer passengers came from other airports than Schiphol, which results in the fact that transfer passengers did not go trough the security check point of Schiphol. Therefore, they had no reason to book a time slot for the security check point. In addition, as explained in chapter 1, few airport have implemented a time slot system and no other airport applies the system of Schiphol. Concluding, transfer passengers have been excluded in analyses regarding the number of time slot reservations and the awareness of the time slot tool. As transfer passengers do have flight experience (as they have had at least 1 flight to go to Schiphol), they were able to answer other questions of the survey properly. Therefore, for answers of transfer passengers could be used in all analyses other than time slot awareness and reservations.

The trip related characteristics are shown in table 6.2.

Table 6.2: Trip related characteristics of the sample

Characteristic	Option	Frequency	Percentage
Trip purpose	Business	102	12.2%
	Non-Business	734	87.8%
Business Trip Experience	Yes	361	43.2%
	No	475	56.8%
Time Slot Awareness (no transfer)	1 = Yes	334	49.4%
	2 = No	342	50.6%
Time Slot Reservation (no transfer)	1 = Yes	112	16.6%
	2 = No	564	83.4%
Area	1 = Schengen	413	49.4%
	2 = Non-Schengen	423	50.6%
Flight Company	1 = Alone	379	45.3%
	2 = Adults	391	46.8%
	3 = Children	66	7.9%
Travel Mode Towards Airport	Transfer	160	19.1%
	Bus	38	4.5%
	Train	393	47.0%
	Car (kiss&ride)	94	11.2%
	Car (parking)	50	6.0%
	Taxi	75	9.0%
	Other	26	3.1%
Flight Frequency	0	29	3.5%
	1-3	295	35.3%
	4-10	413	49.4%
	10+	99	11.8%

To begin, passengers were asked whether they were familiar with time slots for the security check point and whether they have booked them. As explained before, the results of these questions are cleaned, as transfer passengers are not included in the results. Almost half of the passengers was aware of the security time slots (49%), but only 16.6% booked a time slot (33% of the passengers who were aware of time slots). This shows that many passengers were not aware of time slots, which indicates potential the future regarding awareness. Actually, the booking percentage in the sample is lower than the reservation rate in peak periods (20% during summer peak). Therefore, it can be concluded that this research is representative for regular weeks of Schiphol, so not for exceptionally quiet periods, but also not for very busy peak periods.

Within the sample, only 12% of the respondents are business passengers. This is lower than the population, as approximately 27% of all passengers (Schengen and non-Schengen are almost equal) are business passengers. This is as expected, as business travellers are more challenging to reach for surveys, as they are likely to work in lounges before their flight (the survey was not spread in airport lounges, as elaborated in section **??**). To compensate, passengers were also asked whether they have made any business related flights before. This ratio was more in balance, as 43% of the respondents have business related flight experience. Obviously, this is more than the population, but this is not really a problem, as it is more important to gain robust results for each group (business vs non-business) than to have perfectly representative ratios, as each group will have individual interpretations of the results.

The ratio between Schengen and Non-Schengen passengers in the sample is almost 1:1, while in the population slightly more non-Schengen passengers are present (4:5). The perfectly balanced sample is not a coincidence, but is caused by the fact that a balanced ratio for this variable was desired to create robust results for both Schengen and non-Schengen passengers. Whenever the variable was unbalanced, more survey were spread in the other part of the airport.

The variable 'company' shows how contexts were distributed. The number of passengers with children was very low. This can be explained by the fact that they were often busy with their children at the airport and did not want to answer the survey. This was anticipated, as people with older children were also allowed to answer the context with younger children (as older children were younger once). However, the number of respondents which are parents is still lower than desired. There is no data at Schiphol available regarding travel company.

The variable for Travel mode towards the airport shows that the majority of passengers go to Schiphol by train. Next, the kiss&ride facility is used the most. Relatively few respondents went to Schiphol by bus. Comparing the sample with the population shows a correct distribution in the sample, as the majority of people arrive by train, followed by car. One noticeable result is that 19% of the sample includes transfer passengers. This is lower than the population at Schiphol (36%). However, this is does not cause any problems for two reasons. First of all, the research is focussed on people with an originated departure from Schiphol. In addition, transfer passenger were able to answer the whole survey (as if the were going trough the security at Schiphol), due to explanations given in the survey. It will be mentioned and motivated in the descriptive text of analyses whenever transfer passengers are not part of the analysis.

Finally, respondents were asked to give their flight frequency for the previous year. The majority of respondents did fly frequently (4-10 times last year). Only 3.5% of all respondents did not fly at all before the flight they had planned at the day of answering the survey. Comparing the sample to the population shows that the sample includes slightly too many respondents in the 4-10 frequency, while having too few passengers in the 10+ segment. This does not necessarily cause issues, as these passengers can be described as experienced flyers, who know the security system well.

Concluding, the sample is representative for both the demographic- and the trip related characteristics and can be used for further analyses. The sample is representative for a regular week at Schiphol, which means that it is not representative for very busy and quiet periods.

6.3.1. Arrival at Security

As explained in previous chapters, one of the main goals of time slots at Schiphol is peakshaving. Peakshaving removes passengers from their original arrival time at the security check point into earlier or later time slots, whenever their original arrival time was involved in a peak. This section focusses on the preferred arrival time at the security check point. This information can be used as input for potential optimizations of the peak shaving algorithm. Figure 6.1 shows the distribution of the preferred arrival time at the security check point.

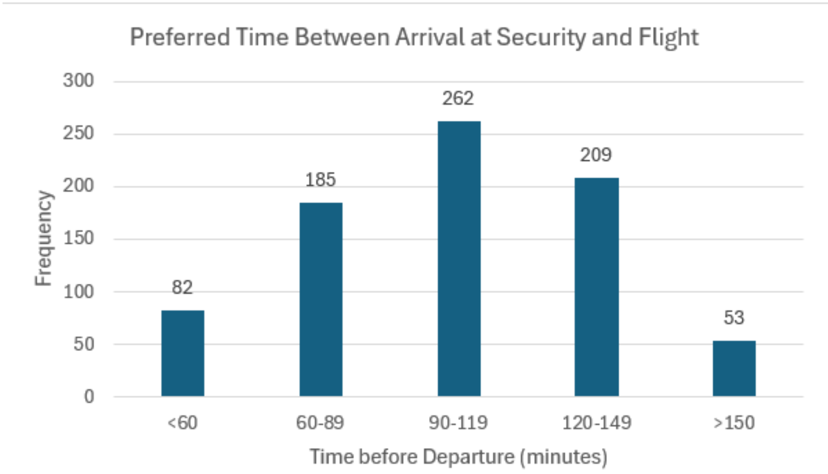

Figure 6.1: Distribution of passengers' preferred arrival time at the security check before departure

One thing that becomes clear is that the distribution is shaped as an normal distribution. The largest spike is between 90 and 119 mins before departure of the flight. However, the shape of this distribution is somewhat misleading, as the level of detail is relatively low. A more detailed distribution is given in appendix D, figure C.1. This figure shows that the distribution is not a perfect normal distribution, as the majority of passengers choose options which were easier to interpret, such as 60/90/120 minutes. Nevertheless, the main take-away of figure 6.1 is still valid, as the majority of passengers prefer to go to the security checkpoint between 90 and 119 minutes before departure of their flight.

This conclusion is in line with data gathered by Schiphol. This data shows that the majority of passengers arrives around 100 minutes before their flight at the security check point. This data is based upon realised numbers, so might differ from the data gathered by this research, as revealed and stated preference of people are not always equal (Louviere et al. 2000).

6.3.2. Appreciation of Time Slot Tool

This section describes the results of the survey question that focussed on passengers' appreciation of the time slot tool in terms of waiting time saved at the security queue. This question isolates the attribute waiting time saved in order to gain more information on this attribute. The question asked to respondents is:

"If you can take a look into the future: how many minutes of waiting time in the security queue would a time slot reservation need to save you for it to be worth making that reservation?"

As can be seen in figure 6.2 below, a distribution is made of passengers' appreciation of the time slot system regarding waiting time saved. Chapter 8 will focus on general preferences of waiting time saved, while taking other variables into account. A figure with a higher level of detail is shown in Appendix C, figure C.2. In addition, figure 6.3 shows the cumulative numbers, based upon the same data.

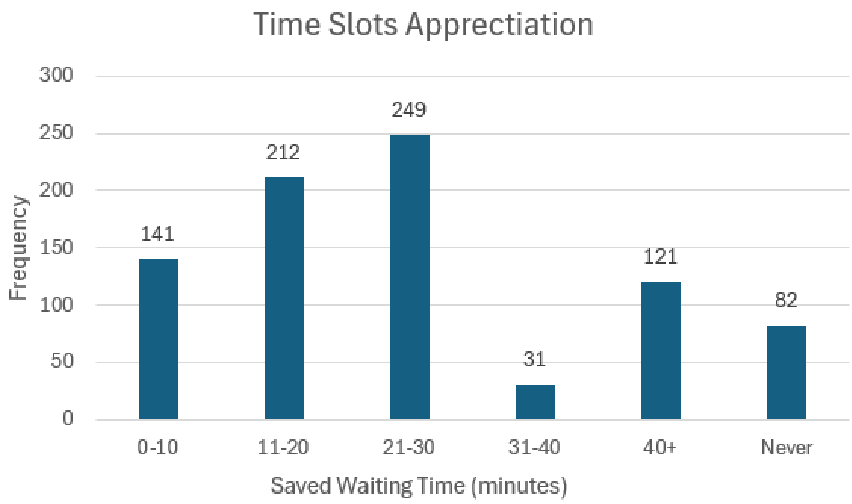

Figure 6.2: Distribution Appreciation Time Slots

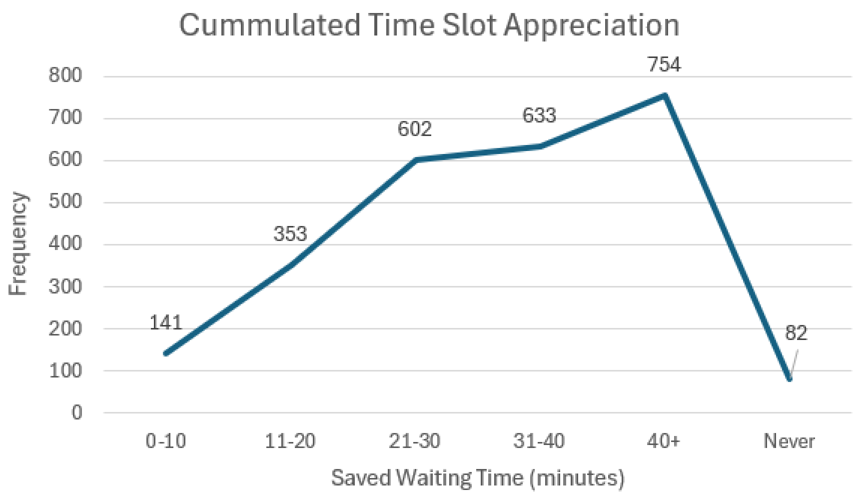

Figure 6.3: Cumulative Appreciation Time Slots

One thing that becomes very clear is that there is a clear distinction between passengers who are potentially willing to make a time slot reservation (based upon this variable) and passengers who are not likely to make a time slot reservation. Passengers which only make a time slot reservation whenever they save 40+ minutes with the tool are probably not going to make a time slot reservation. Obviously, passengers who answered that they never want to make a reservation, can also be seen as non-potential time slot users.

However, the split between potential time slot users and non-users is still difficult to make, based on this data. For instance, based on the distinction described above, the ratio of time slot users vs non-users would be 7:2, while survey data shows a ratio of 1:5. Whenever the ratio 1:5 would be representative, the split should be roughly 15 minutes. In reality, Schiphol data shows a ratio of approximately 1:10. This would indicate that the split should be around 10 minutes.

Currently, there is no real-time data available for the number of minutes saved by reserving a time slot. In addition, it is unlikely that this will be part of the time slot tool in the near future. However, researching this variable is still valuable, as it gives information about the perception of passengers regarding waiting time saved.

6.4. Mode Choice Split

This section explores the decisions that respondents have made while answering the stated preference questions. As mentioned earlier, respondents answer 9 choice questions in the survey. For each question, respondents could choose between time slot A, time slot B or no reservation. Figure 6.4 shows the distribution of choices across all choice sets. On average (average of all choice sets combined), a time slot was reserved 49.0% of times (25.3% time slot A, 23.7% time slot B). This means that respondents choose to make no reservation at 51.0% of times.

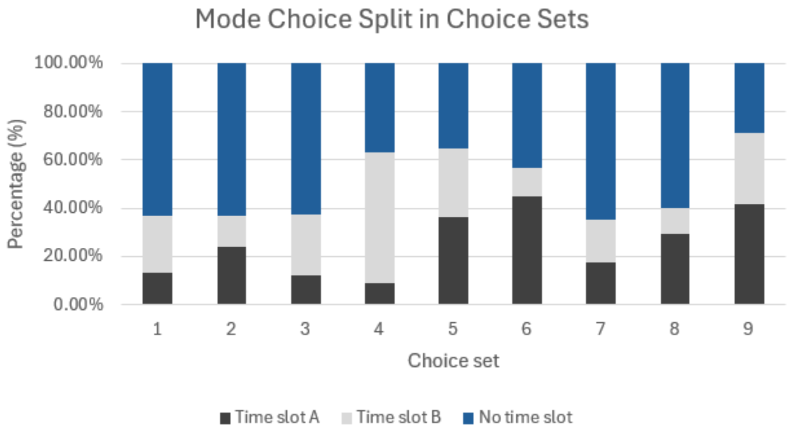

Figure 6.4: Mode split of all respondents for each choice set

From the mode choice split of figure 6.4 can be concluded that the choice sets are constructed well, as there is no choice set which is completely dominated by a specific alternative. In addition, sometimes, the option of ”no time slot reservation” is chosen more frequently, while in other choice set, time slot A or time slot B is more preferred. In-debt conclusion are challenging to be made from this figure alone, which is why attribute interpretations will be done after applying a interpretation model to the results (chapter 9)

6.5. Factor Analysis

As explained in section 4.11 statements were included in the survey in order to research passengers' motivation to reserve or not reserve a time slot for the security check point at Schiphol. These motivations of person-related characteristics can be explained as latent factors. Latent factors are factors that cannot be observed directly, but can be researched by analysing a set of variables. For instance, it is impossible to observe why people would make a time slot reservation, but answering multiple statements related to this topic can create information about time slot reservation drivers.

The Factor Analysis has been executed following the Exploratory Factor Analysis process as proposed by E. Molin (2017). This process combines a set of latent factors into a smaller number of factors. This set of latent factors is created by communality (common variance) between these latent factors. Therefore, the Factor Analysis explains the correlations between variables. Appendix D shows how the process has been executed with all steps included.

There are two main types of factor rotations: orthogonal and oblique. Orthogonal rotation assumes that the underlying factors are not correlated, while oblique rotation assumes they are. In this study, oblique rotation is applied because underlying factors are expected to be connected (Abdi 2003).

6.5.1. Formed Factors

The results of the Exploratory Factor Analysis for this research is formed by using the answers of all respondents. The main take-away of this analysis is to create the factors and their statements. Afterwards, the total respondent sample can be split into sub-groups for which differences can be analysed.

There are two main types of factor rotations: orthogonal and oblique. Orthogonal rotation assumes that the underlying factors are not correlated, while oblique rotation assumes they are. In this study, we started with oblique rotation because we expected the underlying factors to be connected.

The original result of the factor analysis includes three factors (appendix D). However, the Cronbach's alpha and the Pearson correlation were not strong enough for the third factor, which means that the statements were not closely related to each other (Tavakol and Dennick 2011). Therefore, the decision has been remove the two statements from factor 3 and iterate the factor analysis again. This process is shown in appendix D, section D.1.1. As a result, the same two factors were formed. The factors created, including the variables included are shown in table 6.3 below.

Table 6.3: Factors and their statements

Variable	Statement
Factor 1: Benefits of time slots	
Planning_3	I like security time slots, as they enable me to plan my whole trip (travel to the airport, luggage check-in, security check, walk to the gate) in more detail.
Awareness_2	I would recommend time slots to other travellers.
Stress_2	I believe that a reserved time slot for the security checkpoint lowers my stress levels.
Perception_5	I find the certainty of passing through the security checkpoint within a specific time provided by a time slot very important.
Perception_6	Time slots are also useful during quiet times, not only during peak travel times.
Innovation_1	I am interested in trying new tools to lower waiting times, such as the time slot reservation system.
Perception_3	I would prefer time slots which also include luggage check-in.
Factor 2: Downsides of time slots	
Perception_1	I (expect to) find it too much effort to reserve a time slot.
Perception_2	The time slots available do not align with my preferred travel times (real life, not the time slots shown in the experiment).
Perception_4	(I expect that) Time slots do not save me significant time in the security queue.
Planning_2	I dislike time slots, as a dedicated time slot for the security check gives me less flexibility for other steps in my airport process (travel to the airport, luggage check-in etc.)
Planning_4	I prefer to join the security whenever I want, rather than a dedicated time slot.

As can be seen in table 6.3, the statements are subdivided into three factors. One factor contains statements that have a positive attitude towards time slots, another factor contains statements with a negative attitude towards time slots and the final factor contains statements that are focussed on waiting behaviour.

Not all statements are included in the factors.Two statements are left-out (Planning_1 and Awareness_1) as these statements did not load enough (<0.3) on any of the three factors. This does not mean that they do not offer information, only that they cannot be interpret together with other statements. In addition, two statements (Stress_1 and Stress_3) used to form factor 3, but these have been left out as well (low Cronbach's alpha and Pearson correlation).

As explained before, the Cronbach's alpha is checked for the created factors to check how closely related a set of items are as a group. The test divides groups in the following segments (Tavakol and Dennick 2011):

- alpha ≥ 0.9: Excellent reliability
- 0.8 ≤ alpha < 0.9: Good reliability
- 0.7 ≤ alpha < 0.8: Acceptable reliability
- 0.6 ≤ alpha < 0.7: Questionable reliability
- alpha < 0.6: Poor reliability

Table 6.4: Reliability of Scales

	Factor 1	Factor 2
Cronbach's alpha	0.84	0.76

The outcome of this test shows that the statements within factors are well related as a group. Therefore, it is not necessary to make any further adjustments to factor 1 and 2. Subsequently, these will be used for further analyses.

6.5.2. Results within Factors

As the factors are now defined, the results of the factors can be explored. Before creating results, it is important to have identical directions for all variables within each factor. This is the case for factor 1 and 2. It used to be a problem for factor 3, but splitting the factor into two separated variables already solved the issue. Therefore, all factors are suitable to be interpreted.

To create results, average scores of factors are calculated. As explained in section 4.11, each answer can be translated into a number (Fully Disagree can be translated into 1 and fully agree becomes 5). This way, it is possible to calculate the average value per statement, which makes it possible to calculate the average score of factors. Calculating the average score is a variation of the sum-score method, which is an often applied method in Factor Analyses (Molin 2024). The average score is applied instead of the sum-score, as the average score is easier to interpret.

In order to have the opportunity to do more in-debt interpretations, standard deviations (SD) and standard errors (SE) are also shown. Standard deviations measure the spread of individual data points around the mean. This can be used to describe the variability within a dataset. The standard error measures the accuracy of the sample mean as an estimate of the population mean. This can be used to estimate how much the sample mean deviates from the true population mean.

Table 6.5: Factors and their statements

Variable	Average score	SD	SE
Factor 1: Benefits of Time Slots			
Planning_3	3.3	1.0	0.04
Awareness_2	3.4	0.9	0.03
Stress_2	3.3	1.1	0.04
Perception_5	3.4	1.0	0.04
Perception_6	3.0	1.1	0.04
Innovation_1	3.7	1.0	0.04
Perception_3	3.7	1.0	0.04
Factor 2: Downsides of Time Slots			
Perception_1	2.8	1.2	0.04
Perception_2	3.0	0.9	0.04
Perception_4	3.1	1.0	0.04
Planning_2	3.3	1.1	0.04
Planning_4	3.4	1.1	0.04

As can be seen in table 6.5, the majority of statements has an average value of approximately 3.0, which represents the answer ”indifferent”. This is logical, as this overview includes all respondents. In detail, the standard deviations are relatively large, which implies that respondents did not have a unified attitude towards the statements (which is the reason why a factor analysis is done).

In order to get more information about differences between groups regarding their attitude towards time slots, an one-way ANOVA test is executed. This test will study whether different groups have significant different perceptions.

6.5.3. Differences between selected groups

As stated before, to gain more information about the factors, it is interesting to see how different groups within trip related variables value the factors. By applying an one-way ANOVA test, one can check whether groups have significantly different behaviour. Within this test, a significance level of 95% is applied, which sets the boundary at a p-value of 0.05. Besides analysing whether there is a difference between the two groups, SD's and SE's can be interpret to see if specific groups have lower variability and smaller deviations than the whole set of respondents.

A complete overview of the one-way ANOVA results and corresponding interpretations is given in appendix D, section D.3. This section will only discuss the main take-aways of trip-related characteristics (business vs non-business, reservation vs no-reservation, aware vs not aware, travel mode, flight frequencies)

Table 6.6: Factor scores

Variable	Factor 1	SD1	SE1	Factor 2	SD2	SE2
General	3.4	0.76	0.02	3.1	0.82	0.02
Business	3.3	0.79	0.08	3.1	0.79	0.08
Non-Business	3.4	0.75	0.03	3.2	0.82	0.03
Reservation	4.0	0.67	0.06	2.4	1.00	0.09
No Reservation	3.3	0.73	0.03	3.3	0.73	0.03
Aware	3.6	0.77	0.04	2.9	0.87	0.05
Not Aware	3.3	0.73	0.03	3.3	0.74	0.03
No Reservation but is Aware	3.4	0.72	0.05	3.1	0.72	0.05
No Reservation and Not Aware	3.3	0.73	0.03	3.4	0.73	0.05
Transfer	3.5	0.69	0.05	3.2	0.70	0.06
Bus	3.3	0.68	0.11	3.1	0.77	0.12
Train	3.4	0.75	0.04	3.1	0.81	0.04
Taxi	3.6	0.74	0.09	3.2	0.86	0.10
Car (Kiss&Ride)	3.5	0.86	0.09	3.2	0.94	0.10
Car (Parking)	3.5	0.81	0.11	3.0	0.91	0.13
Other	3.2	0.72	0.14	3.3	0.80	0.16
0 Flights	3.5	0.87	0.16	3.4	0.86	0.16
1-3 Flights	3.4	0.81	0.05	3.2	0.80	0.05
4-10 Flights	3.4	0.71	0.03	3.1	0.83	0.04
10+ Flights	3.4	0.75	0.08	3.2	0.78	0.08

*Grey-couloured estimates are insignificant ANOVA-test results

Reservation vs No Reservation (transfer passengers excluded)

The difference between these two categories is significant for both factors. The outcome is as expected, as passengers with a reservation score higher on factor 1 and passengers without a reservation score higher on factor 2. In detail, the score of non-reserving passengers on factor 1 is still above 3 (3.3), which implies that they do experience benefits from time slots. However, they also score above 3 (3.3) for factor 2, which means that the benefits of time slots are counterbalanced by the downsides of time slots, which could explain the fact that they did not make a reservation.

On the other hand, the benefits outweigh the downsides for passengers with a reservation (4 vs 2.4), which explains why they made a reservation.

Finally, it is remarkable that the group of passengers with a reservation have a smaller SD for factor 1 than factor 2, which implies that they have a more unified opinion about the benefits of time slots than about the downsides. For instance, some people might not see any downsides, while other people also see downsides besides the positive elements of time slots. This effect cannot be seen for passengers without a reservation, as both SD's are almost equal. This does not mean that they have equal opinions about benefits and downsides, but this means that differentiations within the group are equal for both the benefits and the downsides, so there still are some differentiations.

As the comparison between these two categories is part of RQ1, the details of the differences is further analysed in more detail in the following section.

Aware vs Not Aware (transfer passengers excluded)

The group of people who are aware exists out of passengers with and passengers without a time slot who knew that time slots exist. Both results for factor 1 and factor 2 implies that people who are aware react different than people who are not aware. The results show that people who are aware see more benefits in time slots and are more or less indifferent to downsides of time slots.

However, this effect could be heavily influenced by the fact that there is a mix of passenger with and without a reservation. As concluded previously, passengers with a reservation score way higher on factor 1 and lower on factor 2. This effect occurs as well within the analysis of awareness, as results of the group of people who are aware are mixed. Therefore, this result cannot be interpreted on its own. In order to see the real impact of awareness, the awareness is studied for passengers without a reservation.

No Reservation and Not Aware vs No Reservation and Aware (transfer passengers excluded)
As the title of these categories already implies, the difference between these two categories lies in the fact that some passengers answered that they were aware of the fact that time slots existence and deliberately did not make a time slot reservation, while the other category of passengers did not make a time slot reservation, because they were not aware of the possibility to do so. Remarkably, the only difference in score is seen on factor 2. Passengers who were not aware were more negative than passengers who were aware. There seems to be no significant difference on factor 1, so people who are aware of time slots (without a reservation) do not see more/less benefits than people who are not aware.

However, this conclusion must be nuanced, as people who have no reservation and are not aware could get to know the system, find out about the benefits and downsides and decide to make a reservation. Therefore, it can be concludes that awareness reduces the attitude towards downsides of time slots, but it cannot be concluded that it does not impact the attitude towards benefits.

Transport Mode to Airport
Results show that transport mode does not have major impact on how passengers rate benefits and downsides of time slots. There obviously are some differences, but these are rather small.

Flight Frequencies
Passengers who did not fly in the previous 12 months score significantly higher on downsides of time slots than passengers who did have flights in previous. This may be caused by them being less experienced with all airport processes (described in section 2.1). Therefore, these passengers might be less flexible to switch from no time slot reservation towards a time slot reservation, which results in more resistance towards time slots and a higher score on the second factor.

6.5.4. Reservation vs No Reservation (individual statements)

As described in previous section, people with and without a reservation score significant different to the factors in the factor analysis. The factor interpretation is already done, but to answer RQ1 in more detail, the largest differences for individual statements are also studied. This is done to understand which factors of the time slot system cause the majority of the difference in attitude towards time slots. Table 6.7 below shows the results.

Table 6.7: Difference Highest statements of Reservation

Statement number	Factor	Reservation score	SD	SE	No Reservation score	SD	SE	Delta
Planning_2	2	2.5	1.24	0.11	3.5	1.07	0.04	0.923
Stress_2	1	4.1	0.91	0.08	3.2	1.06	0.04	0.908
Awareness_2	1	4.2	0.84	0.07	3.3	0.92	0.03	0.892
Perception_1	2	2.1	1.29	0.11	3.0	1.11	0.04	0.850
Planning_4	2	2.7	1.23	0.11	3.5	0.99	0.04	0.817

The largest difference between the two groups can be found for statement ”planning_2”. This statement focusses on the fact that time slots cause less flexibility during airport processes. As expected, passengers with a reservation find this issue less important than passengers without a reservation.

The statement of ”stress_2” focuses on stress levels. It claims that time slots lowers stress levels of passengers. Passengers with a reservation highly agree with this statement, while passengers without a reservation find this statement somewhat exaggerated, as the average score is 3.2. This score would mean that people are between indifferent and agree, but more towards agree.

Next, the statement of ”Awareness_2” asks passengers whether they would recommend time slots to other passengers. Passengers with a reservation really appreciate the tool, as they score 4.2 on this statement. On the other hand, passengers without a reservation score only 3.3, which is somewhere between indifferent and agree.

The statement of ”perception_1” claims that reserving a time slot is too much effort. As expected, passengers without a time slot reservation score higher than passengers with a reservation. However, they still score relatively low, as the score is only 3.0. This indicates that the effort to reserve a time slot is probably not the largest issue for passengers without a reservation.

The statement of planning_4 has comparable content to planning_2, but defines it as ”joining the security queue whenever preferred”. These statements have more or less the same result, as passengers with a reservation find this less important than passengers without one.

Concluding, for both factor 1 and factor 2 are the outcomes as expected. Passengers with a reservation score higher on positive statements about time slots and lower on negative ones, while passengers without a reservation have more conservative positive scores and lower scores for negative factors. However, the groups are not complete opposites to each other, as passengers without a reservation do not score below the score of 3 (which would have been towards disagree) for positive statements.

The most important differences between passengers with/without a time slot reservation are caused by flexibility in airport processes, impact on stress levels and the effort it takes to make a reservation.

Integration of luggage check-in system

Passengers without a time slot reservation implied to dislike time slots due to the inflexibility aspect of the tool. Time slots require passengers to be at a specific time at the security checkpoint, otherwise they will miss their time slot and probably their flight. Therefore, the statement with the subject of luggage integration is reviewed individually, as this could reduce the impact of the inflexible tool. The results are shown in table 6.8 below.

Table 6.8: Individual analysis luggage integration

Statistic	Result Reservation	Result no Reservation
Mean	3.8	3.7
SD	0.94	0.99
SE	0.08	0.04

As can be seen in the table, both groups prefer to have the luggage system integrated in the time slot tool. This is as expected, as it reduces the effect of an inflexible time slot tool. Both SD’s are relatively large, which implies that there are large differences in attitude towards luggage check-in within the groups. However, these differences are not large enough to create another conclusion. Thus, implementing luggage check-in in the time slot tool would improve the quality of the product.

7

MNL Model Selection

This chapter explains how the MNL interpretation model is selected for the stated preference analysis. Section 7.1 explains the utility functions of considered interpretation models and section 7.2 compares the results of the model estimations and selects a model which will be used for the main research.

7.1. Utility Functions

In the estimation of a MNL model, it is assumed that consumer preferences are homogeneous, meaning that a single set of general preferences is derived for all respondents. As explained in the methodology, passengers have three alternatives in the choice experiment. Each of the alternative has its own utility function. The order of utility functions per alternative is shown in table 7.1 below.

Alternative	Utility function
Time slot A	1
Time slot B	2
No reservation (base alternative)	3

Table 7.1: Utility function per alternative

The set of variables is equal in the systematic utility functions of the time slot alternatives. This way, information of both alternatives can be combined into generic results for every variable. First, a linear model with only the attributes and the context variables is explained. Afterwards, a model with added non-linear components to the utility functions is explained. Finally, a model in which interaction variables are added to the utility functions is elaborated.

7.1.1. Linear model

$$V_i = ASC_{\textbf{Time slot}} + B_{\text{costs}} \cdot \text{Costs} + B_{\text{saved}} \cdot \text{Saved} + B_{\text{time}} \cdot \text{Time} + B_{\text{Schengen}} \cdot \text{Schengen} + B_{\text{Adults}} \cdot \text{Adults} + B_{\text{Children}} \cdot \text{Children} + B_{\text{Business}} \cdot \text{Business} \quad (7.1)$$

$V_i =$ Systematic utility of alternative i (i=1,2,3)

$ASC_{\text{Time slot}} =$ Constant (=base utility) of reserving a time slot

$B_{\text{costs}} =$ Parameter for the ”reservation costs” attribute

$B_{\text{saved}} =$ Parameter for the ”saved waiting time” attribute

$B_{\text{time}} =$ Parameter for the ”time before departure” attribute

$B_{\text{Schengen}} =$ Parameter for the Schengen context (dummy coded)

$B_{\text{Adults}} =$ Parameter for the travelling with adults context (dummy coded)

$B_{\text{Children}} =$ Parameter for the travelling with children context (dummy coded)

$B_{\text{Business}} =$ Parameter for the business travel context (dummy coded)

The alternative ”No reservation” functions as a base alternative within this study. This way, the impact of making a reservation can be tested. Since this alternative is the base case, the systematic utility function can be described as:

$$V_3 = 0 \quad (7.2)$$

The decision has been made to apply dummy coding for the contexts ”Schengen” and ”Business”, since these attributes have 2 levels each. The context for ”travel company” includes 3 levels, which makes it impossible to have one general parameter for this context variable. Therefore, one reference value is chosen from the three levels, while the other two levels form two dummy coded variables (Louviere et al. 2000). This creates the following structure for the dummy coded variables:

	Variable: Adults	Variable: Children
Travel company: Adults	1	0
Travel company: Children	0	1
Travel company: Alone	0	0

Figure 7.1: Structure dummy coding

As can be seen in figure 7.1, there are two variables: ”Adults” and ”Children”. A one indicates that the travel company context is active for that variable, while a zero means that the variable is not equal to the context. As there is no variable for the travel company context of ”alone”, both variables have the value of zero.

7.1.2. Non-Linear Model

As mentioned before, this MNL model includes non-linear components for the attribute parameters. The context parameters cannot be tested for non-linearity, as they are dummy either true or false.

$$\begin{aligned} V_i = ASC_{\textbf{Time slot}} &+ B_{\text{costs}} \cdot \text{Costs} + B_{\text{costs\_Q}} \cdot \text{Costs}^2 + B_{\text{saved}} \cdot \text{Saved} + B_{\text{saved\_Q}} \cdot \text{Saved}^2 \\ &+ B_{\text{time}} \cdot \text{Time} + B_{\text{time\_Q}} \cdot \text{Time}^2 + B_{\text{Schengen}} \cdot \text{Schengen} \\ &+ B_{\text{Alone}} \cdot \text{Alone} + B_{\text{Adults}} \cdot \text{Adults} + B_{\text{Business}} \cdot \text{Business} \end{aligned} \tag{7.3}$$

Additional parameters are:

$$\begin{aligned} B_{\text{costs\_Q}} &= \text{Parameter for the quadratic costs attribute} \\ B_{\text{saved\_Q}} &= \text{Parameter for the quadratic saved waiting time attribute} \\ B_{\text{time\_Q}} &= \text{Parameter for the quadratic "time before departure" attribute} \end{aligned}$$

7.1.3. Non-Linear Interaction Model

Next, the a MNL model with interaction effects is made to test whether context variables have interaction effects with the attributes (Louviere et al. 2000). This effect is visualised in figure 7.2 below. (inspired by (Molin 2024)).

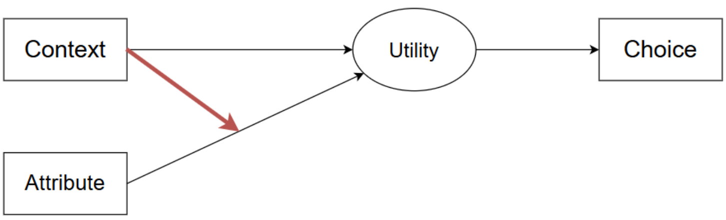

Figure 7.2: Explanation Interaction Effect

As there barely is existing literature regarding time slot research at airports, it is challenging to estimate a distinction between realistic and unrealistic interaction effects. Therefore, all possible interaction effects have been tested, to explore possible outcomes.

$$\begin{aligned} V_i = ASC_{\textbf{Time slot}} &+ B_{\text{costs}} \cdot \text{Costs} + B_{\text{costs\_Q}} \cdot \text{Costs}^2 + B_{\text{saved}} \cdot \text{Saved} + B_{\text{saved\_Q}} \cdot \text{Saved}^2 \\ &+ B_{\text{time}} \cdot \text{Time} + B_{\text{time\_Q}} \cdot \text{Time}^2 + B_{\text{Schengen}} \cdot \text{Schengen} \\ &+ B_{\text{Alone}} \cdot \text{Alone} + B_{\text{Adults}} \cdot \text{Adults} + B_{\text{Business}} \cdot \text{Business} \\ &+ B_{\text{costsXSchengen}} \cdot \text{Costs} \cdot \text{Schengen} + B_{\text{costsXAlone}} \cdot \text{Costs} \cdot \text{Alone} \\ &+ B_{\text{costsXAdults}} \cdot \text{Costs} \cdot \text{Adults} + B_{\text{costsXBusiness}} \cdot \text{Costs} \cdot \text{Business} \\ &+ B_{\text{savedXSchengen}} \cdot \text{Saved} \cdot \text{Schengen} + B_{\text{savedXAlone}} \cdot \text{Saved} \cdot \text{Alone} \\ &+ B_{\text{savedXAdults}} \cdot \text{Saved} \cdot \text{Adults} + B_{\text{savedXBusiness}} \cdot \text{Saved} \cdot \text{Business} \\ &+ B_{\text{timeXSchengen}} \cdot \text{Time} \cdot \text{Schengen} + B_{\text{timeXAlone}} \cdot \text{Time} \cdot \text{Alone} \\ &+ B_{\text{timeXAdults}} \cdot \text{Time} \cdot \text{Adults} + B_{\text{timeXBusiness}} \cdot \text{Time} \cdot \text{Business} \end{aligned} \tag{7.4}$$

Additional parameters are all interaction parameters. The description of all parameters is the same:

$$B_{\text{costsXSchengen}} = \text{Parameter for the interaction effect between the attribute costs and context Schengen}$$

As can be seen, this utility function is very large and overwhelming due to the large number of parameters. This makes it challenging to intepret the effects of the attributes, as it is not very clear where they influence the utility function. Therefore, the utiltiy function is rewritten in order to create a better insight in the effect of the attributes on the utility function.

$$\begin{aligned} V_i = {} & ASC_{\textsf{Time slot}} \\ & + \text{Costs} \cdot (B_{\text{costs}} + B_{\text{costsXSchengen}} \cdot \text{Schengen} + B_{\text{costsXAlone}} \cdot \text{Alone} \\ & + B_{\text{costsXBusiness}} \cdot \text{Business} + B_{\text{costsXAdults}} \cdot \text{Adults}) + B_{\text{costs\_Q}} \cdot \text{Costs}^2 \\ & + \text{Saved} \cdot (B_{\text{saved}} + B_{\text{savedXSchengen}} \cdot \text{Schengen} + B_{\text{savedXAlone}} \cdot \text{Alone} \\ & + B_{\text{savedXAdults}} \cdot \text{Adults} + B_{\text{savedXBusiness}} \cdot \text{Business}) + B_{\text{saved\_Q}} \cdot \text{Saved}^2 \\ & + \text{Time} \cdot (B_{\text{time}} + B_{\text{timeXSchengen}} \cdot \text{Schengen} + B_{\text{timeXAlone}} \cdot \text{Alone} \\ & + B_{\text{timeXAdults}} \cdot \text{Adults} + B_{\text{timeXBusiness}} \cdot \text{Business}) + B_{\text{time\_Q}} \cdot \text{Time}^2 \\ & + B_{\text{Schengen}} \cdot \text{Schengen} + B_{\text{Alone}} \cdot \text{Alone} \\ & + B_{\text{Adults}} \cdot \text{Adults} + B_{\text{Business}} \cdot \text{Business} \end{aligned} \tag{7.5}$$

As can be seen, there are no interaction effects implemented for the effect between the quadratic components of attributes and contexts. There are two main arguments for the decision not to include these interaction effects.

First, the primary goal of the interaction effects is to understand how context influences the main trends in attribute effects. Adding interactions between contexts and quadratic components would make the results of the model unnecessary complex to interpret (J. Sidey-Gibbons and C. Sidey-Gibbons 2019). Therefore, a more parsimonious model (one that balances complexity and explanatory power) is preferable (Preacher 2006).

Second, too many interaction terms can lead to overfitting (Frost 2017). Quadratic components of attributes already account for the changing effects of different attributes, so adding interactions effects between quadratic components and context variables might just create confusion instead of actually improving how accurately we can predict outcomes.

7.1.4. Interpretation model with factor effects included

Finally, an interpretation model with factor effects included is made. Thus, this interpretation model includes latent variables in order to research their impact on the decision whether to make a time slot reservation. The decision has been made to also include interaction effects between the latent variables and the linear components of attributes. There are no interaction effects estimated for the quadratic components due to the same reasons described earlier in section 7.1.3. The equation is as follows:

$$
\begin{aligned}
V_i = {} & ASC_{\textbf{Time slot}} \\
& + \text{Costs} \cdot (B_{\text{costs}} + B_{\text{costsXSchengen}} \cdot \text{Schengen} + B_{\text{costsXAlone}} \cdot \text{Alone} + B_{\text{costsXBusiness}} \cdot \text{Business} \\
& + B_{\text{costsXAdults}} \cdot \text{Adults} + B_{\text{costsXFac1}} \cdot \text{Fac1} + B_{\text{costsXFac2}} \cdot \text{Fac2}) + B_{\text{costs\_Q}} \cdot \text{Costs}^2 \\
& + \text{Saved} \cdot (B_{\text{saved}} + B_{\text{savedXSchengen}} \cdot \text{Schengen} + B_{\text{savedXAlone}} \cdot \text{Alone} + B_{\text{savedXAdults}} \cdot \text{Adults} \\
& + B_{\text{savedXBusiness}} \cdot \text{Business} + B_{\text{savedXFac1}} \cdot \text{Fac1} + B_{\text{savedXFac2}} \cdot \text{Fac2}) + B_{\text{saved\_Q}} \cdot \text{Saved}^2 \\
& + \text{Time} \cdot (B_{\text{time}} + B_{\text{timeXSchengen}} \cdot \text{Schengen} + B_{\text{timeXAlone}} \cdot \text{Alone} + B_{\text{timeXAdults}} \cdot \text{Adults} \\
& + B_{\text{timeXBusiness}} \cdot \text{Business} + B_{\text{timeXFac1}} \cdot \text{Fac1} + B_{\text{timeXFac2}} \cdot \text{Fac2}) + B_{\text{time\_Q}} \cdot \text{Time}^2 \\
& + B_{\text{Schengen}} \cdot \text{Schengen} + B_{\text{Alone}} \cdot \text{Alone} \\
& + B_{\text{Adults}} \cdot \text{Adults} + B_{\text{Business}} \cdot \text{Business} \\
& + B_{\text{Fac1}} \cdot \text{Fac1} + B_{\text{Fac2}} \cdot \text{Fac2}
\end{aligned}
\tag{7.6}
$$

Additional parameters are all factor parameters. The description of both factor parameters is equal.:

$$
\begin{aligned}
B_{\text{Fac1}} &= \text{Parameter for the main effect of factor 1} \\
B_{\text{costsXfac1}} &= \text{Parameter for the interaction effect between the attribute costs and factor1}
\end{aligned}
$$

7.2. Model Estimations

The Log-Likelihood shows how well a model explains the data, with less negative numbers meaning it does a better job (Hauber et al., 2016). You can use Log-Likelihood to compare different models, but it shouldn't be the only thing you look at to see how well a model fits. McFadden's ρ^2 is another way to check how well a model fits, and higher values indicate a better model (Chorus, 2022). In addition, the Bayesian Information Criterion (BIC) and the Akaike Information Criterion (AIC) help in judging how good a model is by trying to reduce information loss. Models with lower BIC and AIC scores are usually better performing models. A good rule of thumb is that if the BIC difference is more than 10, the more complicated model is likely to be a better performing model (Paetz et al., 2019).

In order to test whether the more complex models work better than the more simple models, a likelihood ratio test is executed. The likelihood ratio test compares the Loglikelihood from two models and compares these with a chi-squared distribution. This chi-squared distribution is based upon the difference in degrees of freedom (number of parameters) in the model. The larger the difference, the higher the difference in loglikehood must be in order to have a significant better performing model.
The formula of the Likelihood ratio test is shown below.

$$
\Lambda = -2 \log \left(\frac{L_0(\theta_0)}{L_1(\theta_1)} \right) \tag{7.7}
$$

where:

- $L_0(\theta_0)$ is the likelihood of the null model (restricted model).
- $L_1(\theta_1)$ is the likelihood of the alternative model (unrestricted model).
- θ_0 and θ_1 are the parameters of the null and alternative models.

Under the null hypothesis, the test statistic Λ follows a chi-square distribution:

$$
\Lambda \sim \chi^2(k)
$$

Where k is the number of parameters estimated in the alternative model but not in the null model (the degrees of freedom).

Table 7.2: Statistical Performance Models

Model name	LogLikelihood	# Parameters	ρ^2	BIC	AIC
Linear	-7215.9	8	0.130	14521.2	14451.9
Non-Linear	-7159.4	11	0.133	14434.9	14344.9
Non-Linear Interactions	-7124.8	23	0.134	14326.2	14317.7
Non-Linear Interactions and factors	-7120.8	31	0.139	14545.0	14309.6

As can be seen in table 7.2, all model performance indicators improve, whenever the models become more complex. This is as expected, as the number of parameters is rising, which means that more knowledge can be captured. The models described above can be explained as nested models, which means that the linear model is forming the base for the other two models. The non-linear model is an extension of the linear model and the non-linear interaction model is an extension of the non-linear model. However, the exact components of the linear model are also integrated in the non-linear and non-linear interaction model.

Table 7.3: Comparison models

Model Comparison	k	Chi-squared	P-value
Linear vs non-linear	3	113.1	0.000
Non-Linear vs non-linear interaction	12	69.2	0.000
non-linear interaction vs Non-Linear Interactions and factors	8	8.0	0.433

As can be seen in table 7.3, the non-Linear model performs better than linear model and the non-linear interaction model performs better than the non-linear model. However, the model with factor effects included does not perform better than the non-linear interaction model. Therefore, the non-Linear Interaction model will be used as the interpretation model in this research. However, the non-linear interaction model with factors included is also calculated. These results can be found in appendix E.

8

Stated Preference Results

In previous chapter, a MNL model with non-linear interaction effects has been selected as the interpretation model. This chapter shows the results obtained from that interpretation model. Therefore, it provides answers for RQ3.

The results of the interpretation model are divided into sections, so that it becomes easier to interpret the effects. Section 8.1 discusses the results of the attributes, section 8.2 interprets the results of the context variables and section 8.3 discusses the interaction effects. An overview of all results within one table is shown in appendix E, table E.1.

8.1. Main effects (constant and attribute parameters)

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Table 8.1: Main Effects

Beta variable	Value	Rob. s.e.	T-test	P-value
ASC_Time slot	-0.853	0.185	-4.626	0.000
Costs_L	-0.308	0.038	-8.068	0.000
Costs_Q	0.024	0.007	3.645	0.000
Saved_L	0.027	0.003	7.760	0.000
Saved_Q	-0.0003	0.000	-5.733	0.000
Time_L	0.826	0.161	5.136	0.000
Time_Q	-0.320	0.039	-8.146	0.000

First of all, all parameters are significant, which means that none of the parameters are fixed to the value of 0.

The constant is negative, which would normally suggest a negative attitude towards time slots in general. Then, this parameter would be interpreted as the utility of the reference alternative, which means that all dummy coded variables have the reference value.

However, the attributes are not dummy coded. To cancel the effect of these attributes on the utility function, every level of the attributes should be fixed to 0 in order to create 0 obtained utility from the attributes. This is not possible for the attribute of Time. Therefore, this constant value must be seen as a starting point for the utility calculation, rather than a general attitude of all variables are fixed to 0.

As stated in equation 7.5, the final utility obtained from the attributes is also dependent on context factors, due to interaction effects. In order to see the relation between the linear and quadratic component of the attributes, interaction effects should be minimized. This can be done by choosing a scenario for contexts in which the interaction effects are equal to 0 (all dummy variables are 0). This scenario includes the following conditions:non-Schengen, Alone, non-business. Now, the relation between the linear and quadratic components of the attributes can be discussed.

The linear component of costs is negative, which means that people receive negative utility when costs are rising. However, the quadrati parameter is positive, which implies that people are more price sensitive between €0 and €2,50 than between €2,50 and €5,00. This can also be seen in figure 8.1, as the utility function is decreasing less rapidly when the price is rising.

The linear parameter of ”Waiting Time Saved” is positive, which indicates that people gain utility by saving time. However, the quadratic component is negative, which means that less utility is added, when the saved time is becoming larger. Figure 8.2 shows function of Saved Waiting Time. As can be seen, the positive character of the linear component gets compensated as more waiting time is saved.

The linear component of ”Time Before Departure” is positive relative strong, compared to the linear components of other attributes. The quadratic one is negative, which means that this positive character is compensated as well. However, the linear component is so strong, that the equation starts more or less horizontal. First, as can be seen in figure 8.3, utility stays on more or less the same value, as more time is between arrival at the security check point and the departure time. However, after roughly 1.33 hours, te quadratic component becomes stronger, which results in a downwards utility function.

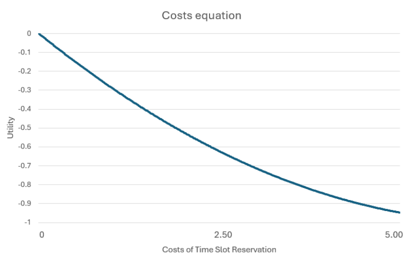

Figure 8.1: Costs equation

Figure 8.2: Saved Waiting Time equation

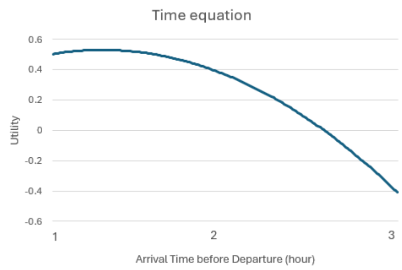

Figure 8.3: Time Before Departure Equation

Comparing the three different attributes with each other gives insight in the utility impact of each attribute in the general utility function. This impact can be translated to the importance of an attribute. as a larger impact means that passengers focus more in that attribute. The utility ranges of the attributes are:

- Costs: 0 until -0.9 (range: 0.9)
- Saved: 0 until 0.5 (range: 0.5)
- Time: 0.5 until -0.4 (range: 0.9)

Concluding, the impact of each attribute depends heavily on the value that is being applied for the attribute. Both the attributes ”Costs” and ”Time” have an utility range of 0.9, which makes them more impactful than the attribute ”Saved”. The impact of ”Costs” is larger when costs are low (the equation is steeper at the beginning), while the impact of ”Time” is larger with higher values.

However, it must be noted that this order is only viable for the comparison of the linear and quadratic components of the MNL model. As stated before, interaction effects could influence the equations of the obtained utility per attribute, creating a different impact on the utility equation.

8.2. Context effects

Table 8.2: Context Effects

Beta variable	Value	Rob. s.e.	T-test	P-value
Schengen (vs non-Schengen)	0.405	0.132	3.077	0.002
Adults (vs Alone)	-0.150	0.137	-1.095	0.274
Children (vs Alone)	-0.078	0.253	-0.309	0.757
Business (vs non-business)	0.416	0.137	3.038	0.002

*Grey-coloured estimates are insignificant parameters

One thing that stands out is the fact that all dummy coded contexts of ”Travel Company” are insignificant. This means that group size does not directly impact the decision-making process regarding time slot consideration, as there is no differentiation between these groups.

In addition, the values of ”Schengen” is positive, which means that passengers assign extra utility to time slots, whenever they travel within Schengen. This implies that passengers within Schengen are more likely to make a time slot reservation. The impact of this variable is relatively large, compared to the attribute impact discussed earlier, which represents a strong differentiation between these passengers within and outside of Schengen.

The value of ”Business” is also positive, which means that business travellers gain more utility than non-business travellers for reserving time slots. This effect is also relative large, compared to the earlier discussed results of the attributes. Apparently, characteristics of time slots suit business passengers well.

However, one thing must be nuanced in relation to the interpretation of context variables. As discussed in section 8.1, interaction effects are also part of this MNL model. This could influence the magnitude of influence of influence of all context variables. Therefore, the impact of Schengen and Business could become smaller or even larger. This will be explored in chapter 9. In addition, it cannot be concluded that there is no differentiation at all for the insignificant main effects of contexts, because they could still have significant interaction effects, thus having impact on the utility function.

8.3. Interaction effects

As explained earlier in 7.1.3, two (or more) variables could have a combined effect, which is called interaction effects. By also researching interaction effects, more information will be obtained about preferences of passengers and especially the differences between passenger groups. This section is split-up into three different sub-sections. Each sub-section will present and discuss the interaction effects between one attribute and all context variables.

8.3.1. Interaction Costs

First, interaction effect with costs will be discussed. This information can be used by Schiphol to decide whether or not to implement time slot costs for specific groups (in case Schiphol decides to implement time slot costs at all).

Table 8.3: Interaction Effects Costs

Beta variable	Value	Rob. s.e.	T-test	P-value
SchengenXCosts	-0.022	0.021	-1.058	0.290
AdultsXCosts	-0.002	0.022	-0.096	0.924
ChildrenXCosts	0.093	0.041	2.285	0.023
BusinessXCosts	0.070	0.022	3.183	0.001

*Grey-coloured estimates are insignificant parameters

The first thing that stands out in table 8.3 is the fact that there seems to be no difference between Schengen and non-Schengen passengers regarding the interaction effect with costs, while both variables have significant main effects. This means that passengers within and without Schengen react more or less similar to potential costs of time slots.

Next, there seems to be no difference in attitude towards time slot costs between people who travel alone and people who travel with a group of adults. This effect is as expected, as a group of adults could be seen as a group of individual ticket bookers. Whenever you travel alone, you obviously need to pay for the time slot costs by yourself. Whenever you travel with a group adults, it is possible to split the time slots costs with the other adults, which basically means that you only pay for your own time slot.

Subsequently, there is a difference present in attitude towards time slot costs between people who travel alone and people who travel with small children. This is also as expected, as the individual traveller only needs to pay for its own time slot, while the person who made the reservation of the group with children needs to pay for the whole group (you pay for each time slot to be reserved, a time slot can only be used for 1 person). Obviously, whenever children are still young, you cannot split the time slot costs with the group. However, the positive value is not expected, as this implies that passengers with children are less sensitive towards costs, while they are expected to be more sensitive, as they need to pay multiple tickets. Apparently, people travelling with children focus less on costs and might be focussed more on other aspects of time slots.

Finally, there is a difference present between business passengers and non-business passengers regarding their attitude towards potential time slot costs. This is also as expected, as business passengers often do not pay for their tickets (their company pays the ticket), while non-business passengers need to pay them. Therefore, business passengers are less likely to be influenced by potential costs, as they probably do not need to pay these costs.

All significant interaction effects have positive values, which indicates that these groups react slightly less negative (having costs equation of figure 8.1 in mind) towards costs. The magnitude of this compensating effect regarding costs is rather big. Therefore, costs are less of an issue for people travelling with children and business passengers.

The interaction effect between people who travel with children and costs is slightly stronger than the interaction effect between business passengers and costs. This means that people who are travelling with children are willing to pay more for a time slot reservation than business travellers.

8.3.2. Interactions Saved Waiting Time

Next, interaction effects regarding saved waiting time caused by time slots are shown. This information helps Schiphol to understand how passengers value saved waiting time in more detail.

Table 8.4: Context Effects

Beta variable	Value	Rob. s.e.	T-test	P-value
SchengenXSaved	0.000	0.002	0.008	0.994
AdultsXSaved	0.001	0.002	0.707	0.479
ChildrenXSaved	-0.003	0.004	-0.934	0.350
BusinessXSaved	0.000	0.002	0.133	0.895

*Grey-coloured estimates are insignificant parameters

It is striking to see that none of the contexts seems to have different attitudes towards waiting time saved by using time slots. This indicates that contexts do not influence the attitude towards this attribute. Therefore, the equation shown in figure 8.2 is true for all contexts.

This outcome is as expected for the context of Area, as it is not expected that flight destinations influence waiting behaviour of passengers.

However, it was expected to have differences in travel company, as it is likely that people find waiting alone more disturbing than travelling with a group. In addition, it was expected that people who travel with young children would prefer to save more waiting time, as queuing with children could cause children to misbehave.

Finally, it was also expected that business passengers would have a different attitude than non-business passengers regarding saved waiting time, as business passengers are likely to optimize their trip. Many business passengers also do work-related things at the airport, which is why it was assumed that business passengers prefer to reduce waiting time in comparison to non-business passengers.

If the insignificant values were to be significant, the interactions of ”Schengen”, ”Adults” and ”Business” with ”Saved” have a positive value, which means that these contexts obtain more utility than their reference context as the amount of waiting time saved is rising. This effect is as expected for business passengers and could be true for people travelling within Schengen, but this is not expected for people travelling with a group of adults. It was expected that waiting in a queue would be more disturbing while travelling alone. Having this in mind, it is expected that a positive value would be insignificant.

Contrary, the parameter of the interaction effect of ”Children” and ”Saved” is negative, which means that passengers with children obtain less utility than passengers who travel alone. This is not as expected, for the same reasoning as above. Therefore, it is logical that this variable is insignificant.

As can be seen in table E.3, the parameter values are all rather small, which indicates that the impact of these interaction effects would have been slim if they were to be significant.

8.3.3. Interactions Time

Next, interaction effects regarding time between the security and departure are shown. This information helps Schiphol to understand how passengers value this time. This can be used to optimize the peak shaving algorithm within the time slot tool.

Table 8.5: Context Effects

Beta variable	Value	Rob. s.e.	T-test	P-value
SchengenXTime	-0.242	0.050	-4.832	0.000
AdultsXTime	0.059	0.052	1.126	0.260
ChildrenXTime	-0.002	0.096	0.025	0.987
BusinessXTime	-0.262	0.050	-4.998	0.000

*Grey-coloured estimates are insignificant parameters

The results in table 8.5 show that there is a difference present between passengers within and outside of Schengen regarding how they evaluate the time between the security check point and the departure of their flight. This is as expected, as the airport processes are different for both destinations (non-Schengen includes border control). Therefore, the negative sign is also as expected, as this means that Schengen passengers dislike more time between the security and the departure.

Furthermore, it is striking that there seems to be no difference between the contexts of ”Travel Company” regarding the Time attribute. It was expected that people who travel with children would prefer to have more time between the security and the departure of their flight, as children could be unpredictable. For instance, the nappy of your child might need to be cleaned in this time period, or you child is distracted by the things to do behind security which adds travel time to the gate. It was also expected that people travelling with adults would have different behaviour than people travelling alone, as travelling with a group often takes more time than travelling alone. In addition, it was expected that people who travel in groups are less time sensitive, as they have more opportunities to be entertained while waiting for the flight compared to people travelling alone (this is not true for everybody, but is an expectation for the majority of people).

Finally, Business passengers have a different attitude towards the Time attribute than non-business passengers, which is expected. As explained earlier, business passengers are likely to prefer an efficient airport process, which makes it logical that they prefer to have less time between the security and departure of their flight. The value is negative, which means that business passengers lose utility as more time is between the security checkpoint and their flight, which is an expected outcome.

The magnitude of these interaction variables is relatively large. The equation of ”Time” (figure 8.3) has values between +0.5 and -0.4 utils. Both interaction effects cause a fluctuation approximately -0.25 utils in the utility equation of ”Time”, which is a relatively strong impact.

If the insignificant parameters were to be interpret, the positive value of the interaction effect of people travelling with adults is as expected, as this would have implied that they are less time sensitive than people travelling alone (see explanation above). On the other hand, the negative value for people travelling with children was not expected, as this would have implied that they dislike time between the security and their flight more than people travelling alone. It was expected that people travelling with children would prefer more time (see previous explanation), which would have had a positive value.

If the insignificant parameters were to be significant, their impact would have been rather small.

9 Application of SP Results

This section converts previously obtained sp results into results that are easier to interpret. This way, it is possible to answer RQ4 and RQ3 with more detail.

9.1. Predicted Time Slot Utilities

Whenever the parameter estimates are incorporated in the utility function (equation 7.5), the impact of the attributes and contexts become more clear. This incorporated utility function can be seen below in equation 9.1.

$$
\begin{aligned}
V_i = &-0.853 \\
&+ \text{Costs} \cdot (-0.308 + 0.093 \cdot \text{Children} + 0.0.070 \cdot \text{Business}) + 0.024 \cdot \text{Costs}^2 \\
&+ 0.027 \cdot \text{Saved} + B_{\text{saved\_Q}} \cdot \text{Saved}^2 \\
&+ \text{Time} \cdot (0.826 - 0.242 \cdot \text{Schengen} - 0.262 \cdot \text{Business}) - 0.320 \cdot \text{Time}^2 \\
&+ 0.405 \cdot \text{Schengen} + 0.416 \cdot \text{Business}
\end{aligned} \tag{9.1}
$$

This equation creates a better overview of the different influences of both attributes and contexts in the utility equation. Scenarios can be created in which levels are choosen for both the attributes and the contexts. The following two subsections will show the influence of all attributes and the contexts.

After creating scenarios, a comparison can be made between them. This can be done by comparing obtained utilities, but utility cannot be interpret. Therefore, obtained utility is converted into a chance of booking (Train 2002, Ben-Akiva and Lerman 2018). This represent the percentage of passengers that would make a time slot reservation (for the specific scenario created).

$$P_i = \frac{e^{U_i}}{\sum_{j=1}^{J} e^{U_j}} \times 100\% \tag{9.2}$$

Where:

- P_i: The probability (in percentage) of choosing alternative i.
- U_i: The utility of alternative i
- J: The total number of alternatives

In this case the number of alternatives is 2 (section 7.1): passengers can decide to either make a reservation or make no reservation. Section 7.1 also explains that the obtained utility for no reservation is 0, as it is the reference value. Therefore, the formula can be rewritten into:

$$P_i = \frac{e^{U_i}}{e^{U_i} + 1} \times 100\% \tag{9.3}$$

Now, scenarios can be constructed and estimated following utility function 9.1 and formula 9.3.

9.2. Willingness-to-pay

This section calculates the willingness-to-pay for time slots. Within this research, time slots have three different components (attributes). As stated by (Train 2002), willingness to pay can be calculated by a division of the value of a parameter in de model and the value of the costs parameter. In this case, the willingness to pay for both the ”Saved” and ”Time” attributes is calculated. However, all attributes have multiple variations in variables, such as a linear variable, a squared variable and interaction variables. Therefore, the calculation becomes somewhat more challenging, as the derivative of the Time or Saved component should be divided by the derivative of the Costs component, as can be seen in equation 9.4 and 9.5 (Ben-Akiva and Lerman 2018, Train 2002). The equation of ”Saved” is multiplied bij 60, to create identical units. The unit of ”Time” is in hours and the unit of ”Saved” is in minutes.

$$\text{WTP}_{\text{Time vs Costs}} = -\frac{\frac{\partial U}{\partial \text{Time}}}{\frac{\partial U}{\partial \text{Costs}}} \tag{9.4}$$

$$\text{WTP}_{\text{Saved vs Costs}} = -60 \cdot \frac{\frac{\partial U}{\partial \text{Saved}}}{\frac{\partial U}{\partial \text{Costs}}} \tag{9.5}$$

In order to create the derivative of of the ”Time”, ”Saved” and ”Costs” attributes, all variables that are multiplied by Time or Saved are included (Train 2002). Than, the derivative is calculated, as can be seen in the equations below.

$$\frac{\partial U}{\partial \text{Time}} = \beta_{\text{Time}} + 2 \cdot \beta_{\text{Time}^2} \cdot \text{Time} + \beta_{\text{interaction\_Time\_Schengen}} \cdot \text{Schengen} + \beta_{\text{interaction\_Time\_Business}} \cdot \text{Business} \tag{9.6}$$

$$\frac{\partial U}{\partial \text{Saved}} = \beta_{\text{Saved}} + 2 \cdot \beta_{\text{Saved}^2} \cdot \text{Saved} \tag{9.7}$$

$$\frac{\partial U}{\partial \text{Cost}} = \beta_{\text{costs}} + 2 \cdot \beta_{\text{costs}^2} \cdot \text{Cost} + \beta_{\text{interaction\_Children\_costs}} \cdot \text{Children} + \beta_{\text{interaction\_Business\_costs}} \cdot \text{Business} \tag{9.8}$$

Integrating the obtained parameters from MNL model in these derived equations will generate the final equations for WTP calculations.

$$\text{WTP}_{\text{Time vs Costs}} = -\frac{-0.826 + 0.641 \cdot \text{Time} + 0.262 \cdot \text{Business} + 0.242 \cdot \text{Schengen}}{-0.308 + 0.048 \cdot \text{Cost} + 0.093 \cdot \text{Children} + 0.070 \cdot \text{Business}} \tag{9.9}$$

$$\text{WTP}_{\text{Saved vs Costs}} = -60 \cdot \frac{-0.027 + 0.001 \cdot \text{Saved}}{-0.308 + 0.048 \cdot \text{Cost} + 0.093 \cdot \text{Children} + 0.070 \cdot \text{Business}} \tag{9.10}$$

The WTP equations show that the WTP for a specific passenger scenario is a linear equation in which costs are the independent variable.

9.3. Passenger profiles Exploration

This section aims to create and explore passenger profiles which are likely to be travelling at Schiphol. First, passenger profiles are created based upon likely combinations of contexts. After creation of these passenger profiles, the likeliness to reserve a time slot and the willingness to pay are calculated for these passengers compositions. These variables form KPI's which can be compared among the scenarios.

As stated above, the first step is to create passenger profiles. Passenger profiles are based upon a combination of all context variables and the attribute ”Time”. Only the context variables and the Time attribute are used in the passenger profiles, because passengers can influence this by themself, while the attributes ”Costs” and ”Saved” cannot be influenced by passengers.

The first and second passenger profiles are focussed on business passengers. As these profiles represent a business trip in economy class, these business passengers are likely to have a short time between the security and departure of the flight. The first profile represents a short business trip within Schengen. This could, for instance, be a flight towards another office location of the company your working for. Therefore, you fly alone. The second profile represents a long business trip, for instance, a trip to the USA. Such a trip is often done together with other colleagues to be more efficient.

The third passenger profile represents a family holiday towards another continent. As explained in previous chapter, people travelling with children are expected to have more time between the security and the departure of their flight, as children could cause unforeseen events, which take time.

The forth passenger profile represents a group of adult friends going on a trip. Such a holiday is often a shorter trip, which is the reason why they are likely to travel within Schengen. This group arrives 2 hour before departure of the flight at the security.

Finally, someone who is going to make a world tour is represented. This person travels alone and outside of Schengen. As this person needs to go trough border control, 2 hours is planned between the security and the departure of the flight.

The passenger profiles are shown in table 9.1 below.

Table 9.1: Passenger Profiles

Composition Name	Purpose	Company	Area	Time
Short Business Trip	Business	Alone	Schengen	1 hour
Long Business Trip	Business	Adults	Non-Schengen	1 hour
Family Holiday	Non-Business	Children	Non-Schengen	3 hour
Friends Holiday	Non-Business	Adults	Schengen	2 hour
World Tour	Non-Business	Alone	Non-Schengen	2 hour

Now that the passenger compositions are created, the compositions can be explored. As elaborated in sections 9.1 and 9.2, the outcomes of the likeliness to make a reservation and the WTP for a timeslot depend on several factors, including the context variables and attribute integrated in the passenger composition, but also the attributes ”Costs” and ”Saved”. Therefore, scenarios are created and each passenger composition will be tested for these scenarios. Results can be interpret, by comparing passenger compositions over different scenarios. The formed scenarios are shown in table 9.2 below.

Table 9.2: Time Slot Scenarios

Scenario Name	Costs	Saved
Free time slot in quiet time in a regular week	€0.00	0 minutes
Free time slot in rush hour of a regular week	€0.00	15 minutes
Free time slot in busiest period of the year	€0.00	30 minutes
Trial for paid time slot in rush hour of a regular week	€2.50	15 minutes
Expensive time slot in busiest period of the year	€5.00	30 minutes

9.3.1. Exploration free time slots

First, three scenarios in which free time slots are offered to passengers are discussed. The first of these three scenarios includes a free time slot in a quiet period of the day. This scenario allows to interpret main effects of the passenger profiles, as both costs and saved waiting time are 0.

Table 9.3: Results free time slot in quiet period of a regular week

Passenger Composition Name	Booking %	WTP Time (€/hour)	WTP Saved (€/hour)
Short Business Trip	49.2%	-€1.34	€6.79
Long Business Trip	45.2%	-€0.32	€6.79
Family Holiday	22.1%	-€5.08	€7.50
Friends Holiday	36.3%	-€2.26	€5.25
World Tour	38.2%	-€1.47	€5.25

Interpretation booking percentages

First, it is striking that very high booking percentages are forecasted by the model, compared to the current reservation percentages at Schiphol. It seems like the model is overestimating booking behaviour of passengers. Therefore, the results of the model should not be used to forecast scenarios. Nevertheless, passenger behaviour can still be analysed by the model.

It is remarkable that business passengers are more likely to make a time slot reservation than non-business passengers. This is as expected, as business passengers have a short time between the security and the departure of their flight. The options for travel company cannot make an impact, as there are no differences found in the results of the MNL model in chapter 8. Therefore, the higher likeliness to make a reservation for a ”short business trip” compared to ”long business trip” is caused by the fact that the short business trip is inside Schengen area. As long as there is short time between the security and the departure, Schengen passengers are more likely to make a time slot reservation than non-Schengen passengers.

People who are going on a family holiday are the least likely to make a time slot reservation from the five passenger profiles. This can be explained by the long time between the security and the departure and the trip destination, which is non-Schengen.

It is interesting to compare a long business trip, a family holiday and a world tour with each other, as these passenger profiles all have trips in non-Schengen area. The difference between a family holiday and a world tour is larger (approximately 16%) compared to the difference between a world tour and a long business trip (approximately 7%). This difference is caused by the impact of the time attribute, as passengers really dislike to go trough security long before their flight departure (figure 8.3).

Finally, the small difference between ”friends holiday” booking percentages and a ”world tour” booking percentages is caused by the trip destination. However, this effect is the opposite from the effect describe for business passengers, as non-Schengen passengers are more likely to make a reservation. This is due to the fact that the time attribute is larger for these scenarios, which causes a change in effect for the Area context. When the time attribute is small (i.e. 1 hour), passengers within Schengen are more likely to make a time slot reservation. However, somewhere between 1 hour and 2 hours, this effects switches, as non-Schengen passengers become more likely to make a time slot reservation compared to Schengen passengers. This is caused by time sensitivity of Schengen passengers, while non-Schengen passengers are less sensitive for this time.

Interpretation WTP's

It is noticeable that the WTP for time is negative, while the WTP for saved is positive. This can be explained by the estimation that people would prefer to have less time between the security and their departure, which results in a negative WTP. This negative WTP basically means the amount of money you pay to have one our less time between the security and the departure of your flight. On the other hand, people prefer to save as much time as possible, which results in a positive WTP.

Furthermore, the WTP's of saved are relatively high. This can be explained by the fact that this scenario includes 0 saved minutes. Therefore, the model calculates that people are willing to pay quite some money to save more waiting time. People with children are willing to pay the most for waiting time saved, which is as expected. Next, business passengers are willing to pay more for saved waiting time, which is also expected, as they are less costs sensitive. The WTP for saved is the lowest for non-business passengers who travel alone of with adults.

The WTP's of time are all rather low, compared to the WTP's of saved. Especially the WTP's of business passengers is very low. This can be explained by the fact that they only have 1 hour planned between the security and their departure, which means that they are not likely to pay for even less time in-between. The WTP of business passengers within Schengen is higher than outside Schengen, which is logical. This can be explained by the result that Schengen passengers are more time sensitive, therefore, they might even be willing to pay for less than one hour in-between security and departure.

The reversed effect can be seen for world tour passengers, as they have almost similar as Schengen business passengers. World tour passengers arrive earlier at the airport, which causes more WTP, but travelling towards non-Schengen area lowers the wtp at the same time. As a results, the wtp for world tour passengers regarding time is relatively low.

The highest wtp for time can be found for family holiday passengers. This is as expected, as they have three hours between the security and the departure of their flight, which is a lot. Travelling with children create even more WTP for the less time.

Tables 9.4 and 9.5 can be used to see the impact of saved waiting time, for the scenario of a free time slot. These tables form the base for the comparison with paid time slots later in this section.

Table 9.4: Results free time slot in rush hour of a regular week

Passenger Composition Name	Booking %	WTP Time (€/hour)	WTP Saved (€/hour)
Short Business Trip	57.8%	-€1.34	€4.77
Long Business Trip	53.8%	-€0.32	€4.77
Family Holiday	28.6%	-€5.08	€5.26
Friends Holiday	44.6%	-€2.26	€3.68
World Tour	46.6%	-€1.47	€3.68

Table 9.5: Results free time slot in busiest period of the year

Passenger Composition Name	Booking %	WTP Time (€/hour)	WTP Saved (€/hour)
Short Business Trip	63.1%	-€1.34	€2.74
Long Business Trip	59.3%	-€0.32	€2.74
Family Holiday	33.4%	-€5.08	€3.03
Friends Holiday	50.2%	-€2.26	€2.12
World Tour	52.1%	-€1.47	€2.12

First of all, booking percentages rise due to higher saved waiting time, which is an expected outcome. However, the differences between 0 and 15 minutes saved seems to be larger than the differences between 15 and 30 minutes saved. This is as expected, as the graph of the attribute saved has a less steep curve, as the saved attribute increases. This analysis confirms that passengers react more to the first couple of minutes saved, regarding considerations for making a time slot reservations, but this effect reduces as more waiting time is already saved. For instance, people are reacting more to a shift in Schiphol estimation from 0 to 5 minutes saved waiting time than to a shift from 15 to 20 minutes saved.

In addition, the wtp of saved decreases, as more saved waiting time is estimated by Schiphol. This is in line with previous findings, as people are willing to pay more for 'the first' couple of minutes, while people are willing to pay less for more saved waiting time, when some waiting time is already estimated by Schiphol. The order within the different categories of passengers is also as expected, as non-business passengers without children have the lowest wtp, followed by business travellers and passengers with children have the highest wtp.

Finally, the wtp of time is not influenced by differentiations in saved waiting time, which is as expected.

9.3.2. Exploration trials for paid time slots

This time slot scenario can be used to research the impact of paid time slots on the selected KPI's. First, the scenario with €2,50 costs for a time slot is discussed, afterwards the scenario with €5.00 costs is explored.

Table 9.6: Results trial for paid time slot in rush hour of a regular week

Passenger Composition Name	Booking %	WTP Time (€/hour)	WTP Saved (€/hour)
Short Business Trip	46.7%	-€2.68	€9.93
Long Business Trip	42.7%	-€0.64	€9.53
Family Holiday	21.4%	-€11.30	€11.75
Friends Holiday	30.2%	-€3.68	€5.99
World Tour	31.9%	-€2.40	€5.99

Table 9.7: Results trial expensive time slots in busiest period of the year

Passenger Composition Name	Booking %	WTP Time (€/hour)	WTP Saved (€/hour)
Short Business Trip	48.5%	-€3.43	€9.13
Long Business Trip	44.5%	-€1.07	€9.13
Family Holiday	23.6%	-€22.32	€13.30
Friends Holiday	28.1%	-€9.43	€4.60
World Tour	29.7%	-€7.72	€4.60

Booking percentages As expected, booking percentages drop whenever costs for time slots are introduced. However, costs are not the only variable that influences likeliness to make a booking, as previously described variables still influence this KPI as well. Therefore, the influence of costs can be discussed by taking these previous findings into account, while looking at the results. This influence will be discussed by comparing table 9.6 with table 9.4 and table 9.7 with table 9.5. Afterwards, the comparison between table 9.6 and 9.7 can be made to find out how the effect of costs differentiates for different costs applied.

Looking at the difference between €0.00 and €2.50 show that introducing costs reduces the likeliness to make a reservation for all passengers, but specifically for ”friends holiday” and ”world tour” passenger profiles. This is as expected, as business travellers and passengers travelling with children are less sensitive to potential costs of time slots, which results in smaller differentiations due to implemented costs.

The results in the scenario of €5.00 for a time slot are as expected for ”friends holiday” and ”world tour” passenger profiles, as booking percentages drop further due to increased costs. However, for the other three passenger profiles, the likeliness for a booking rises, while costs are higher. This can be explained by an underlying mechanism. The interaction effects for business passengers and passengers with children create less sensitivity towards incasements of costs. Therefore, the difference between a implementation of €2.50 or €5.00 is smaller. It becomes even smaller than the positive effect of increased saved waiting time (30 instead of 15). Therefore, higher booking percentages are realised.

This effect is not applicable to ”friends holiday” and ”world tour” passenger profiles, as they have no interaction effects. Therefore, rising costs has a larger negative influence than the positive influence of saved waiting time.

Concluding, introducing costs into the time slot system heavily impact the likeliness to make a reservation for non-business passengers who do not travel with children. For business passengers or passengers who travel with children, this effect is smaller, but still present. The impact from a differentiation from free time slots towards a cheap trial of time slots (€2.50) is larger than the impact of an increasement of costs in the future (€2.50 towards €5.00).

Interpretation WTP's

In previously discussed scenarios, no costs were applied for time slot reservations, which resulted in constant WTP for Time. Within the trials for paid time slots, deviations in WTP for Time can be seen, due to the implementation of costs. As a result of costs, passengers have a higher WTP for the Time attribute. This effect is as expected, as people pay for a time slot, which means that their WTP for the attributes of that time slot increase, as the time slot is formed by the attributes.

The results for WTP Saved have similar effects, but slightly more complex as the number of saved minutes play a role as well. As discussed before, a higher number of saved minutes leads to a lower WTP for Saved, while higher costs increases WTP. It can be seen that this effect of costs is especially true for Family Holiday passengers and business travellers. The effect of costs on wtp are particularly visible at the wtp of Family Holiday passengers for Saved, as more minutes saved should result in a lower wtp. However, the wtp for Saved is higher in the scenario of an expensive trial (compared to the cheaper trial), due to increased costs. this implies that the effect of costs on wtp is stronger than the effect of saved minutes. Concluding, business travellers and family holiday travellers have the highest wtp, while other non-business passengers have relatively lower wpt's.

Concluding, this section shows that passenger profiles heavily impact the likeliness that a passenger would make a time slot reservation. Or, in other words, it cannot be concluded that there is an order of importance between attributes, as this depends on the levels applied for a specific passenger profile. Therefore, the passenger profiles should not be seen as representative passenger profiles, as there is a lot of diversity within passenger profiles. For instance, some business travellers prefer to go early to the airport, as this enables them to finish some work before catching their flight. Therefore, the passenger profiles only represent a specific combination of attributes, which means that the differences in attribute impact should be seen as main conclusions. Main insights are:

- Passengers prefer to have less than 100 minutes (see appendix F for reasoning) between the security and their departure, more time would decrease their utility and eventually even cause negative utility.
- Passengers are more impacted by the introduction of costs (free time slot towards paid one), than by costs increasements later on.
- Passengers gain more utility when their estimated number of saved waiting time minutes is risen from 0 to 5, compared to 15 to 20.
- No difference between passengers who travel alone and passengers who travel in groups of adults
- Business passengers and passengers with children are less sensitive to costs
- Passengers travelling with Schengen prefer shorter time between the security and their departure, compared to passengers travelling to non-Schengen areas.
- The wtp of Time is highly impacted by the value of the Time attribute. Shorter Time values cause lower wtp, as less room for improvement is available and passengers are already satisfied with their time slot (and vice versa)
- The wtp of saved is also impacted by the value of the attribute Saved, the same way as it does with Time
- WTP's rise when costs are introduced.

10
Simulation Model Results

This chapter shows the results of the simulation model. By interpreting the results, RQ5 can be answered.

10.1. Overview Results

This section presents and interprets the results of the scenarios within the simulation model. As discussed before, two main KPI's will be interpret: maximum waiting time of passengers (minutes), occupancy rate of security lanes (%).

The overview of the results can be found on the next page.

Interpretation:

As more passengers use time slots, the number of people using the regular security lanes goes down. This effect the occupancy rate of non-time slot security lanes, as these occupancy rates go down. This makes sense because with fewer people in the standard queue, those lanes will have lower occupancy.

Interestingly, passengers with time slot reservations still face relatively long wait times, even though their dedicated lanes have fewer people compared to the regular lanes. This is surprising because it was expected that fewer people would cause shorter waiting time. It implies that there might be some issues causing delays in the time slot lanes.

Overall, the type of security lane used doesn't seem to have a big effect on waiting times, which are mostly influenced by busy periods. This is logical since delays usually happen when there are a lot of passengers, no matter how they are spread out across the lanes.

When only 10% of passengers had time slot reservations, there weren't enough security lanes available, resulting in wait times of at least 15 minutes during the tests. This shows that even a small number of time slot users requires enough dedicated lanes to avoid long waits.

Adding more security lanes can help to reduce waiting times, but the benefit decreases as the overall wait times get shorter. This means that opening an extra lane is most effective when waits are already long, making it a better solution during busy times rather than when things are less crowded.

To make the time slot lanes work better, it might be a good idea to allow other types of passengers to use those lanes too. This could help fill up the time slot lanes more effectively, improving their efficiency and reducing any delays.

Table 10.1: Results Discrete Event Simulation

KPI	Sc 1	Sc 2	Sc 3	Sc 4	Sc 5	Sc 6	Sc 7	Sc 8	Sc 9	Sc 10	Sc 11
Max waiting time No Time slot (minutes)	14.9	17.8	25.1	8.3	11.5	16.6	7	10.3	10.1	8.1	15.1
Max waiting time Time slot (minutes)	0	0	10.1	4.7	18.4	17.4	8	16.7	22	11.3	12.1
No Lane 1	76.0%	76.4%	77.8%	70.5%	70.8%	71.9%	66.9%	67.7%	72.1%	64.3%	68.9%
No Lane 2	72.3%	73.0%	75.2%	64.5%	64.9%	66.5%	58.8%	59.8%	66.5%	55.3%	62.5%
No Lane 3	67.9%	68.7%	71.0%	59.0%	59.6%	61.4%	52.4%	53.9%	X	48.1%	X
No Lane 4	78.3%	79.9%	83.1%	69.2%	69.9%	72.7%	59.9%	62.6%	74.1%	55.6%	70.6%
No Lane 5	73.7%	75.2%	79.4%	66.0%	67.0%	70.3%	55.8%	59.1%	69.9%	51.8%	66.4%
No Lane 6	70.4%	72.1%	76.8%	62.8%	64.3%	67.7%	54.7%	57.9%	65.7%	51.0%	64.6%
No Lane 7	70.5%	74.0%	81.0%	62.9%	65.8%	72.5%	54.4%	60.7%	65.3%	56.4%	71.7%
No Lane 8	68.8%	72.7%	79.4%	61.3%	64.0%	71.0%	52.2%	58.3%	62.9%	X	X
No Lane 9	61.4%	66.4%	X	52.8%	56.1%	X	46.1%	X	55.0%	X	X
No Lane 10	65.2%	X	X	53.5%	X	X	X	X	X	X	X
Yes Lane 1	33.3%	35.0%	50.7%	50.8%	57.3%	57.2%	57.2%	62.7%	67.6%	63.4%	65.1%
Yes Lane 2	15.2%	17.1%	X	37.9%	48.4%	48.2%	46.3%	55.8%	63.2%	54.5%	56.7%
Yes Lane 3	11.0%	X	X	33.9%	X	X	43.8%	43.0%	60.3%	42.5%	49.6%
Yes Lane 4	X	X	X	X	X	X	X	42.7%	X	41.4	49.6%
Yes Lane 5	X	X	X	X	X	X	37.4%	X	X	43.9%	47.7%
Yes Lane 6	X	X	X	X	X	X	X	X	X	32.5%	X

Table 10.2: Results peak shaving effects

	Experiment 1	Experiment 2	Experiment 3	Experiment 4
Max waiting time No Time slot	24.0	15.2	7.69	9.8
Max waiting time Time slot	8.1	11.3	15.0	9.0
No Time slot Lane 1	77.7	71.7	67.7	68.9
No Time Slot Lane 2	74.6	66.1	59.5	62.1
No Time slot Lane 3	70.9	61.3	53.6	X
No Time slot Lane 4	82.2	72.2	61.6	69.6
No Time slot Lane 5	79.3	70.3	59.3	66.2
No Time slot Lane 6	76.9	68.3	58.1	65.0
No Time slot Lane 7	78.4	68.5	56.1	67.5
No Time slot Lane 8	81.2	70.6	56.3	X
No Time slot Lane 9	X	X	X	X
No Time slot Lane 10	X	X	X	X
Time Slot Lane 1	50.5	56.9	67.0	64.2
Time Slot Lane 2	X	47.8	62.1	56.1
Time Slot Lane 3	X	X	59.8	48.6
Time Slot Lane 4	X	X	X	48.2
Time Slot Lane 5	X	X	X	46.7
Time Slot Lane 6	X	X	X	X

It is noticeable that peak shaving lowers the maximum waiting times of passengers. Therefore, the results of the simulation indicate that peak shaving is an effective tool to prevent long waiting times.

The occupancy rates during these experiments were higher than in situations without peak shaving. This makes sense because peak shaving helps to spread out passenger arrivals more evenly, which leads to a better use of the available security lanes and minimizes extreme changes in occupancy.

11 Discussion

This chapter focuses on the discussion of the final research results. It starts with a summary of the main findings, along with a reflection that connects these results to the current literature (if possible). Whenever it is not possible to connect literature to the findings, logical reasoning will be used to reflect upon the results. Next, it addresses the limitations of the research and highlights the scientific contributions made by this study. The chapter ends with suggestions for future research and concludes by discussing the practical implications of the findings.

11.1. Reflection upon Key Findings

This section is split into three parts, as three different methods were used in the study. Each part includes the most important findings, interpreted in previous chapters. the first part discusses the results of the factor analysis, which can be seen as general impressions of security time slots. The second part captures stated preference results, which can be seen as detailed time slot preferences. The third part includes the simulation results, which can be seen as the scenario exploration.

General Impressions of Time Slots Findings:

One of the key findings of the factor analysis is the difference in attitude towards time slots between people who made a reservation and people who did not make a reservation. This outcome is in line with earlier research (Wu 2018). This study revealed that when customers enjoy using its online booking system, their satisfaction and likelihood of using that system again for future reservations go up a lot. This indicates that interacting with reservation systems boosts customer satisfaction and improves how they see the service.

Another key finding is focussed on the trade-off between flexibility during airport processes and certainty to catch a flight. Passengers without a reservation indicate that they dislike the fact that time slots are not very flexible, which forces them to be on time. This trade-off is something which is a common problem within supply chains (Prater et al. 2024). This research discussed that increased flexibility can enhance responsiveness of transportation system, but it may also introduce complexity, thus lowering certainty. This is aligned with the outcomes of this research, as more flexility would decrease the effectiveness of time slots, which decreases the certainty to get to your flight. On the other hand, the system which is currently applied by Schiphol offers certainty with the downside that it is less flexible.

Another key finding is the large difference in the attitude towards the influence of time slots on stress levels. Passengers with reservations have the feeling that the system helps to lower their stress level, as it offers a clear structure and predictability during their airport experience. However, those without reservations are less likely to see this advantage, possibly because these passengers are unfamiliar with the potential of the time slot system or do not have confidence in how well time slots work. However, the time slot effect on stress levels might be nuanced a bit. Figure 3.2 shows stress levels of passengers during their departure process. It can be seen that their stress level peaks during the security process. This stress is caused by several factors, such as general stress for the security check, stress to be at the correct queue, stress to be on time etc. Time slots might lower stress levels, as it gives passengers certainty to catch their flight. However, it is likely that this stress does not suddenly disappears, rather it is moved towards an earlier airport process, as people need to be on time for their time slot. Therefore, passengers might experience stress during luggage drop-off or during ticket check-in, as they need to be on time for their time slot, whereas they would not have had this stress at these stages of the departure process if they had no time slot reservation. Therefore, time slots are more likely to spread stress levels of passengers over more stages of the departure process, rather than to remove stress.

Finally, another interesting finding is the effect of awareness on the attitude towards time slots. People who are not aware of time slots seems to have a more negative attitude towards time slots than people who are aware. This finding aligns with previously done research (Rillotta & Neckelbeck 2007). According to this research, awareness can effectively reduce negative perceptions, as long as comprehensive information is being offered. Therefore, it is important for Schiphol to communicate clearly about time slots, so that potential misunderstandings are solved.

Detailed Time Slot Preferences Findings:

Passengers find the time between arrival at the security checkpoint and their flight's departure very important for their decision whether to book a time slot. This research finds that passengers have optimal valuation as long as this time is smaller than 100 minutes. From 100 minutes onwards, passengers start to receive less added value with a time slot reservation. This effect becomes stronger as more time is between the security and the departure of the flight. This is as expected, as people have broad preferences regarding this time, but do agree that too much time is not desired. Therefore, the effect of time starts neutral and decreases after 100 minutes. There is limited research done to the preferred time between the security and departure of the flight. However, it is known that passengers have various activities such as eating, shopping, or working after passing through security. This does effect the preferred time. This might explain why there is no difference between passenger profiles regarding preferred time (interaction effect between context and Time), as it depends more on individual preferences rather than contexts.

Another finding is the attitude towards Costs, which implies that passengers increasingly dislike time slots as costs rise, which is an expected outcome of the research. As can be seen in figure 8.1, the costs equation is not linear, but forms the beginning of a valley parabola. This implies that people become less sensitive to raising costs, than to shifting from a free product towards a paid one. This phenomenon could be caused by the zero price effect, which states that consumers often show a much stronger liking for products or services that are free rather than those that are just low-priced. This phenomenon indicates that people tend to value free items way more than what typical cost-benefit analyses would suggest. As a result, a non-linear relationship is formed between price and how sensitive consumers are to costs (Shampanier et al. 2007). Thus, it can be stated that people dislike the introduction of costs for time slots.

More or less the same effect as seen for costs, is also seen for the waiting time saved by using a time slot, as people additional satisfaction (utility) gained from an additional unit decreases as passengers receive more of it. This principle is called diminishing marginal utility (Mackie et al. 2024). This effect can be found often in transports studies, for instance in travel time savings. Obviously, saved waiting time is comparable to travel time savings.

Comparing the three attributes with each other, shows that passengers are more sensitive to differentiations in Time and Costs, rather than differences in Saved. This does not mean that the attribute of saved is less important, as importance of attributes depends on the selected value. However, the fact that passengers are less sensitive to saved waiting time is aligned with the finding that more than half of the passengers wants to save at least 20 minutes of waiting time with a time slot for it to be worth making a reservation (keeping other attributes out of the consideration). 20 minutes of saved waiting time is a lot and will probably not often occur. This finding implies that saved waiting time does not weigh heavily in the consideration of time slots for many people, which confirms the finding of less sensitivity towards additional minutes waiting time saved.

Regarding contexts, business travellers and passengers with children are less sensitive to potential costs of time slots. This effect is as expected for business travellers, as the shared-costs effect is applicable to them: business travellers are less price-sensitive because their companies usually cover the expenses (McGuire 2018). The effect of passengers with children is less obvious, but does also align with previous research results. Previous studies imply that families with children prioritize service quality and are willing to pay premium prices to ensure a comfortable and convenient travel experience (Yas et al. 2019).

This research also includes a finding which states that Schengen passengers are more likely to make a time slot reservation when the time between the security and their departure is less than 100 minutes. Whenever this time is longer than 100 minutes, non-Schengen passengers are more likely to make a time slot reservation than Schengen passengers. This results is difficult to reflect upon in research, as this time is barely researched. However, more general research to arrival times is done between Schengen and non-Schengen passengers. Outcomes of such a research show that passengers for non-Schengen flights often arrive earlier at the airport than passengers for Schengen flights (Buire et al. 2021). This could explain why Schengen passengers prefer to have less time between the security and the departure of their flight.

Scenario Exploration Findings:
An important finding of this analysis is the outcome that more used security lanes does lower maximum waiting time of passengers, but this effect becomes less strong as waiting times reduce in the queue. Previously done research aligns with this outcome, as this research suggests that while increasing the number of open lanes can reduce passenger wait times, the benefits are more visible during peak periods with high passenger volumes. During off-peak times, opening additional lanes may lead to underutilization of resources without significant improvements in wait times (Chitty et al. 2016).

Another finding shows that dedicated security lanes for time slot passengers is very inefficient as long as the number of time slot passengers is slim. This outcome is comparable to the outcome of another research, which states that dedicated security lanes are most effective when there is a substantial and consistent volume of specific passengers. Otherwise, a dedicated security lane might result in inefficiencies (Janssen et al. 2020).

11.2. Limitations of the Research

The Multinomial Logit (MNL) model has been helpful in understanding how passengers make choices, but there are some important limitations of the method.

A drawback of the MNL model is how it handles the understanding of parameters. The model didn't really dive into how the attributes interact with each other, while these factors often affect each other in real life. The combined effect of these factors on what passengers decide could be really important, and by overlooking these interactions, the model might not explain things as well as its potential. An example of a possible interaction effect between attributes could be the interaction effect between Time and Saved, as people might be less sensitive to the number of saved minutes, as more time is between the security and the departure of their flight (or vice versa). In addition, not all the real-world elements that have impact on passengers' choices were considered in the analysis. This gap limits the model's ability to accurately reflect how passengers behave (Wulff 2015). However, it is not possible to include all factors in the model, which play a role in real life, as this might cause dozens of factors to be integrated in the model.

This MNL model includes context variables, which give information about behaviour of groups, but there can still be differences among passengers even in the same context. This is caused by the fact that contexts are revealed (specifically distributed), instead of random. For instance the context of travelling with children: this context could contain people with a lot of experience with flying, maybe even business related frequent flyers. On the other hand, this context could also contain people who have never flown before. The difference between these type of passengers could result in different attitudes towards time slots, which is currently not captured in the model.

Another limitation of the MNL model lies in the fact that it is a snapshot for the current attitude towards time slots. Security time slots are still a relatively new phenomenon in the aviation industry, especially the implementation of the system of Schiphol. However, as also discussed in the results of the factor analysis, awareness of time slots influences the attitude of people regarding time slots. Therefore, results of this research might not be robust on the long term, whenever passengers are more aware of time slots in the future. This effect is regardless of the context of passengers, so could be true for any of the contexts used in this research.

The survey sample in this study was large and divers, but it might not cover all types of passengers, especially those who travel infrequently and elderly. These passengers might behave differently than other passengers and their impact in this research was small. Because of this, the results may not be suitable to apply to all potential passengers. More research is necessary to gain insights into the preferences of various travel groups and to enhance how well the model fits different populations (Wulff 2015).

Finally a limitation of this research is that people only had the option to choose between 2 time slots, where in reality, passengers have the option to choose between more than 2 possible time slots. Therefore, it gets easier for passengers to select a time slot that they prefer.

Besides the limitations of the MNL model there are also limitations with the factor analysis that was executed. Factor analysis helps to find connections between different variables, but it doesn't prove that one causes the other. In other words, it can't clarify why specific factors come up (VanderWeele and Batty 2022). This effect can be seen in the factors created during the process of creating the final factor composition, as some variables switched during the steps towards another factor (based upon the new characteristics of that specific factor).

In addition, some variables might load onto multiple factors, making it difficult to assign them to a single factor (Beauducel and Hilger 2023). This issue arrised mostly because of the decision that the sum-score (average score) was used to interpret the results. Whenever the factorscore was calculated, this issue would have been solved (but other issues would be present, such as the fact that lower scoring variables are also included).

Finally, limitations of the discrete event simulation method are discussed. First, simulation outcomes heavily depend on assumptions about probability distributions, queueing behavior, and operational rules. Small changes in these assumptions can have impact on the results.

In addition, as the model is made by one modeller, modeller's bias could play a role. Modeller's bias refers to the influence of a modeller's subjective choices and assumptions on the outcomes of a simulation or model, potentially leading to results that reflect personal biases rather than objective reality (Albanito et al. 2022). Despite using the real world security filter as an example, modeller's bias can lead to results that favor a particular outcome or fail to capture important real-world complexities.

11.3. Contribution to the Research Field

This research plays an important role in transportation studies, airport management, and behavioral decision-making by combining factor analysis, stated preference analysis, and discrete event simulation to evaluate how effective a security time slot reservation system is at Schiphol Airport.

From a behavioral perspective, the factor analysis obtains drivers behind passengers' preferences, giving a clearer picture of general attitudes and motivations. The stated preference analysis focus on the passengers decision in more detail, researching the main factors that affect their willingness to use time slot reservations.

Regarding airport management, discrete event simulation provides a way to assess how different ratios of passengers with and without a time slot reservation impact the efficiency of security checkpoints. By exploring multiple scenarios, this study connects theoretical passenger preferences with potential system performances.

This interdisciplinary combination of methods adds to existing research by showing how merging behavioral and operational modeling techniques can yield more indebt policy insights. While earlier studies typically concentrated on either passenger choice modeling or simulation-based operational enhancements, this research stands out by integrating both elements, creating a broad analysis for improving airport securities.

In the end, this study aims to enhance airport operations, improve passenger experiences, and refine queue management strategies. By doing so, this research provides a base for other airports (or other transportation fields) which are considering to implement similar reservation-based queuing systems.

11.4. Unanswered Questions and Future Research

Despite the broad variety of results from this research, there are still some un-answered questions.

First, a replication of this study could be done with a larger dataset, so that every context and demographic group contains sufficient respondents. This research has provided the methodology to prepare research data for future research

Furthermore, it is interesting to explore the potential of this research a little bit further. The factor analysis gave a first impression of potential differences between groups, but this could be further analysed by executing a Latent Class Choice model (LCCM) analysis. This is especially interesting whenever a larger and more complete dataset is gathered for future research. The LCCM analysis is able to analyze the preferences of different groups. This way, it becomes more clear to Schiphol how different type of passengers react to the time slot tool. This is especially interesting to get more detailed information about differences within contexts, as previously described in the limitations section.

Another important area to explore further is how passengers' preferences for time slots change in the upcomming years. As explained before, awareness of time slots does have influence on the attitude of passengers. It would be interesting to see how these preferences develop as passengers get more used to the system. At first, passengers might have a wide variety of preferences while they learn about time slots and how the system works. But eventually, passengers' preferences could stabilise or change based on their experiences and familiarity. Understanding these stabilising effects could be really important for improving systems efficiency and attractiveness.

Another interesting issue is to expand the time slot system in another stated preference analysis to research which additions to the time slot tool are desired. It is, for instance, possible to combine luggage check-in as an attribute to this stated preference analysis. As explained in the survey construction chapter, luggage check-in was left out of the stated preference analysis to research factors that are already part of the system or factors that could easily be implemented. However, passengers indicated that they would prefer to have luggage check-in included. This integration could lead to logistical challenges, such as timing issues, compatibility problems between operating systems, and the risk of delays or congestion. In addition, a proper stakeholder analysis is important, as all airlines should (in an optimal scenario) be integrated in the time slot tool. Therefore, researching this integration in more detail is essential for a smooth and efficient implementation. Other extensions of the model could include missing interaction effects (for instance between attributes, as explained in the limitations), incorporating demographic variables in the MNL model and adding more variables to the research to improve completeness. Potential interesting variables could be: arrival time at the airport, length of trip (more detailed than Schengen vs non-Schengen) and estimated walking time between the security checkpoint and the gate.

Finally, this research is focussed on the security system of Schiphol, but it is also interesting to research the impact of another airport on the security time slot system. Different passenger demographics, infrastructure, or regulatory frameworks might lead to other outcomes of the study, or could confirm outcomes obtained from this research.

11.5. Implications of the Results

With the increasing demand for flights, airports will have to come up with effective strategies to handle capacity challenges. This means that long security queues are probably going to be a remaining issue in the near future, particularly during peak periods.

This research not only looked into passengers' perceptions regarding security time slots but also aimed to help Schiphol tackle queuing issues. By offering data-driven insights, the study seeks to improve decision-making for better management of capacity shortages and flow management. The findings are designed to have real-world applications and are organized into strategic, tactical, and operational levels, which match the decision-making processes at Schiphol.

11.5.1. Strategic Research Implications

The strategic decision-making level represents the long-term vision and policies that impact the whole organization at Schiphol. This level is carried out by the managements of all departments within Schiphol.

Improve Awareness: This study shows that awareness has an effect on the attitude towards time slots, which ultimately leads to an impact on the number of time slot reservations. Therefore, it could be interesting for Schiphol to commit employees from the department of commercial to improve the awareness of time slots.

This can be done in multiple ways. One way is to directly advert towards potential passengers with general advertisements. Another (and maybe more effective) way is to aim for collaborative work with airlines, so that time slots can be reserved in the process of ticket purchases. For instance, time slots could be added to the list of potential additions to the flight tickets, such as an extra suitcase or more legroom. This way, more passengers are likely to be aware of time slots. In addition, this could decrease the effort it takes for passengers to make a time slot reservation, as this is also an issue for non-reserving passengers.

Offering Tailor-made Time Slots: Peak shaving is applied by relocating passengers to earlier or later time slots. The study shows that passengers really care about the time between the security and the departure, but also shows differences among passenger profiles regarding these preferences. Therefore, the peak shaving algorithm could be improved by implementing tailor-made time slot recommendations to passengers. This way, peak shaving effects could be improved, while passengers are more likely to get their desired time slot.

Avoid Time Slot Pricing: This study shows that all passengers are affected by the introduction of costs for time slot reservations. Especially the difference in benefit between free time slots and some form of payment is large. Currently, one of the main goals for the time slot tool is to increase the use rate. Therefore, it is not desired to implement costs for reservations.

Implementation of Time Slots to other Systems: Time slots could be beneficial to other systems at the airport, other than just the departure process. This research shows that people appreciate time slots (whenever they made a reservation), so it could be interesting to expand the deployment of the system.

It could, for instance, be interesting to implement time slots for non-Schengen transfer passengers, as they need to go trough border control before being able to catch their next flight. Another possibility for time slots lies in the luggage reclaim area of the airport. Sometimes, system errors cause major disruptions of the baggage system. Schiphol could, during long and heavy errors, send people home and asks them to pick-up their luggage on another moment. This could cause major queues in time periods that people are able to claim their luggage. Therefore, time slots could be useful for this system as well to be able to manage these passenger flows more efficiently.

11.5.2. Tactical Research Implications

The tactical decision-making level involves reviewing things monthly and is more focused on individual wards within departments.

Reduce flexibility issue: For passengers who are not making a time slot reservation, the flexibility of time slots is an important issue, as passengers are restricted to go trough security at a specific time. This inflexible system can lead to stress, especially if there are delays earlier in the airport process or even before getting to the airport, which could make them miss their time slot.

As mentioned in an earlier implication, by including luggage check-in in the time slot system, a major stress issue could be solved, as luggage check-in could cause delays. Additionally, other things might be considered as well, for instance, Schiphol could consider to expand the buffer of the time slot, so that it becomes easier to be on time.

Predictability of Waiting Time: Passengers would appreciate information regarding waiting time in the security queue. This study shows that passengers care about saving time. In addition, passengers imply that they care less about waiting, when it was expected to have waiting time. This kind of predictability could lead to more trust in the system, making more travellers want to use it. Therefore, it is important to communicate this feature of time slots to passengers.

11.5.3. Operational Research Implications

The operational decision-making level involves the daily process of deciding the amount of time slots open for a given time and the process of solving occurring errors in the reservation system. These decision are made by the product owner of the time slot ward (Greenwave) at Schiphol, while being supported by other team members.

Improve data gathering of time slots: Currently, the data available of used time slots at Schiphol includes bias. As explained before, the QR-code of time slots should be scanned at the entry of the security checkpoint. Data shows that majority of the reserved time slots is not scanned right now. Due to this missing data, it becomes more difficult to estimate the use rate of time slots.

A solution could be to place automated gates at the entry of the time slot waiting line. This way, all time slot passengers that actually use time slots will be scanned, as human error is not an issue any more. This way, data is more reliable and can be used to find out how many passengers actually lose their time slots (and how many no-shows are part of the system). This information can be used in the future to make further improvements.

Set a benchmark for creating dedicated time slot waiting lines: As discussed previously, the percentage of passengers with a time slot fluctuates over time. Especially during peak periods of Schiphol, more time slots are being used. As described in chapter 2, time slots passengers are currently mixed with priority class passengers. Schiphol could consider to apply a benchmark for the percentage of passengers with a time slot. Whenever this benchmark is being crossed, a dedicated time slot waiting line could be created.

It is important to create a dedicated queue for time slot passengers, whenever the percentage of time slot passengers is large enough, to guarantee user experience for priority class passengers. Otherwise, priority class passengers would be negatively influence due to the fact that more time slot passengers enter the system.

12 Conclusion

This study investigated how passengers value time slots for the security checkpoint at Schiphol. The main goal of this thesis is as follows:

"The goal of this research is to investigate passengers' preferences of a security time slot reservation system at Schiphol Airport. Additionally, the study aims to identify efficient security lane strategies for different ratios of passengers with/without a time slot to ensure system effectiveness in the future."

This goal has been achieved by applying three types of research dimensions. The first two dimensions, general impressions and detailed preferences, have been conducted by spreading and analysing a survey among passengers at Schiphol. Additionally, a scenario exploration is executed via discrete event simulation.

General impressions of security time slots

The most important differences between passengers can be found between passengers with/without a time slot reservation. Passengers with a reservation focus more on positive factors and less on negative ones, while passengers without a reservation experience less benefits and more downfalls of time slots. These passengers did not make a reservation, because negative aspects of time slots were too important for them. The most important differences between passengers with/without a time slot are:

- Flexibility in airport processes. Time slots ensures passengers to be at the security checkpoint at a specific time. As a result, potential delays in previous steps of airport processes (luggage check-in, trip to the airport etc.) could cause missed time slots (which results in missed flights). Especially passengers without a time slot reservation dislike the inflexibility features of the time slot tool.
- Impact on stress levels. Passengers with a reservation experience lower stress levels due to time slots, as time slots give them certainty to catch their flight (as long as they are on time). People without a reservation do not experience lower stress levels due to time slots.
- Effort for a reservation. People without a reservation find it too much effort to make a reservations. This (in combination with other negative factors) demotivate these passengers to make a reservation, as benefits are dominated by downfalls.

Passengers would find it beneficial to include luggage check-in in time slots. Included luggage check-in reduces the impact of the inflexibility aspect of time slots, as luggage check-in is an uncertain step in the airport process for passengers. Therefore, including luggage check-in would solve these uncertainties, which makes it less challenging to be on-time for your time slot.

Finally, awareness of time slots lowers the negative factors of time slots. Thus, more information lowers uncertainties regarding time slots, which results in less negative attitudes. Postive factors are barely influenced by more awareness, but lowering the negative factors due to more awareness could still result in more time slot reservations. Currently, less than 50% of all passengers (transfer passengers excluded) were aware of time slots at Schiphol. Therefore, more potential is yet to be captured.

Detailed Time Slot Preferences

From this research can be concluded that passengers likeliness to make a time slot reservation depends not only on time slot factors, but also on passenger profiles. Main effects of time slot factors are:

- Passengers have more sensitivity towards the variables of "Time between security and departure of flights" and "Costs of time slot" than to "saved minutes of waiting time", which means that they react more on differentiations for these variables. This aligns with the result that more than half of the passengers wants to save at least 20 minutes of waiting time with a time slot for it to be worth making a reservation, which is a relatively high value compared to waiting times throughout majority of days at Schiphol.
- People gain most benefits regarding the time between the security and the departure, as long as it is shorter than 100 minutes. Whenever this time is longer than 100 minutes, benefits of time slots reduce and eventually (after time > 2.5 hours) become even disadvantages.
- Passengers react more to an introduction of costs (instead of a free time slot) than to future price differentiations, whenever costs are already introduced.
- Passengers are reacting more to a shift in Schiphol estimation from 0 to 5 minutes saved waiting time than to, for example, a shift from 15 to 20 minutes saved.

Main effects of passenger profiles are:

- No difference between passengers who travel alone or passengers who travel in a group of adults.
- Business passengers and passengers with children are less sensitive to costs.
- There is no differentiation between passenger profiles regarding how much time they prefer to have between the security and their flight. However, it is expected that passengers within contexts have different attitudes towards this time, as the utility is equal between 60 minutes and 100 minutes.
- Schengen passengers are more likely to make a reservation with Time < 100 minutes, otherwise non-Schengen passengers are more likely to make a reservation.
- WTP's for time slots must be split into WTP-Time and WTP-waiting-time-saved. Both WTP-Time and WTP-saved are linear equations, in which the wtp variable is the independent factor. The more beneficial the value for the independent factor is (perspective of passengers), the lower the WTP becomes, as less opportunities for improvements are possible and passengers become satisfied with their time slot option. introducing costs results in higher WTP.

Scenario Explorations

It can be concluded that the findings on the scenario exploration can be used as a starting point for future policies regarding security checkpoint arrangements. These findings are:

- More used security lanes does lower maximum waiting times of passengers. However, this effect becomes smaller as the waiting time reduces. Thus, opening a lane has more impact when there are high waiting times.
- It is highly inefficient to apply dedicated security lanes for time slot passengers. Therefore, It might be useful to search for a combination with other types of passengers for the security lanes with a time slot, in order to increase the average occupancies of security lanes.
- Peak shaving is an effective tool to lower maximum waiting time, while keeping occupancy rates high. The tool becomes more effective as more time slots are being reserved.

Concluding Remarks

This research provides a better understanding of passengers' perceptions regarding security time slots. By identifying and quantifying benefits and downfalls of time slots, the findings can be used by Schiphol to improve the use rate of security time slots. This research provided practical insights and recommendations that could help Schiphol in their decision-making process regarding security time slots.

Currently, a major challenge for both passengers and airports is the unpredictability and inefficiency of security checkpoint queues. This research advances airport optimization systems by offering new insights into passengers' perceptions of time slots and security checkpoint strategies. These insights can help enhance societal benefits at airports by reducing passenger stress levels.

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A

Literature Review Attributes

A.1. Attribute Selection

As stated before, few research has been done to the usage of time slots within airport systems. As a result, it is not possible to select attributes that have been used in other research to time slots at the airport. Therefore, a second literature review is conducted to take inspiration for relevant attributes. This literature focuses on other stated preference researches with relatable environments. This inspiration is combined with information from Schiphol airport in order to select the attributes for this research.

The research of Thorhauge, Cherchi, and Rich 2016 explores the relationship between scheduling flexibility and departure time choices for commuters. The study investigates how constraints on daily activities, including work schedules and other out-of-home activities, influence willingness to shift departure times and willingness to pay (WTP) for reductions in travel time and delays.

The researchers conducted a stated preference experiment among workers commuting to Copenhagen's city center during peak hours. The experiment evaluated preferences based on key attributes: travel time, travel cost, scheduling delays for early and late arrivals, and penalties for lateness. The flexibility of work schedules was analyzed through two operational measures: fixed versus flexible working hours and constraints on late arrival at work.

Findings revealed that individuals with flexible working hours do not necessarily lack constraints on late arrivals, indicating that the two measures capture distinct aspects of flexibility. Those with no work constraints showed higher sensitivity to constraints on other daily activities, such as leisure or errands, especially when these activities were spatially or socially constrained.

The study also highlights the implications for transport policies. For instance, models that overlook constraints from non-work activities tend to overestimate the shift in departure times caused by interventions like toll pricing. By integrating constraints on daily activities into models, the research provides a more accurate understanding of commuter behavior, emphasizing the need for nuanced approaches in transport demand forecasting and policy design.

The research of Kalakou and Moura 2021 investigates passenger behavior in airport terminals, focusing on their choices between aeronautical and non-aeronautical activities. Using Lisbon Humberto Delgado Airport as a case study, the research applies discrete choice modeling to understand the factors influencing passenger preferences for activity locations before and after the security checkpoint.

The study highlights the evolution of airport environments, where non-aeronautical activities, such as dining, retail, and leisure services, have significantly diversified. These activities are crucial for enhancing passenger experience and generating revenue, which, as of 2018, accounted for approximately 40% of global airport revenues. The analysis explores how passenger demographics, psychological factors, and trip characteristics influence decisions regarding where and whether to engage in such activities within the terminal.

A passenger survey conducted at Lisbon Airport gathered data on time management, personal details, flight information, and activities performed in different terminal areas. Results showed that passengers with pre-planned activities, online check-ins, or who traveled alone preferred engaging in non-aeronautical activities after passing security. Conversely, tourists and group travelers favored performing activities in both pre- and post-security areas, while younger passengers and those seeking simpler experiences often avoided these activities altogether.

Discrete choice models revealed significant impacts of factors like trip purpose, arrival time, and check-in methods on passenger preferences. The study also modeled potential shifts in behavior under scenarios such as increased online check-ins or widespread pre-planning of activities, predicting a rise in post-security activity engagement under these conditions.

The findings provide insights for airport managers to optimize terminal layouts, improve passenger flow, and enhance revenue generation. By understanding activity preferences and their drivers, airports can strategically adapt spaces to align with passenger needs, thereby offering better experiences and maximizing commercial potential. This methodology demonstrates a valuable approach for airport planning and decision-making at operational, tactical, and strategic levels.

The research of Silva et al. 2022 explores the application of discrete choice models, particularly logit models, to understand passenger preferences in airport check-in processes. Using data from three major Brazilian airports (Guarulhos, Congonhas, and Viracopos), the study investigates how factors such as queue time and service time influence passenger choices between traditional and biometric check-in options.

The research emphasizes the limitations of traditional binary logit models, which often fail to capture the nuanced heterogeneity in individual preferences. To address this, the study employs a logit model with random parameters, which allows for greater flexibility and provides richer insights into passenger behavior. The results reveal that while both queue and service times significantly impact decisions, queue time has a broader influence across individuals, whereas service time exhibits less variation.

Key findings suggest that biometric check-in is generally preferred due to its efficiency, especially by younger and tech-savvy passengers. However, older passengers demonstrate reluctance to adopt new technologies, highlighting the need for supportive measures, such as staff assistance and targeted campaigns, to improve inclusivity.

The study also compares the predictive accuracy of conditional logit and random parameters logit models. Simulations indicate that the random parameters model provides more stable and generalizable results, capturing individual differences better than traditional approaches. However, it remains challenging to transfer findings across different airports, suggesting the need for localized analysis in diverse settings.

The research underscores the importance of integrating technological innovations in airport operations to enhance passenger experiences and operational efficiency. It highlights the potential of biometric check-in systems to reduce waiting times and optimize space usage, but also stresses the need for strategic investments and user-centric implementation. The findings offer valuable guidance for airport operators and policymakers in planning future technology adoption while ensuring accessibility and user satisfaction.

B

Choice Sets for Survey

	Time Slot A	Time Slot B
Expected saved waiting time (minutes)	0 minutes	0 minutes
Time before departure (hours)	3 hours	2 hours
Time slot costs (€)	€0,00	€2,50

Figure B.1: Choice Set 1

	Time Slot A	Time Slot B
Expected saved waiting time (minutes)	0 minutes	30 minutes
Time before departure (hours)	1 hour	3 hours
Time slot costs (€)	€5,00	€2,50

Figure B.2: Choice Set 2

	Time Slot A	Time Slot B
Expected saved waiting time (minutes)	30 minutes	30 minutes
Time before departure (hours)	3 hours	2 hours
Time slot costs (€)	€2,50	€5,00

Figure B.3: Choice Set 3

	Time Slot A	Time Slot B
Expected saved waiting time (minutes)	60 minutes	30 minutes
Time before departure (hours)	3 hour	1 hour
Time slot costs (€)	€5,00	€0,00

Figure B.4: Choice Set 4

	Time Slot A	Time Slot B
Expected saved waiting time (minutes)	60 minutes	60 minutes
Time before departure (hours)	2 hours	1 hours
Time slot costs (€)	€0,00	€2,50

Figure B.5: Choice Set 5

	Time Slot A	Time Slot B
Expected saved waiting time (minutes)	60 minutes	0 minutes
Time before departure (hours)	1 hours	3 hours
Time slot costs (€)	€2,50	€0,00

Figure B.6: Choice Set 6

	Time Slot A	Time Slot B
Expected saved waiting time (minutes)	0 minutes	0 minutes
Time before departure (hours)	2 hours	1 hour
Time slot costs (€)	€2,50	€5,00

Figure B.7: Choice Set 7

	Time Slot A	Time Slot B
Expected saved waiting time (minutes)	30 minutes	60 minutes
Time before departure (hours)	2 hours	3 hour
Time slot costs (€)	€5,00	€5,00

Figure B.8: Choice Set 8

	Time Slot A	Time Slot B
Expected saved waiting time (minutes)	30 minutes	60 minutes
Time before departure (hours)	1 hour	2 hours
Time slot costs (€)	€0,00	€0,00

Figure B.9: Choice Set 9

Correlations

		TimeA	DepartA	CostsA
TimeA	Pearson Correlation	1	,000	,000
	Sig. (2-tailed)		1,000	1,000
	N	9	9	9
DepartA	Pearson Correlation	,000	1	,000
	Sig. (2-tailed)	1,000		1,000
	N	9	9	9
CostsA	Pearson Correlation	,000	,000	1
	Sig. (2-tailed)	1,000	1,000	
	N	9	9	9

Figure B.10: Correlations Alternative A

Correlations

		TimeB	DepartB	CostsB
TimeB	Pearson Correlation	1	,000	,000
	Sig. (2-tailed)		1,000	1,000
	N	9	9	9
DepartB	Pearson Correlation	,000	1	,000
	Sig. (2-tailed)	1,000		1,000
	N	9	9	9
CostsB	Pearson Correlation	,000	,000	1
	Sig. (2-tailed)	1,000	1,000	
	N	9	9	9

Figure B.11: Correlations Alternative B

Correlations

		TimeB	DepartB	CostsB	TimeA	DepartA	CostsA
TimeB	Pearson Correlation	1	,000	,000	,333	-,167	,000
	Sig. (2-tailed)		1,000	1,000	,381	,668	1,000
	N	9	9	9	9	9	9
DepartB	Pearson Correlation	,000	1	,000	-,167	-,500	,333
	Sig. (2-tailed)	1,000		1,000	,668	,170	,381
	N	9	9	9	9	9	9
CostsB	Pearson Correlation	,000	,000	1	-,500	,333	,167
	Sig. (2-tailed)	1,000	1,000		,170	,381	,668
	N	9	9	9	9	9	9
TimeA	Pearson Correlation	,333	-,167	-,500	1	,000	,000
	Sig. (2-tailed)	,381	,668	,170		1,000	1,000
	N	9	9	9	9	9	9
DepartA	Pearson Correlation	-,167	-,500	,333	,000	1	,000
	Sig. (2-tailed)	,668	,170	,381	1,000		1,000
	N	9	9	9	9	9	9
CostsA	Pearson Correlation	,000	,333	,167	,000	,000	1
	Sig. (2-tailed)	1,000	,381	,668	1,000	1,000	
	N	9	9	9	9	9	9

Figure B.12: Correlations Combined

C

Detailed Results

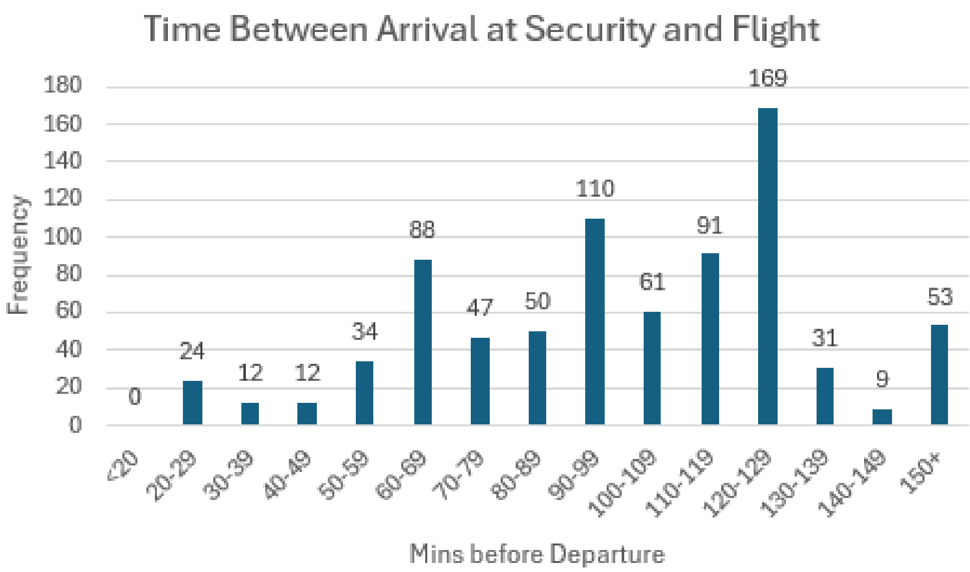

Figure C.1: Distribution of passengers' arrival time at the security check before departure

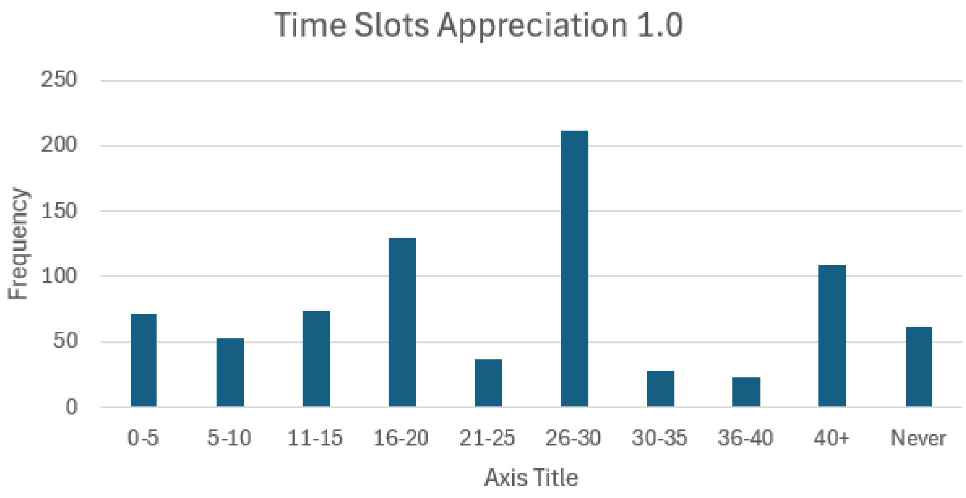

Figure C.2: Distribution Appreciation Time Slots

D

Factor Analysis Details

D.1. Process

Communalities

	Initial	Extraction
Planning_1	1,000	,483
Planning_2	1,000	,594
Innovation_1	1,000	,508
Perception_1	1,000	,592
Perception_2	1,000	,573
Stress_1	1,000	,642
Awareness_1	1,000	,272
Planning_3	1,000	,662
Perception_3	1,000	,336
Perception_4	1,000	,558
Stress_2	1,000	,648
Stress_3	1,000	,592
Perception_5	1,000	,595
Planning_4	1,000	,615
Perception_6	1,000	,454
Awareness_2	1,000	,676

Extraction Method: Principal Component Analysis.

Figure D.1: Step 1 factor analysis

Total Variance Explained

Component	Initial Eigenvalues			Extraction Sums of Squared Loadings			Rotation Sums of Squared Loadings		
	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %
1	5,289	33,054	33,054	5,289	33,054	33,054	4,056	25,349	25,349
2	2,323	14,518	47,572	2,323	14,518	47,572	3,200	20,003	45,352
3	1,188	7,428	54,999	1,188	7,428	54,999	1,544	9,647	54,999
4	,934	5,840	60,839						
5	,803	5,016	65,855						
6	,713	4,457	70,312						
7	,654	4,085	74,396						
8	,612	3,827	78,223						
9	,573	3,579	81,803						
10	,550	3,439	85,242						
11	,468	2,922	88,164						
12	,427	2,670	90,833						
13	,408	2,551	93,385						
14	,392	2,449	95,834						
15	,341	2,132	97,966						
16	,326	2,034	100,000						

Extraction Method: Principal Component Analysis.

Figure D.2: Step 2 factor analysis

Pattern Matrix[a]

	Factor		
	1	2	3
Planning_3	,672		
Stress_2	,663		
Perception_5	,644		
Awareness_2	,640		
Perception_6	,549		
Innovation_1	,475		
Perception_3	,458		
Awareness_1			
Perception_1		,692	
Perception_2		,672	
Perception_4		,580	
Planning_2		,558	
Planning_4		,551	
Stress_1			-,705
Stress_3	,353		,510
Planning_1			

Extraction Method: Principal Axis Factoring.
Rotation Method: Oblimin with Kaiser Normalization.[a]

a. Rotation converged in 17 iterations.

Figure D.3: Step 3 factor analysis

Total Variance Explained

Factor	Initial Eigenvalues Total	% of Variance	Cumulative %	Extraction Sums of Squared Loadings Total	% of Variance	Cumulative %	Rotation Sums of Squared Loadings[a] Total
1	5,438	33,985	33,985	4,940	30,873	30,873	3,722
2	1,878	11,735	45,720	1,263	7,895	38,768	3,386
3	1,197	7,479	53,199	,624	3,899	42,668	1,711
4	,992	6,197	59,397				
5	,815	5,093	64,490				
6	,753	4,706	69,196				
7	,675	4,220	73,416				
8	,623	3,893	77,310				
9	,590	3,687	80,997				
10	,575	3,596	84,592				
11	,481	3,007	87,600				
12	,444	2,774	90,374				
13	,437	2,733	93,107				
14	,411	2,567	95,674				
15	,360	2,250	97,924				
16	,332	2,076	100,000				

Extraction Method: Principal Axis Factoring.

a. When factors are correlated, sums of squared loadings cannot be added to obtain a total variance.

Figure D.4: Step 4 factor analysis

Pattern Matrix[a]

	Factor		
	1	2	3
Planning_3	,705		
Awareness_2	,684		
Stress_2	,679		
Perception_5	,623		
Perception_6	,574		
Innovation_1	,501		
Perception_3	,494		
Perception_1		,695	
Perception_2		,678	
Perception_4		,563	
Planning_2		,523	
Planning_4		,522	
Stress_1			-,619
Stress_3			,568

Extraction Method: Principal Axis Factoring.
Rotation Method: Oblimin with Kaiser Normalization.[a]

a. Rotation converged in 7 iterations.

Figure D.5: Step 5 factor analysis

Table D.1: 3 Factors and their statements

Variable	Statement	Factor loading
Factor 1: Positive Time Slot Attitude		
Planning_3	I like security time slots, as they enable me to plan my whole trip (travel to the airport, luggage check-in, security check, walk to the gate) in more detail.	0.705
Awareness_2	I would recommend time slots to other travellers.	0.684
Stress_2	I believe that a reserved time slot for the security checkpoint lowers my stress levels.	0.679
Perception_5	I find the certainty of passing through the security checkpoint within a specific time provided by a time slot very important.	0.623
Perception_6	Time slots are also useful during quiet times, not only during peak travel times.	0.574
Innovation_1	I am interested in trying new tools to lower waiting times, such as the time slot reservation system.	0.501
Perception_3	I would prefer time slots which also include luggage check-in.	0.494
Factor 2: Negative Time Slot Attitude		
Perception_1	I (expect to) find it too much effort to reserve a time slot.	0.695
Perception_2	The time slots available do not align with my preferred travel times (real life, not the time slots shown in the experiment).	0.678
Perception_4	(I expect that) Time slots do not save me significant time in the security queue.	0.563
Planning_2	I dislike time slots, as a dedicated time slot for the security check gives me less flexibility for other steps in my airport process (travel to the airport, luggage check-in etc.)	0.523
Planning_4	I prefer to join the security whenever I want, rather than a dedicated time slot.	0.522
Factor 3: Waiting Behaviour		
Stress_1	I don't mind waiting, as long as I expect to do so.	-0.619
Stress_3	I find waiting in queues at the airport very annoying.	0.568

Table D.2: Reliability of Scales

	Factor 1	Factor 2	Factor 3
Cronbach's alpha	0.842	0.757	0.519

As can be seen in table 6.4, the Chronbach's alpha of the third factor does surpass the required value. This can be explained by the fact that this factor only contains two statements. In order to test whether these statements are still suitable to combine a factor, the Pearson correlation is calculated. The Pearson correlation is suitable, as it shows how strong the relation is between two variables. The Pearson correlation only appears to be 0.35, which means that both statements have a weak relation. Therefore, they do not strongly measure the same underlying subject in a consistent way, which means that they are not suitable to form a factor together.

The subject of these statements is waiting behaviour. Despite the fact that it is interesting to study waiting behaviour of passengers, these statements are excluded from the factor analysis. However, these statements will be analysed during individual statement analyses (section X).

D.1.1. Excluding factor 3

Total Variance Explained

Factor	Initial Eigenvalues			Extraction Sums of Squared Loadings			Rotation Sums of Squared Loadings[a]
	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %	Total
1	4,907	40,891	40,891	4,378	36,487	36,487	3,987
2	1,414	11,784	52,675	,826	6,880	43,367	2,737
3	,847	7,062	59,737				
4	,750	6,249	65,986				
5	,713	5,943	71,929				
6	,622	5,184	77,113				
7	,557	4,641	81,753				
8	,510	4,250	86,004				
9	,469	3,906	89,910				
10	,440	3,666	93,576				
11	,398	3,317	96,893				
12	,373	3,107	100,000				

Extraction Method: Principal Axis Factoring.

a. When factors are correlated, sums of squared loadings cannot be added to obtain a total variance.

Figure D.6: Step 6 factor analysis

Pattern Matrix[a]

	Factor	
	1	2
Stress_2	,736	
Awareness_2	,728	
Planning_3	,716	
Perception_5	,692	
Perception_6	,530	
Innovation_1	,526	
Perception_3	,453	
Perception_2		,714
Perception_1		,587
Perception_4		,488
Planning_4		,440
Planning_2		,430

Extraction Method: Principal Axis Factoring.
Rotation Method: Oblimin with Kaiser Normalization.

a. Rotation converged in 6 iterations.

Figure D.7: Step 7 factor analysis

D.2. Detailed results within factors

Table D.3: Results within factors

Factor	Option	Frequency	Percentage
Factor 1: Positive Time Slot Attitude	Fully Disagree	35	4.2%
	Disagree	132	15.9%
	Indifferent	242	29.0%
	Agree	310	37.2%
	Fully Agree	113	13.6%
Factor 2: Negative Time Slot Attitude	Fully Disagree	52	6.2%
	Disagree	200	24.0%
	Indifferent	257	30.8%
	Agree	246	29.5%
	Fully Agree	79	9.5%

D.3. Detailed one-way ANOVA test results

Table D.4: Factor scores

Variable	Factor 1	SD1	SE1	Factor 2	SD2	SE2
General	3.4	0.76	0.02	3.1	0.82	0.02
Business	3.3	0.79	0.08	3.1	0.79	0.08
Non-Business	3.4	0.75	0.03	3.2	0.82	0.03
Reservation	4.0	0.67	0.06	2.4	1.00	0.09
No Reservation	3.3	0.73	0.03	3.3	0.73	0.03
Aware	3.6	0.77	0.04	2.9	0.87	0.05
Not Aware	3.3	0.73	0.03	3.3	0.74	0.03
No Reservation and Not Aware	3.3	0.73	0.03	3.4	0.73	0.05
No Reservation but is Aware	3.4	0.72	0.05	3.1	0.72	0.05
Transfer	3.5	0.69	0.05	3.2	0.70	0.06
Bus	3.3	0.68	0.11	3.1	0.77	0.12
Train	3.4	0.75	0.04	3.1	0.81	0.04
Taxi	3.6	0.74	0.09	3.2	0.86	0.10
Car (Kiss&Ride)	3.5	0.86	0.09	3.2	0.94	0.10
Car (Parking)	3.5	0.81	0.11	3.0	0.91	0.13
Other	3.2	0.72	0.14	3.31	0.80	0.16
0 Flights	3.5	0.87	0.16	3.4	0.86	0.16
1-3 Flights	3.4	0.81	0.05	3.2	0.80	0.05
4-10 Flights	3.4	0.71	0.03	3.1	0.83	0.04
10+ Flights	3.4	0.75	0.08	3.2	0.78	0.08
18-25	3.4	0.66	0.04	3.2	0.75	0.05
25-40	3.5	0.75	0.04	3.1	0.80	0.04
40-65	3.4	0.84	0.06	3.2	0.90	0.06
65+	3.8	0.88	0.14	3.49	0.93	0.15
Male	3.4	0.78	0.04	3.2	0.81	0.04
Female	3.5	0.73	0.04	3.1	0.82	0.04
Non-Binary	3.1	0.69	0.16	3.3	0.69	0.16
Secondary School	3.4	0.71	0.08	3.3	0.78	0.08
Secondary vocational education	3.4	0.74	0.07	3.3	0.81	0.10
University of applied sciences Bachelors	3.4	0.67	0.09	3.1	0.77	0.08
University of applied sciences Masters	3.5	0.79	0.08	3.2	0.88	0.12
University Bachelors	3.5	0.80	0.06	3.1	0.84	0.06
University Master	3.4	0.72	0.05	3.1	0.79	0.05
PhD	3.4	0.77	0.08	3.1	0.86	0.08
Low-Income	3.3	0.69	0.05	3.2	0.73	0.05
Middle-Income	3.5	0.71	0.05	3.1	0.81	0.05
High-Income	3.4	0.83	0.06	3.0	0.89	0.06

*Grey-couloured estimates are insignificant parameters

Age

Within this demographic characteristic, the category of elderly adults (65+) score significantly different than all other categories (which all score insignificantly different to each other) on all three factors. Remarkably, the score is higher for all factors, which means that elderly adults are both more positive and more negative regarding their attitude towards time slots. This could indicate that elderly adults like some parts of time slots very much, but are in doubt to make a reservation, as they also dislike other part of the time slot system. Factor 3 confirms this, as elderly passengers highly dislike waiting in general.

Education
Passengers with different education background score significantly different on factor 3. There seems to be a trend in which people with higher education degrees obtained struggle less with waiting than people with a lower degree. However, this is not very robust hypothesis, as the demographic characteristic ”education” includes many different categories (7) and only 2 statements to test this hypothesis.

Income
Finally, the categories on income score significantly different on factor 2. Passengers with low income score higher on factor 2 than passengers with a high income level. There seems to be no difference for these categories on factor 1 and 3.

Insignificant category differences
It is notable that there is no significant difference in score between business and non-business passengers for all three factors. It was not necessarily expected, but it would be explainable if there would have been a difference between these two categories.

In addition, all categories of both the demographic characteristics ”transport mode towards the airport” and ”gender” do not score significantly different on all three factors. This is as expected, as this has no clear connection to different behaviours towards time slot reservations.

D.4. Highest and Lowest scores Reservation

Table D.5: Difference Highest statements of Reservation

Order	Statement number	Reservation score	No Reservation score	Delta
1	Stress_2	4.099	3.191	0.908
2	Awareness_2	4.190	3.299	0.892
3	Planning_3	3.934	3.176	0.757
4	Innovation_1	4.727	3.657	0.615
5	Perception_6	3.446	2.846	0.601
6	Perception_5	3.884	3.341	0.543
7	Perception_3	3.818	3.663	0.155

Table D.6: Difference Highest statements of Reservation

Order	Statement number	Reservation score	No Reservation score	Delta
1	Planning_2	2.537	3.460	0.923
2	Perception_1	2.124	2.974	0.850
3	Planning_4	2.686	3.503	0.817
4	Perception_4	2.562	3.138	0.576
5	Perception_2	2.579	3.046	0.467

E

Results MNL model

Beta variable	Value	Rob. s.e.	T-test	P-value	95% C.I. -	95% C.I. +
Constant	-0.222	0.066	-3.389	0.001	-0.351	-0.094
Costs_L	-0.109	0.015	-7.167	0.000	-0.139	-0.079
Costs_Q	0.012	0.007	3.646	0.000	0.006	0.018
Saved_L	0.011	0.001	8.303	0.000	0.009	0.014
Saved_Q	-0.0003	0.000	-5.733	0.000	-0.0004	-0.0002
Time_L	0.254	0.065	3.861	0.000	0.125	0.383
Time_Q	-0.320	0.039	-8.147	0.000	-0.397	-0.243
Schengen	0.314	0.074	4.227	0.000	0.168	0.459
Alone	0.001	0.101	0.014	0.989	-0.196	0.199
Adults	-0.148	0.102	-1.445	0.148	-0.349	0.052
Children	-0.076	0.173	-0.437	0.662	-0.415	0.263
Business	0.319	0.072	4.444	0.000	0.178	0.460
costsXSchengen	-0.065	0.013	-5.020	0.000	-0.091	-0.040
costsXNon-Schengen	-0.043	0.012	-3.346	0.001	-0.068	-0.018
costsXAlone	-0.066	0.016	-4.014	0.000	-0.099	-0.034
costsXAdults	-0.068	0.017	-4.111	0.000	-0.101	-0.036
costsXChildren	0.026	0.028	0.932	0.351	-0.029	0.081
costsXBusiness	-0.019	0.014	-1.349	0.177	-0.047	0.009
costsXNon-Business	-0.090	0.012	-7.22	0.000	-0.114	-0.065
SavedXSchengen	0.006	0.001	4.939	0.000	0.003	0.008
SavedXNon-Schengen	0.006	0.001	4.971	0.000	0.003	0.008
SavedXAlone	0.004	0.001	3.038	0.002	0.002	0.007
SavedXAdults	0.006	0.001	3.941	0.000	0.003	0.009

SavedXChildren	0.001	0.002	0.459	0.646	-0.004	0.006
SavedXBusiness	0.006	0.001	4.677	0.000	0.003	0.008
SavedXNon-Business	0.006	0.001	4.983	0.000	0.003	0.008
TimeXSchengen	0.006	0.040	0.146	0.884	-0.073	0.085
TimeXNon-Schengen	0.248	0.042	5.874	0.000	0.165	0.331
TimeXAlone	0.065	0.043	1.513	0.130	-0.019	0.151
TimeXAdults	0.124	0.043	2.844	0.004	0.038	0.210
TimeXChildren	0.063	0.068	0.934	0.350	-0.070	0.197
TimeXBusiness	-0.004	0.042	-0.094	0.924	-0.087	0.079
TimeXNon-Business	0.258	0.042	6.171	0.000	0.176	0.340

Table E.1: All results combined

E.1. Factor scores

Table E.2: Main effects

Beta variable	Value	Rob. s.e.	T-test	P-value
Factor 1	-0.074	0.108	-0.679	0.497
Factor 2	-0.124	0.130	-0.952	0.341

*Grey-couloured estimates are insignificant parameters

df

Table E.3: Factor Interaction Effects

Beta variable	Value	Rob. s.e.	T-test	P-value
Factor1XCosts	0.019	0.017	1.077	0.281
Factor1XSaved	0.002	0.002	1.264	0.206
Factor1XTime	-0.023	0.041	-0.563	0.574
Factor2XCosts	0.010	0.021	0.446	0.655
Factor2XSaved	0.002	0.001	1.100	0.271
Factor2XTime	0.002	0.050	0.133	0.960

*Grey-couloured estimates are insignificant parameters

F

Detailed SP Application

F.1. Impact Main Variables

This section calculates the chance that a timeslot is booked for specific scenarios. First, the scenarios should be created. As can be seen in utility function 9.1, both attributes and contexts have influence on the utility obtained by passengers. First, scenarios will be created in which attribute levels differentiate. Context levels will be kept identical in these scenarios to isolate the effect of the attributes. As also applied in the interpretation of the constant, the context of non-schengen, children and non-business will be applied for the contexts, as this context scenario only includes reference values. This isolates the effect of the attributes.

Table F.1: Attribute Effects

Costs	Saved	Time	Area	Company	Purpose	Booking %
€0.00	0	1 hours	Non-Schengen	Alone	Non-Business	41.4%
€0.00	0	1.35 hours	Non-Schengen	Alone	Non-Business	42.0%
€0.00	0	2 hours	Non-Schengen	Alone	Non-Business	38.2%
€0.00	0	3 hours	Non-Schengen	Alone	Non-Business	22.1%
€2.50	0	2 hours	Non-Schengen	Alone	Non-Business	24.9%
€2.50	15	2 hours	Non-Schengen	Alone	Non-Business	31.9%
€2.50	30	2 hours	Non-Schengen	Alone	Non-Business	36.9%
€2.50	60	2 hours	Non-Schengen	Alone	Non-Business	38.9%
€5.00	0	2 hours	Non-Schengen	Alone	Non-Business	19.3%
€5.00	0	3 hours	Non-Schengen	Alone	Non-Business	9.9%
€5.00	60	1 hours	Non-Schengen	Alone	Non-Business	34.5%

As can be concluded from table F.1, booking percentages differentiate heavily when attribute levels are adjusted. Invidual behaviours are already interpret in section 8.1, but this table shows combined effects. However, using the individual behaviours helps to interpret this table.

For instance, the difference between €0.00 and €5.00 in booking percentages is 18.9% (38.2% - 19.3%) for Time = 2, while the same difference between costs contains a difference in booking percentages of 12.2% (22.1% - 9.9%) for Time = 3. This can be explained by the fact that Time = 2 results in +0.2 utils, while Time = 3 results in -0.4 utils. Therefore, the effect of the difference in time slots costs is compensated when Time = 2, while the effect is reinforced in Time = 3. Reinforcement of negative utility by Time = 3 results in a lower final utility score. This lower score causes lower booking percentages, regardless of the level of costs. Therefore, the difference between booking percentages in the costs spectrum becomes smaller as the Time attribute enlarges (this is true for Time >1.35, this will be discusses at the end of this interpretation). This is also true for the variable ”Saved”. A higher value of Saved compensates the effect of Costs. Therefore, the difference in booking percentages on the spectrum of costs reduces, as the Saved attribute enlarges.

Furthermore, the behaviour of the equation of Saved in figure 8.2 can also be seen in table F.1. A higher number of saved minutes results in higher booking rates. However, this effect is less strong as the values of Saved increase. For instance, the difference in booking percentage between Saved = 0 and Saved = 15 is +7.0% (31.9% - 24.9%), while the difference between Saved = 30 and Saved = 60 is only + 2% (38.9%-36.9%). These numbers are true for Costs = 2.50 and Time = 2. An increasement of the Time attribute (after Time =1.35) results in a compensation effect, as it lowers the total utility obtained (as it also did in the costs example). Due to the positive curve of Saved, the negative addition of Time results in smaller booking differentiations. The attribute costs has the same effect as the attribute of Time, as more costs lowers the total utility obtained, which compensated the positive effect of more time saved.

Finally, the Time attribute is interpreted. As expected, the behaviour of the equation of Time in figure 8.3 can also be seen in table F.1. Especially the parabolic effect of the equation is interesting. As the highest booking percentage for the scenario with Costs = €0.00 and Saved = 0 is obtained for Time = 1.35. Between T= 1 and T= 1.35, the utility function, thus the booking percentages, are more or less equal. After T = 1.35, passengers find time slots less interesting as the booking ratio drops exponential. The relative difference between T = 1.35 and T = 2 is smaller than the difference between T = 2 and T = 3 (-5.85 vs -16.1). As explained in previous two interpretations, the attributes of Costs and Saved have also influence on the effect from Time on the booking ratio of passengers. The negative character of Costs lowers the final obtained utility, which causes lower booking percentages. The positive character of Saved, however, increases the booking ratio.

F.1.1. Impact Context Variables

Equation 9.3 shows the impact of context variables. It is remarkable that the context ”Adults” has no significant value, thus is excluded from the equation. Therefore, the effect of Adults will not be part of this analysis. Just as done in the analysis of the attribute levels, in order to interpret the effects of the contexts properly, all attribute values will be kept constant. In order to see the potential differentiations for contexts, the attributes are selected in such a way that interaction effects are maximised. Earlier, interaction effects were minimised. However, the interpretation of contexts is more interesting for interaction effects, as the context effects are easily readible from utility function 9.1, when interaction effects are minimised. This means that Cost = €5.00, Saved = 0 (no interaction effects are associated with Saved) and Time = 3 are used for the attribute levels. First, this scenario will be calculated for the reference case, as this calculates the results of the attributes. Then, different scenarios can be formed for the contexts.

Table F.2: Context Effects

Costs	Saved	Time	Area	Company	Purpose	Booking %
€5.00	0	3 hours	Non-Schengen	Alone	Non-Business	9.9%
€5.00	0	3 hours	Non-Schengen	Children	Non-Business	14.9%
€5.00	0	3 hours	Non-Schengen	Alone	Business	9.8%
€5.00	0	3 hours	Schengen	Children	Non-Business	11.3%
€5.00	0	3 hours	Schengen	Alone	Business	7.3%
€5.00	0	3 hours	Schengen	Alone	Non-Business	7.4%

As can be seen in figure 8.2, the impact of contexts differentiations is a lot smaller than the the impact of attribute level differentiations. However, some effects are still visible.

People with children are more likely to make a time slot reservation than people without children. This is caused by the compensation effect of the interaction variable between ”Children” and ”Costs”.

Furthermore, business passenger are slightly less likely to make a time slot reservation than non-business passengers. Besides the compensation effect for costs and the positive constant for business passengers, the context ”Business” has a reinforced negative effect on the equation of Time. This effect is stronger than the combined effect of the compensation and the constant, which is why business passengers are less likely to make a reservation.

Finally, Non-Schengen passengers are more likely to make a time slot reservation than Schengen passengers. This is also caused by the interaction effect between ”Time” and ”Schengen”, which is stronger than the constant of the context ”Schengen”.

However, the interpretations are not true for every combination of attribute levels, as other attribute levels cause different interaction effects, which results in different booking percentages. Therefore, next subsection will explore mixed results for both mixed attributes and mixed contexts.

F.1.2. Mixed Results

As concluding in previous sections, mixed results give a more detailed insight in the effects of attributes and contexts, as both the main effects and interaction effects are tested. On the other hand, it is more challenging to isolate interpretations of attributes or contexts effects in mixed results. Mixed scenarios are created by combining attribute columns of rows of attribute table F.1 and context columns of rows of context table F.2. As there are more attribute rows than context rows, a selection has been made. This selection includes a wide variety of levels for all attributes in order to analyse the effects more properly. The mixed results are shown in table

Table F.3: Mixed Effects

Costs	Saved	Time	Area	Company	Purpose	Booking %
€5.00	0	3 hours	Non-Schengen	Alone	Non-Business	9.9%
€0.00	0	1 hours	Non-Schengen	Children	Non-Business	41.4%
€0.00	0	3 hours	Non-Schengen	Alone	Business	16.4%
€2.50	30	2 hours	Schengen	Children	Non-Business	40.5%
€2.50	60	2 hours	Schengen	Alone	Business	38.6%
€5.00	60	1 hours	Schengen	Alone	Non-Business	38.3%

It is remarkable that booking percentages differentiate heavily with the results of table 8.2, despite having the same contexts. This indicates that attributes are dominent in the question whether a passenger will make a time slot reservation.

Furthermore, as costs rise, people with children are more likely to make a time slot reservation in comparison to other passengers of that context. Therefore, there is no difference in the scenario with €0.00 costs and children, but there is a difference in the scenario with €2.50 costs and children, as passengers with children are more likely to make a reservation in that scenario.

Next, the value of ”Time” influence whether passengers within Schengen or passenger within non-Schengen prefer to book a time slot. As long as Time < 1.67 (0.504/0.242), passengers in Schengen are more likely to make a time slot booking. From T=1.67 onwards, passengers are less likely than non-Schengen passengers to make a time slot reservation, as Time increases.

The effect of the context ”Business passenger” is both dependent on the attribute ”Costs” and ”Time”. Business passengers have a positive context constant which generally increases the chance of reserving a time slot. Higher costs increases the relative likeliness of business passengers to book a time slot (compared to non-business passengers), as business passengers are less costs-sensitive. On the other hand, more time between their arrival at the security check point and the departure of their flight strongly decreases their likeliness to create a reservation. Therefore, the effect of Business passengers is strongly dependent on both Costs and Time.

F.2. WTP

Now, WTP can be calculated. The same scenarios will be used as constructed in section F.1.2.

Table F.4: WTP Calculations

Costs	Saved	Time	Area	Company	Purpose	WTPTime	WTPSaved
€5.00	0	3 hours	Non-Schengen	Alone	Non-Business	€-15.55/hour	€22.97/hour
€0.00	0	1 hours	Non-Schengen	Children	Non-Business	€-0.86/hour	€7.50/hour
€0.00	0	3 hours	Non-Schengen	Children	Non-Business	€-5.70/hour	€6.79/hour
€2.50	15	2 hours	Non-Schengen	Alone	Business	€-6.02/hour	€9.53/hour
€2.50	30	2 hours	Schengen	Children	Non-Business	€-7.21/hour	€6.76/hour
€2.50	60	2 hours	Schengen	Alone	Business	€-8.05/hour	€-2.62/hour
€5.00	60	1 hours	Schengen	Alone	Non-Business	€-0.80/hour	€-4.43/hour

Table F.4 shows the WTP for attributes ”Time” and ”Saved”. The WTP for Time can be explained is: the number of euros someone is willing to pay for an extra hour of time between the arrival at the security and the departure of the flight. However, all WTP are negative, which reforms the definition towards: the number of euros someone is willing to pay for one less hour between arrival at the security and the departure of the flight. The unit of WTP Saved is more common, as it includes the number euros someone is willing to pay for one hour of saved waiting time.

First of all, it is remarkable that the first row of the table has very high WTP's for both attributes. This can be explained by the fact that this is the worst possible scenario for passengers, as all three attributes have the least preferred level. Therefore, passengers are in theory (according to the calculations) willing to pay more to improve their situation.

next, it is striking that the WTP for both Time and Saved decreases, as more preferred levels for these attribute are part of the created scenario. As an example, two scenarios with both Costs = 2.5 and Time = 2: Saved = 15 is less preferred than Saved = 30. This results in a higher WTP for Saved when Saved = 15, as passengers are more willing to pay to improve their current situation. A similar effect for WTP of Time can be seen in scenarios with Costs = 0 and Saved = 0.

Finally, the the attribute Costs also influences the hight of both WTP's. This effect of Costs can be seen as a multiplier effect. Higher costs for the scenario cause larger effects of the other two attributes on the two WTP's.

G
Discrete Event Simulation model

G.1. Arrival table

This section includes an explanation of the arrival table. This includes how the arrival table is constructed and how it is implemented.

1. Schiphol data was filtered for a whole day, each data point being 15 minutes. All these data point were noted in an excel sheet.
2. Date and Time variables were added in a column, so that Simio would know how many arrivals should be planned at a specific time at a specific date.
3. The data is implemented into Simio in a regular table.
4. This table is added to the source of the Simio model.

G.2. Work-schedules

This an explanation of the work-schedules. This includes how the work-schedules are constructed and how they are implemented.

1. Different kind of work-schedules were created, ones that are open for a whole day at Schiphol, and work-schedules for specific hours.
2. Each server in the Simio model received a dedicated work-schedule for that server.
3. Via trial-and-error, a setup has been made with work-schedules to get an idea of the number of servers necessary to be able to go trough the day without unrealistic waiting times. The arrival table was already implemented at the time that work-schedules were formed.
4. Based upon this base case, scenarios were formed with different capacities, caused by different kinds of work-schedules combinations.

G.3. Verification

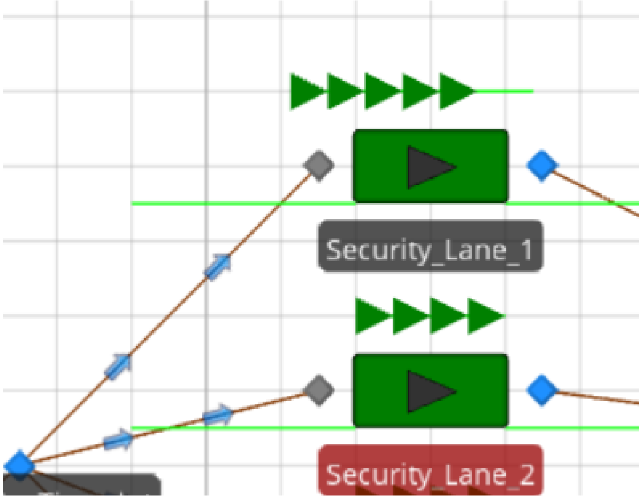

Figure G.1: Verification of number of entities in server

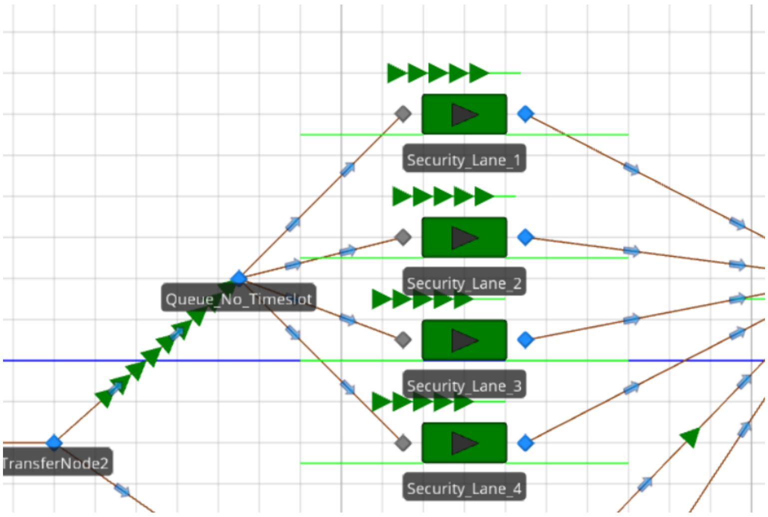

Figure G.2: verification of entities queue

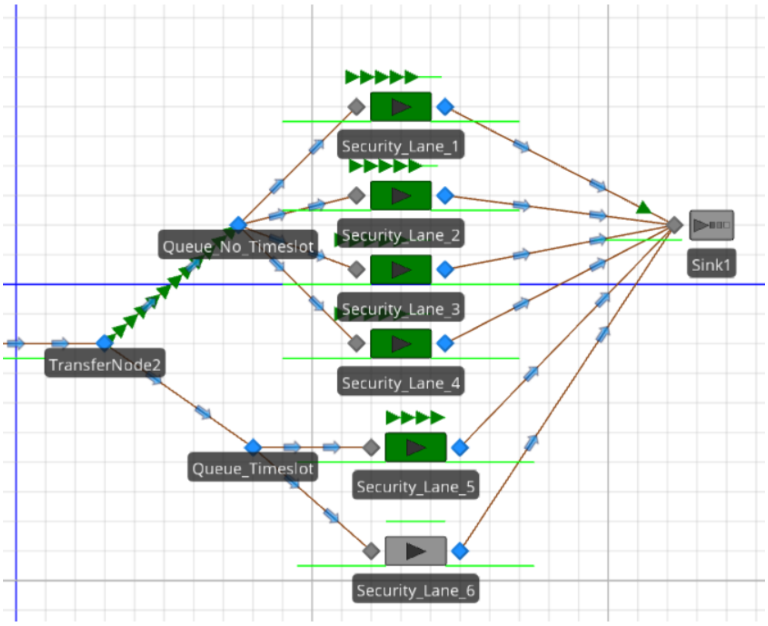

Figure G.3: verification of split in passengers

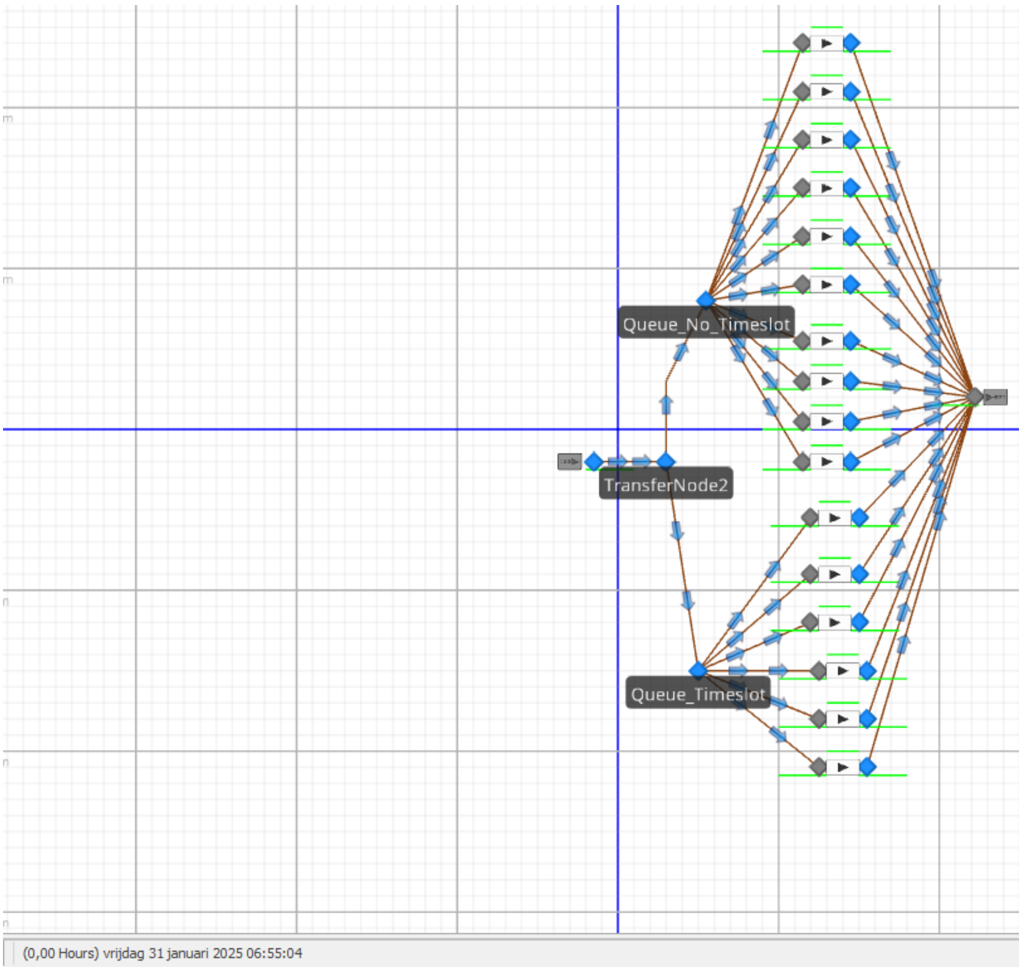

Figure G.4: verification of closed security lanes before 07:00

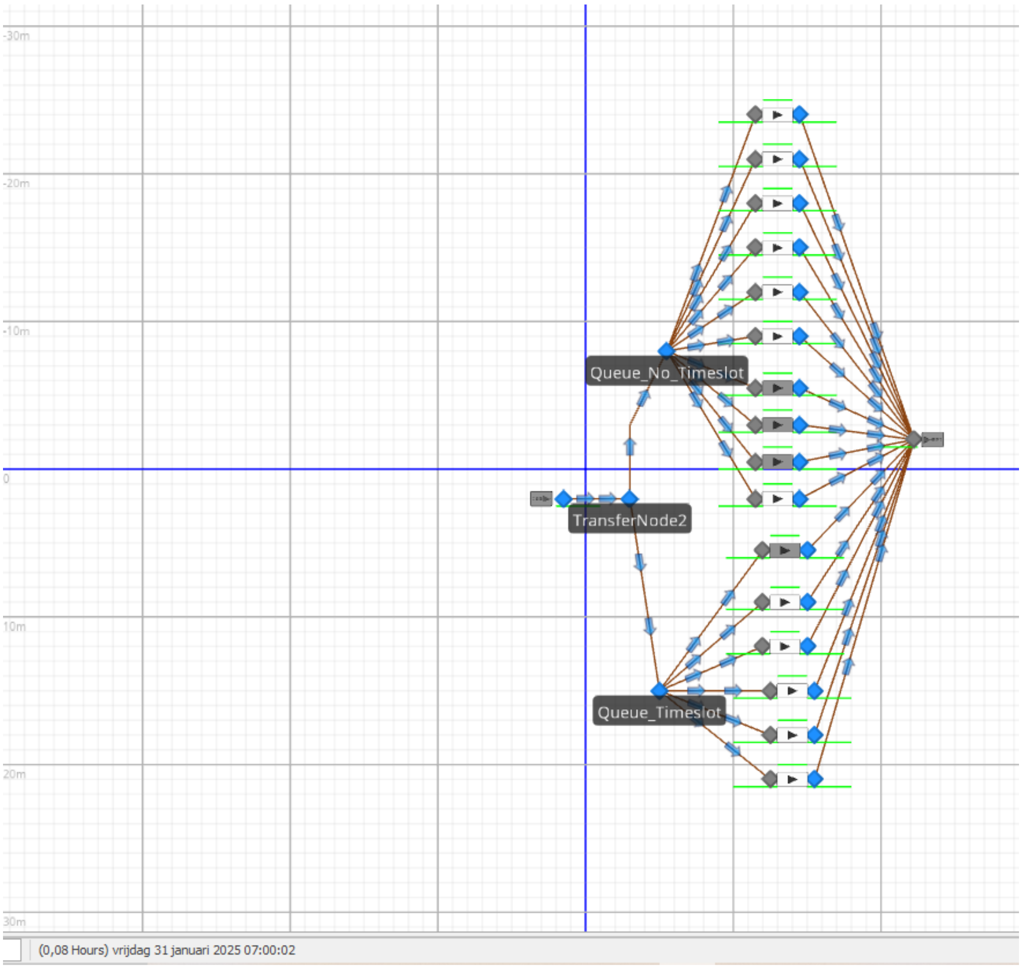

Figure G.5: verification of some open security lanes after 07:00

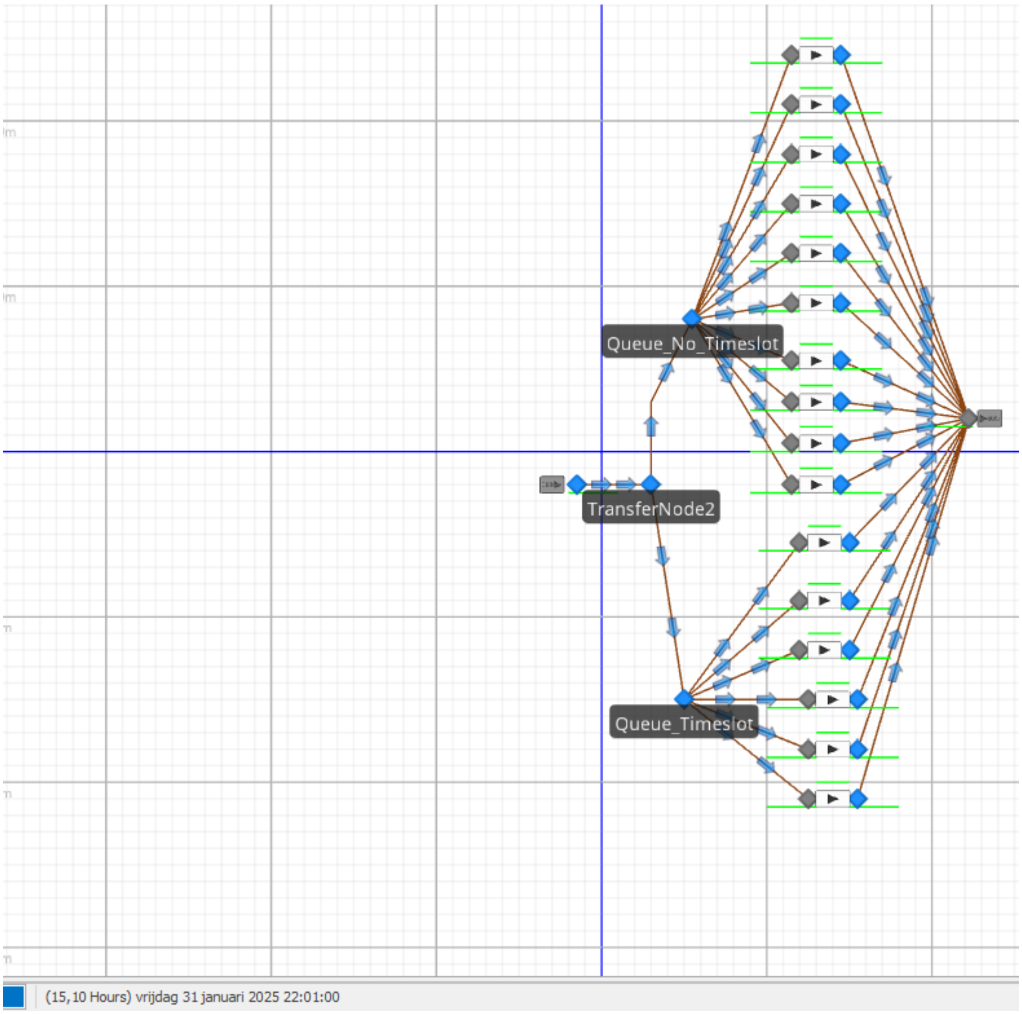

Figure G.6: verification of empty model after 22:00

Sink	Sink1	[DestroyedEntities]	FlowTime	TimeInSystem	Average (Hou...	0,0597
					Maximum (Ho...	0,0597
					Minimum (Hou...	0,0597
					Observations	1,0000
		InputBuffer	Throughput	NumberEntered	Total	1,0000
				NumberExited	Total	1,0000
Source	Source1	OutputBuffer	Throughput	NumberEntered	Total	1,0000
				NumberExited	Total	1,0000
		Processing	Throughput	NumberEntered	Total	1,0000
				NumberExited	Total	1,0000

Figure G.7: Verification of 1 passenger in system

Sink	Sink1	[DestroyedEntities]	FlowTime	TimeInSystem	Average (Hou...	0,2450
					Maximum (Ho...	0,8090
					Minimum (Hou...	0,0386
					Observations	6.642,0000
		InputBuffer	Throughput	NumberEntered	Total	6.642,0000
				NumberExited	Total	6.642,0000
Source	Source1	OutputBuffer	Throughput	NumberEntered	Total	6.642,0000
				NumberExited	Total	6.642,0000
		Processing	Throughput	NumberEntered	Total	6.642,0000
				NumberExited	Total	6.642,0000

Figure G.8: verification of all passengers in system

Path	Line_No_Timeslot	[Travelers]	Throughput	NumberEntered	Total	5.994,0000
				NumberExited	Total	5.994,0000
	Line_Timeslot	[Travelers]	Throughput	NumberEntered	Total	648,0000
				NumberExited	Total	648,0000

Figure G.9: Verification of ratio = 10% time slot passengers

Path	Line_No_Timeslot	[Travelers]	Throughput	NumberEntered	Total	3.342,0000
				NumberExited	Total	3.342,0000
	Line_Timeslot	[Travelers]	Throughput	NumberEntered	Total	3.300,0000
				NumberExited	Total	3.300,0000

Figure G.10: Verification of ratio = 50% time slot passengers

G.4. Validation

The validation is done by comparing peaks in the data with busy periods in the model. In addition, periods with a low number of passengers are also tested, as the model should be empty around that period.

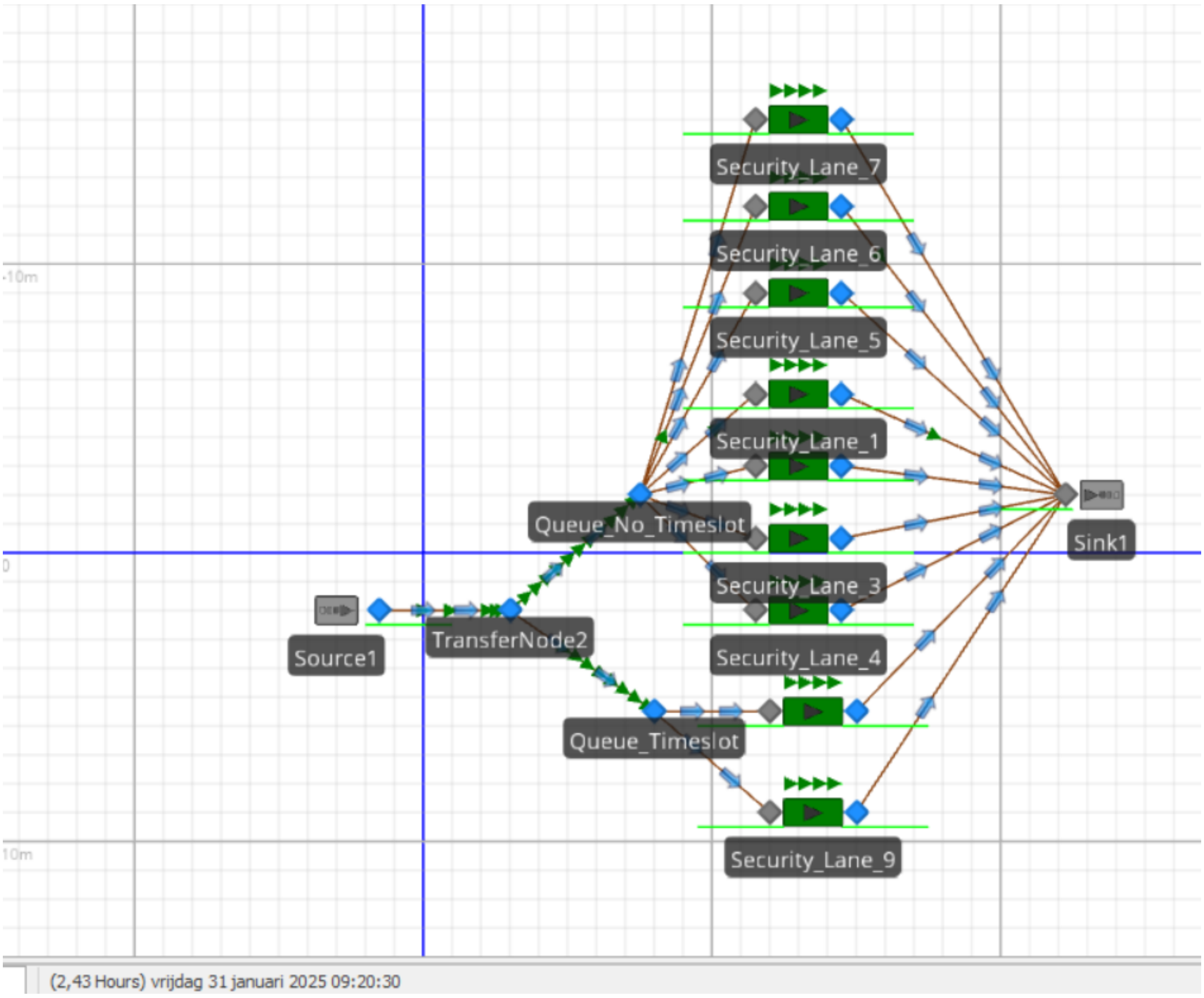

Figure G.11: Validation peak 1

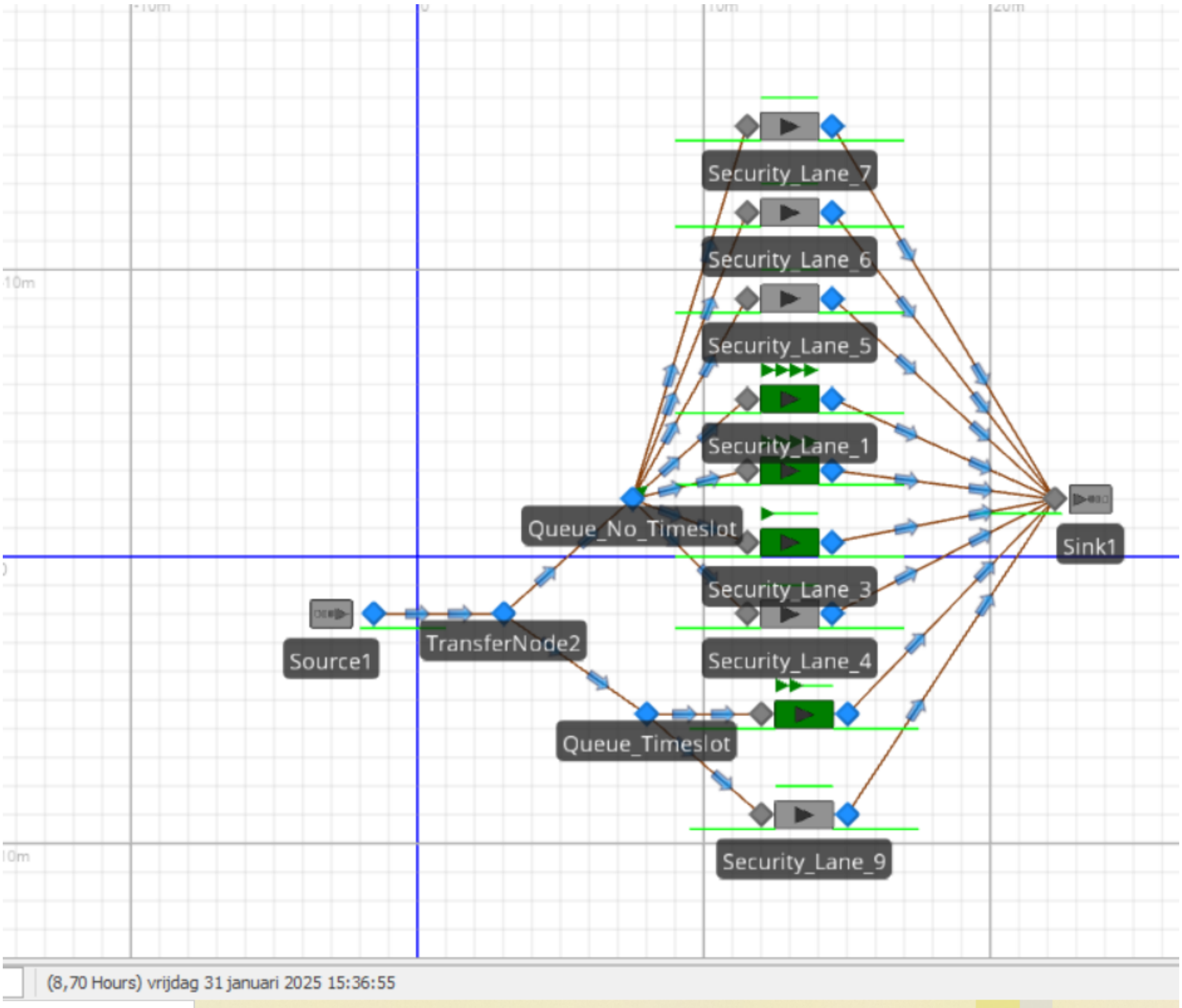

Figure G.12: Validation no peak

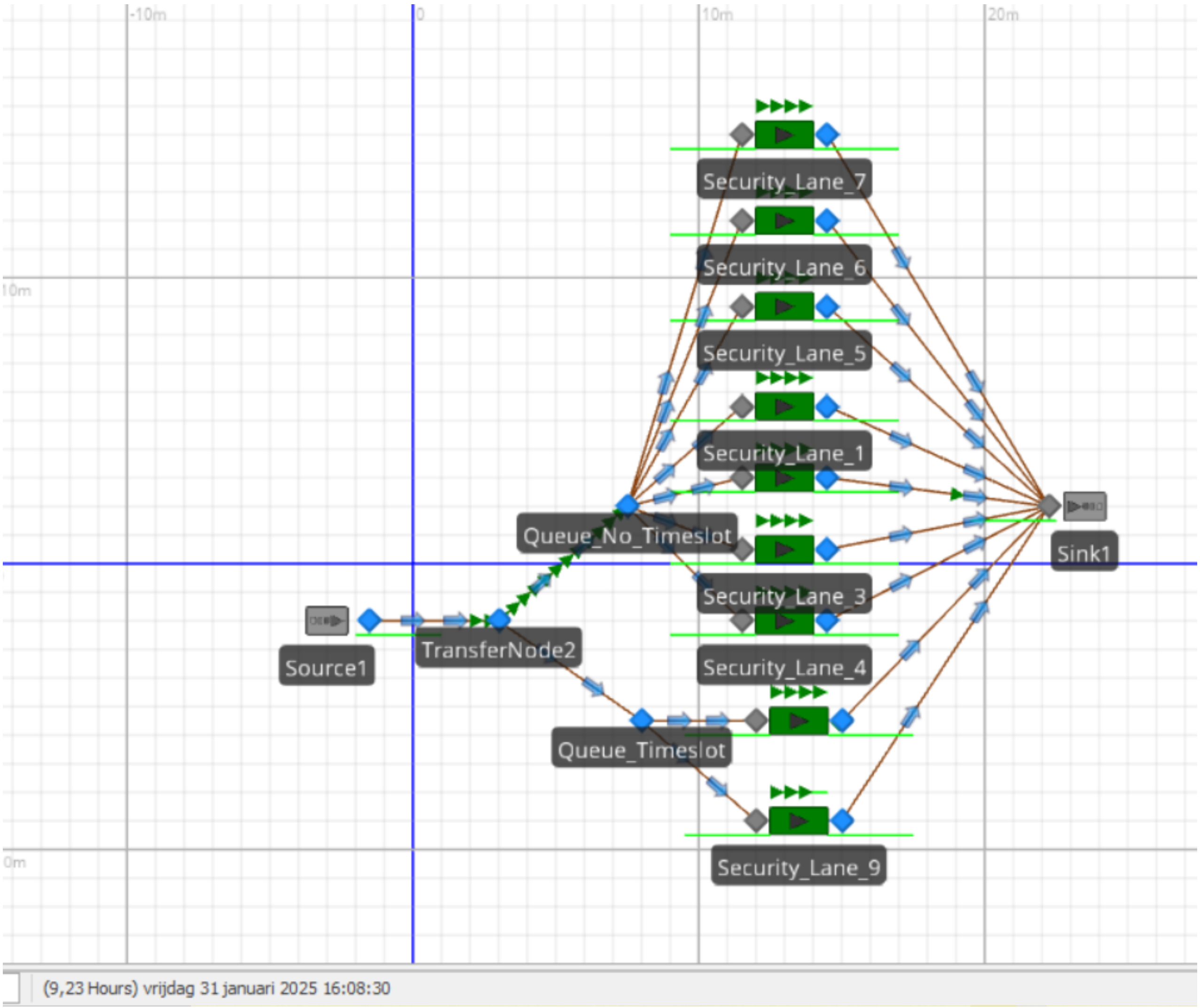

Figure G.13: Validation peak 3

G.5. Peakshaving

Figure G.14: Peakshaving effect 10%

Figure G.15: Peakshaving effect 20%

Figure G.16: Peakshaving effect 30%

Figure G.17: Peakshaving effect 40%

G.6. Boxplots replications

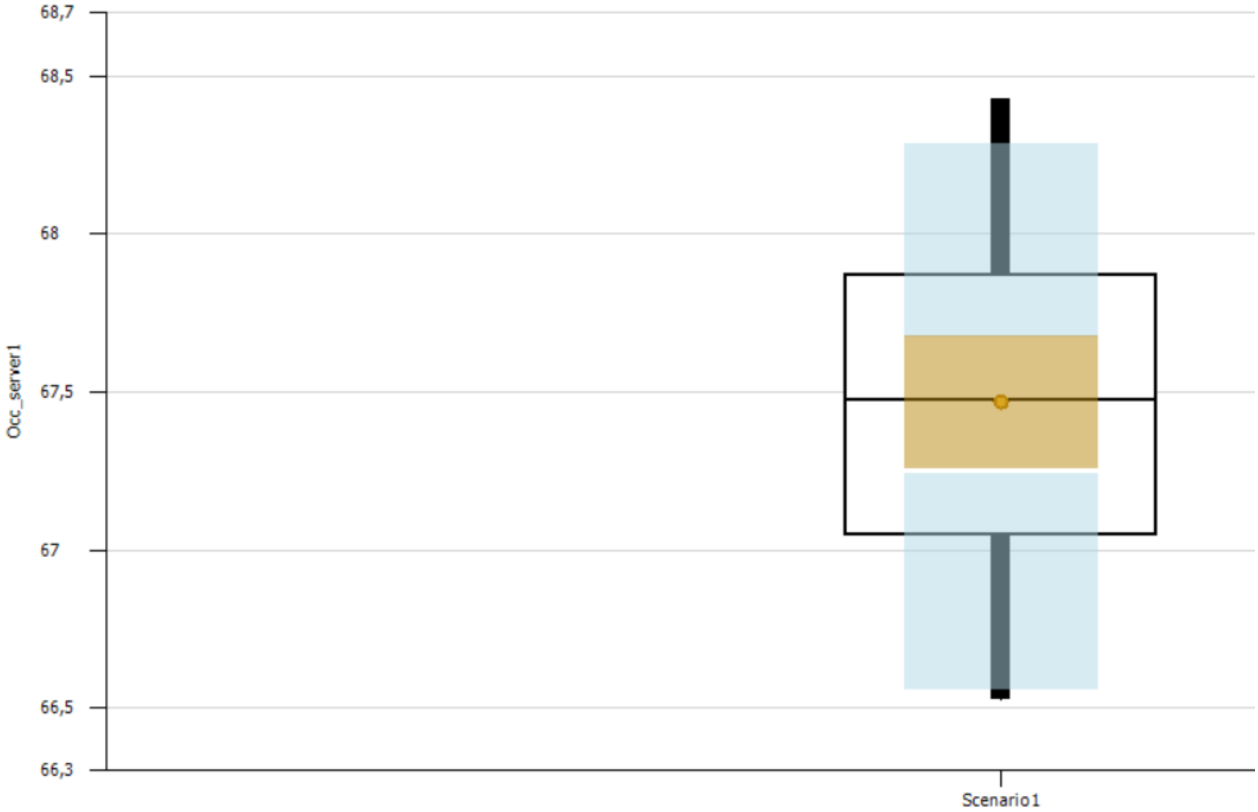

Figure G.18: Boxplot

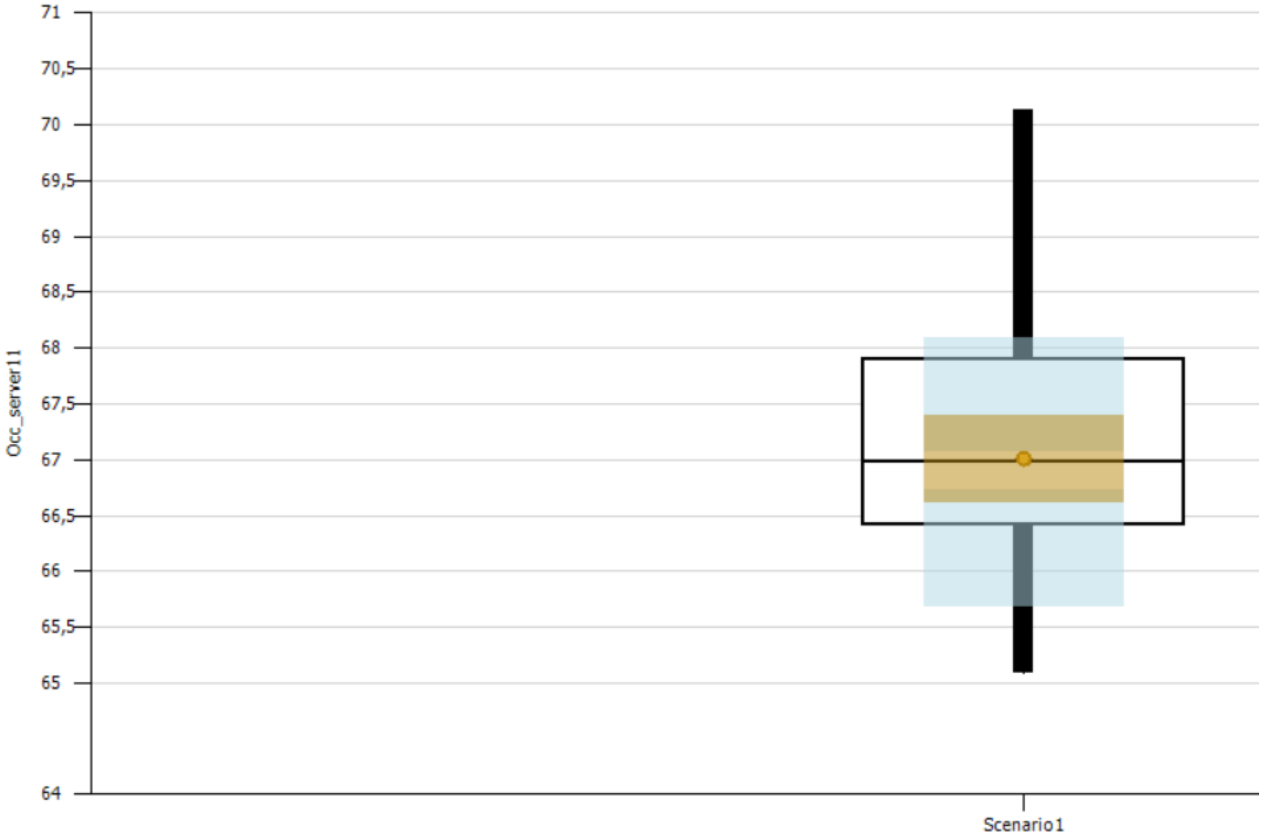

Figure G.19: Boxplot

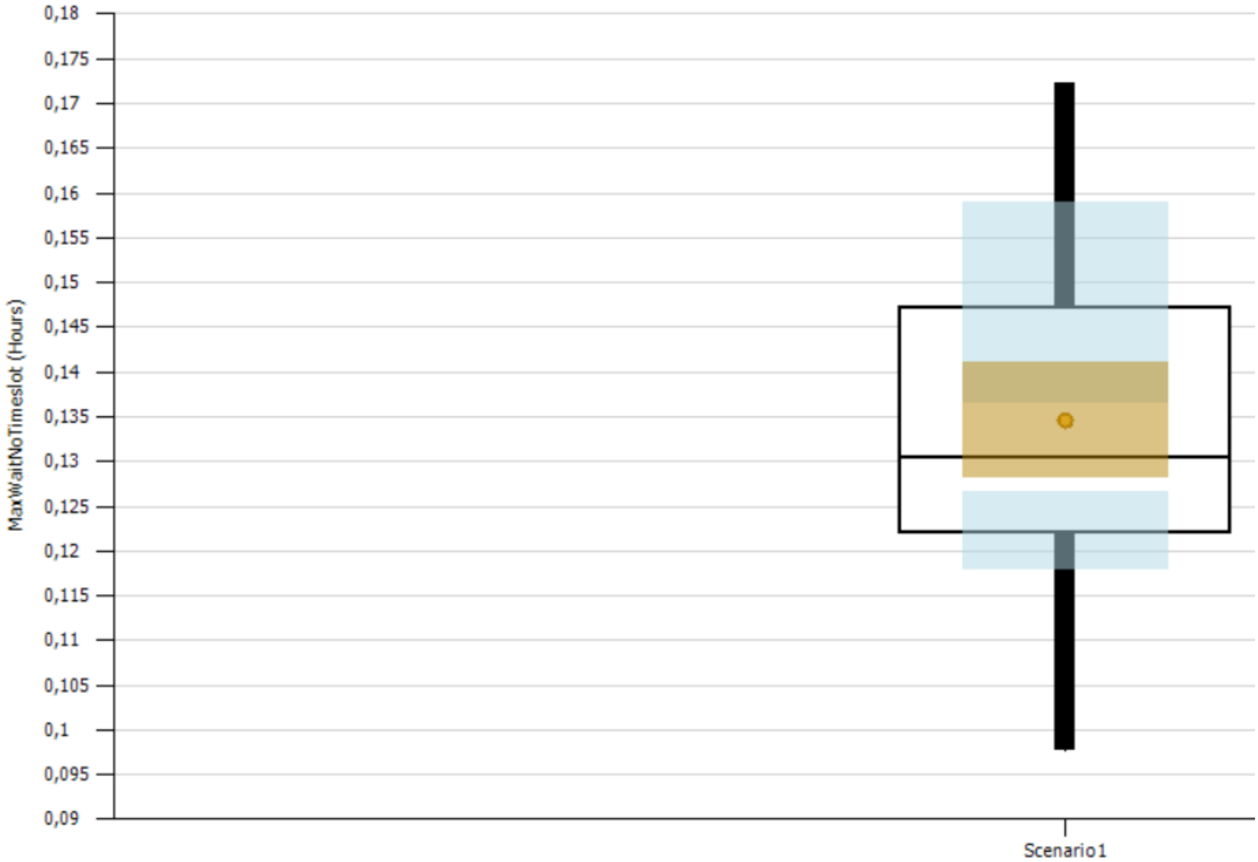

Figure G.20: Boxplot