PERFORMANCE STUDY FOR THE
AMSTERDAM AIRPORT SCHIPHOL BUS STATION

CREATING A BUS STATION SIMULATION TOOL TO OBTAIN PERFORMANCE SCORES

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EXECUTIVE SUMMARY

Introduction

This thesis focuses on the bus station of Amsterdam Airport Schiphol in The Netherlands. A performance study is performed on three criteria: the bus station’s throughput of traffic flow, or: coping with capacity, the safety on the bus lane and quality of the infrastructure as perceived by its user.

There is a projected growth of public transportation through Schiphol Plaza when looking at increasing numbers of air travelers, employees and use of especially the HOV (high quality public transportation) bus lines. There is no knowledge yet on how long the current bus station layout can cope with this growth. This needs to be made clear and a possible solution for appearing bottlenecks needs to be provided.

Methodology

The research on the bus station performance requires methodology that fulfills the requirements of providing performance scores on current and future scenarios for its capacity, quality and safety. For capacity scores it is determined to use average bus delays as suffered at the bus station as units, where also a percentage of buses exceeding the set threshold of 30 seconds delay is taken as a second scoring quantification. For the criterion of quality it is focused on the quality of the infrastructure as perceived by the traveler. The one quality feature that is chosen to be quantified is bus platform pedestrian density.

Using the definitions of these criteria the selected method is a microscopic time-and space-continuous traffic simulation in the form of a tool from-scratch. This tool has the ability of simulating individual buses as well as individual pedestrians. The tool will be able to generate the passengers from and to the buses. The arrivals of buses and pedestrians is linked to input files including bus timetables, train timetables and bus characteristics.

Analysis of the current bus station layout

For the performance up until 2040 use has been of three passenger growth scenarios: the base scenario based on Schiphol prognoses, a 20% higher growth scenario and a 20% lower growth scenario. Application of the simulation tool to Schiphol Plaza’s bus station leads to the observation that although no all-congesting bottlenecks appear in the future until 2040, the performance for capacity and safety soon dip below the set thresholds: in 2027 the quantified safety risk has doubled and in 2040 over 60% of the buses suffers a delay of more than 30 seconds at the bus station. To maintain the quality of the bus station design concepts are provided that could improve the criteria to acceptable levels. From the results follows that special attention should be given to the bus-pedestrian conflicts.

Design concepts for the bus station

Three groups of three proposals are considered: solutions in the form of capacity expansion, concepts for pedestrian rerouting and concepts of reducing bus-pedestrian conflicts. Of each group one is selected through Multi-Criteria Analysis (MCA). The chosen design concepts are:
• Expansion of the bus station by replacing the parallel lanes for public use, Kiss & Ride and the parking garage with a second dedicated bus lane with bus stops. This is a doubling of the capacity in theory.
• Creating an alternative access point from the traverse crossing the roads at the bus station towards the bus platform. By making this the only allowed access point all bus-pedestrian conflicts on the roads are removed.
• Creating an access point from the bus station platforms underneath the bus station. All bus users coming from the train station have a direct access point and do not need to cross any roads. The pedestrian flow at the zebra crossing is severely decreased.

All three concepts are analyzed making use of the simulation tool. They are compared on the same criteria again and a MCA is made.

Results

The traverse access point has the best score of the three design concepts and the zero-alternative. It outscores the other options on the scores of throughput and safety, as well as being less costly than creating a new bus lane or a access through the solid ground towards the train station.

Conclusions

More than might be expected is the interaction between bus and pedestrian leading in the ever growing congestion on Schiphol Plaza’s bus station. Removing this interaction has appeared to be a realistic option and has proven to be highly successful. With such a measure there will be no need for a capacity expansion, since the road capacity is not always leading in the question about bus station capacity. This appears to be the case at Schiphol and solutions are offered. Also does the simulation tool give the opportunity to test variants of the bus station by varying bus stop locations, timetables or pedestrians crossings. It is a user-friendly tool that can help Schiphol as well in obtaining more insight for the new 2025 Master Plan.

Recommendations

Following this research further could be looked into the offered concepts by more closely estimating the costs and exact implications of the construction. Also regarding the simulation tool there is more detailed data that could be obtained through on site research towards identifying pedestrians, their origin and destination. Together with further enhancement of the simulation tool even more possible solutions might appear.
PREFACE

Presented here is the thesis of the graduation research (TIL5050) on the bus station at Schiphol Plaza, the main entrance of Amsterdam Airport Schiphol. The researched is conducted as the master thesis for Delft University of Technology master ‘Transport, Infrastructure and Logistics’.

The research is conducted as commissioned by the institute SIM (Samenwerking Innovatieve Mainport, or ‘Cooperation Innovative Mainport’), which is an alliance between the aviation related parties Delft University of Technology, Schiphol Group N.V., TNO (Dutch knowledge institute for applied research), National Aerospace Laboratory (NLS) and the Dutch flag carrier Koninklijke Luchtvaartmaatschappij (KLM). It provides a platform for graduating students to help Schiphol in their goal of being an innovative mainport in Europe. Through this platform, based at Schiphol Airport, the thesis is organized, but the source of this project lies at the division of Traffic & Transportation, which is in turn a subdivision of Passenger Services at the airport. Traffic & Transportation is the division responsible for all landside activity related to Schiphol’s accessibility. This includes the contracts with the Dutch Railways (NS) for the rail station, the management of the access roads, taxi contracting and the bus station. At Traffic & Transportation Sjoerd de Lange has been the primary mentor, who has been able to provide information and support.

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This leads to the acknowledgements for those who have supported me in realizing this thesis. First of all, I highly appreciate the support of I have received from the graduation committee. From the TU Delft: Winnie Daamen (Civil Engineering, Transport & Planning), John Baggen (TBM, Transport & Logistics), and Serge Hoogendoorn (Civil Engineering, Transport & Planning). I would like to thank you for the guidance I have been given in this process. The directions were very helpful in creating this thesis. Special thanks also to Sjoerd de Lange for all the support he has given during my time at Schiphol. At any given moment he had time to answer questions or provide me with information and data. It was also a very pleasant time with the whole division of Traffic & Transportation. Thank you to all the colleagues there and at the division of ADI, the home base of SIM and a very welcoming place for graduating students. Also the other graduates at Schiphol, friends and family have been very supportive for which I would like to thank all.

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Delft, December 13th 2011
# Contents

**Executive Summary** ................................................................. 2

**Preface** ...................................................................................... 4

1 Introduction .................................................................................. 8
   1.1 General Introduction ............................................................. 8
   1.2 Problem Definition .............................................................. 9
   1.3 Objectives and Research Questions ...................................... 11
   1.4 Scientific and Practical Relevance ....................................... 12
   1.5 Outline of the Report ........................................................... 13

2 Introduction to Amsterdam Airport Schiphol and its bus station .... 16
   2.1 Introduction to Amsterdam Airport Schiphol and its accessibility 16
   2.2 An Introduction to the Public Bus System of Schiphol ............ 17
   2.3 Description of the Bus Station .............................................. 20
   2.4 Stakeholder Analysis ........................................................... 23
   2.5 Concluding Remarks of this Chapter .................................. 25

3 Research Methodology ............................................................... 26
   3.1 General Method Decision ..................................................... 26
   3.2 User and Functional Requirements of the Simulation Tool ...... 26
   3.3 Defining Spatial Scope and Level of Detail ..................... 28
   3.4 Time Frame for the Research ............................................. 32
   3.5 Types of Input and Output for the Simulation ...................... 34
   3.6 Methodology for Input Data Collection and Interpretation ...... 37
   3.7 Methodology for the Modeling Phase .................................. 43
   3.8 Concluding Remarks ......................................................... 45

4 Bus Station Simulation Tool Description .................................... 46
   4.1 Simulation Tool Theory and Assumptions .......................... 46
   4.2 General Set-up of the Simulation Tool ............................... 47
   4.3 The Main Function: The Central Simulation ....................... 49
   4.4 Input Processing ................................................................. 52
   4.5 The Bus Timetable Function ............................................... 54
   4.6 Pedestrian Dynamics Function ............................................ 55
   4.7 Bus Dynamics Function ...................................................... 58
   4.8 Practical Applications and Generality of the Tool ............... 61
   4.9 Validation and Calibration of the Tool ............................... 61
1 INTRODUCTION

This chapter aims to get an insight into the basis of this thesis, including the problem definition, objective and research questions. It starts off with a general introduction to the subject in paragraph 1.1. Paragraph 1.2 provides the problem definition where the origin and nature of the problem becomes clear and the problem owner is defined. Paragraph 1.3 describes the objectives that will be followed in order to solve the problem and the research questions that guide that process and which will be answered in this document. Using the knowledge of the research questions and design objective, an estimation of the project's scientific and practical value is provided in paragraph 1.4. The last paragraph guides the reader through the whole document by explaining the structure and visualizing it in a graph.

1.1 GENERAL INTRODUCTION

This thesis focuses on the bus station of Amsterdam Airport Schiphol in The Netherlands. A performance study is performed on three criteria: the bus station's throughput of traffic flow, or: coping with capacity, the safety on the bus lane and quality of the infrastructure as perceived by its user.

The reasoning of this project is the projected growth of Schiphol Airport and in particular the growth of the number of public bus users. Not only the passenger growth at the airport, but the importance of Schiphol Plaza as a central public transportation node in the Amsterdam region as well as the growing High Speed Line services are the drivers of this projection. To be able to cope with the increased travel demand, the infrastructure needs to maintain sufficient capacity, safety on the roads and platforms, and quality of services – amongst other things as a result of the infrastructure – as perceived by the users. These three criteria combined represent the goal of Schiphol to have the highest quality bus station possible: with sufficient capacity no congestion will occur on these access roads and the bus station will not create (additional) delays, sufficient safety will protect both employees within Schiphol area, air travelers and intermodal transfer passengers, while the criterion quality is responsible for all other quality aspects as perceived by these users besides punctuality and safety. In this project the first extensive research is performed on these criteria combined for the Schiphol Plaza bus station. The criteria are assessed for the current situation and for the future with the eye on the 2025 Master Plan. This way an appearing bottleneck can be identified and action can be taken. The type of action that is advised to be taken is to result from this research. This research will consequently be a tool in advising on the landside Masterplan design. The absence of data from research on the bus station is the main reason for starting this project, since without it any preference of the Traffic & Transportation division on a new bus station design would be unfounded.
1.2 PROBLEM DEFINITION

Amsterdam Airport Schiphol is the main airport of The Netherlands and one of the leading airports in Europe in terms of passenger movements. It ranks high in Europe’s top lists when it comes to quality, especially in the field of accessibility. However, the overall rank of Schiphol in Europe is starting to decline, mainly as a result of recent developments at competing airports. This is mainly on other fields than accessibility, on the field of accessibility Schiphol ranks second below Frankfurt Airport. Direct competitors in Europe are expanding more rapidly than Schiphol, which is why Schiphol is busy setting up the Master Plan for 2025. In order not to lose terrain on the accessibility landside layout will change as well. For this change data is required on how the landside features perform. For the bus station there is little data available. Data is gathered on the actual arrival times of buses, but this only indicates earlier suffered delays. Likewise, no data is available on any safety performance of this part of the infrastructure and existing quality figures describe only the quality of the operators, instead of the infrastructure.

To stop a decline in Schiphol’s position of the quality ranks, or even improve its rank, Schiphol needs to review its quality standards of the bus station. Amongst other things it needs to look into the future and see whether (and until when) the aforementioned quality, capacity and safety of the landside access infrastructure is sufficient and can still compete with rival airports.

An important aspect of the accessibility of Schiphol is the public transportation system and in particular the public bus system, since most workers within Schiphol area make use of it (also those arriving by car and having to transfer to the local bus to get to their work) and it is one of the main intermodal transfer hubs of the region. Schiphol Plaza, the main entrance / exit area of the airport, lies directly next to the road infrastructure for both person cars, public buses, shuttle buses, coaches and taxis. The projected increasing number of passengers is just a minor factor in the required capacity of the public bus system. The largest group of users is the employees at Schiphol and in the Schiphol area. When the airport expands, this group will expand as well. Schiphol Plaza will become a busier and more important public transportation node in the near future. This is the goal of the regional authorities in compliance with Schiphol, but it is also the logical reaction if the public transport network expands and the quality of the service improves. This will lead to a significant increase in the use of regional buses, especially the increasingly popular Zuidtangent. Plans for the extension of the regional bus network are already there [Metropoolregio Amsterdam, 2009], meaning that the main stop of the region is required to have sufficient quality and capacity in the future.

What the increase in bus traffic and its passenger demand and supply will mean for the current bus station layout in terms of capacity, safety and quality is not known. No research has yet been done on the performance of this layout, but it is noticed that current situations are rather busy during peak hours. From interviews it follows that most users experience a not entirely safe and busy bus station, with 86 buses per hour per direction as can be found in Table 5.1. Other than that the criteria are not yet be quantified. The goal of this project is to provide this quantification and to find out how the capacity, safety and quality of this bus infrastructure will change as the amount of users increases as time passes on. Any appearing bottleneck or exceedance of set limits will be noted, including the year in which it is expected to appear. This way the rate of urgency and the deciding factor of the bottleneck can be made clear. This paves the way for new directions within a future design for this public transportation node.
Performance study for the Amsterdam Airport Schiphol bus station

The projected findings will be of value in the decision making process of creating or expanding the bus station where they can have an active role rather than a passive role. In other words, the direction of the design of new landside infrastructure can be influenced by the findings and possible design proposals for the bus lanes, instead of only vice versa. Also it could be used as a tool in negotiations for infrastructure funding. This will be aided by delivering findings in a presentable format where the main results are made clear.

The problem statement could be summarized as follows:

The problem
There is a projected growth of public transportation through Schiphol Plaza when looking at increasing numbers of air travelers, employees and use of especially the HOV bus lines. There is no knowledge yet on how long the current bus lane layout can cope with this growth. This needs to be made clear and a possible solution for appearing bottlenecks needs to be provided.

Who is the problem owner?
The main involved actors are all users and providers of bus services at Schiphol. If the demand exceeds the capacity both the users and service providers will be affected by the problem, but if quality or safety exceeds the minimum in direct sense it will be mainly the users. However, if for any reason less people will be using the bus system, the bus companies are affected by this problem again. As Schiphol aims for high quality, safety and accessibility of the airport, all scenarios of a worsening of any of those factors will affect Schiphol as a company. Because the problem has been introduced by Amsterdam Airport Schiphol as a thesis subject, the fact that Schiphol Group is responsible for the bus station and the fact that for Schiphol customer satisfaction is number one priority – a factor that is highly influenced by quality of accessibility - in the end the main problem owner is the company Schiphol Group. Table 5.1 in paragraph 4.2 provides the overview of all actors in this problem in an actor analysis followed by their interests concerning this research's subject.
1.3 **OBJECTIVES AND RESEARCH QUESTIONS**

The most important goal for Amsterdam Airport Schiphol is to have an undisturbed high quality accessibility for all transportation modes, amongst which is the public bus system. It is important for Schiphol to have a method or study available that provides figures on the quality of this bus system, in particular the performance of the bus station, since it will have to make decisions for the 2025 Master Plan on the design of this infrastructure. This research will provide this method and using the results will come to an adjusted version of the bus station that will satisfy the goal for future demands as well, or if the current layout satisfies the goal the advice will be to have no adjustments.

Therefore the main objective of this study is to assess the Schiphol Plaza bus station on throughput of buses and passengers, quality as perceived by the users and road safety for bus passengers and pedestrians. The system that is the bus station is a complex interaction of pedestrians and buses in which most of the pedestrians originate as passengers of the bus or vice versa. Therefore this requires a method able to handle this complexity. The chosen method should be able to process the current Schiphol Plaza bus station and versions with infrastructural modifications and time table modifications.

Below are the research questions that guide the process of this research.

**Main research question:** “How can Amsterdam Airport Schiphol meet the future demands of users of the public bus station at Schiphol Plaza while maintaining high quality and safety standards?”

- **RQ1:** What are the standards and scoring techniques for bus throughput (capacity), quality and safety for a bus station?
- **RQ2:** How does the Schiphol Plaza bus infrastructure score on these fields?
  - **RQ2.1:** How does the current bus station layout score on throughput /capacity?
  - **RQ2.2:** How does the current bus station layout score on quality?
  - **RQ2.3:** How does the current bus station layout score on safety?
  - **RQ2.4:** What is the robustness of the current bus station?
- **RQ3:** What is the estimated performance of the bus station in future?
  - **RQ3.1:** What are the future scenarios for demand and supply of bus station users?
  - **RQ3.2:** At which point in time does a significant bottleneck appear for these scenarios?
  - **RQ3.3:** Is the first appearing bottleneck a capacity, quality or safety bottleneck?
  - **RQ3.4:** What is the severity of the appearing bottleneck?
  - **RQ3.5:** Are there more significant bottlenecks projected between now and 2025?

In this study the chosen method will be applied to the Schiphol Plaza bus station, and it needs to satisfy the main design objective:

“Creating a design concept for a new bus stop layout or otherwise performance improving concept that meets future requirements in terms of capacity, safety and quality.”
The research will provide the following deliverables that lead to the answers to the research questions:

- A bus station simulation tool that can be applied to Schiphol Plaza bus station.
- Growth scenarios of the bus station users, to be used in the simulation.
- The results of the tool applied to the current Schiphol Plaza bus station in terms of bus throughput (capacity), quality of the bus station layout as perceived by the users and safety of the bus station layout.
- The results for the same situation, only for various future demand scenarios.
- Proposed adjusted layouts for the bus station and/or adjustments that do not require layout change, such as a different allocation of stops for the buses.
- The results of the tool applied to these new variations for each scenario, including the current scenario (zero-scenario).

1.4 **Scientific and Practical Relevance**

The practical relevance of this research is the added value for Schiphol Group of knowing current and future performance figures of their bus station at Schiphol Plaza. Also the prognoses of the performance figures for the future, including an indication whether there will be a bottleneck and when, is of great value for Schiphol. The information on the bus station that follows from this research is the first data available in terms of throughput of this bus station, other than the accumulation of actual arrival times of buses by a system called GOVI. It is also the first prognosis offered for these values, besides prognoses for the amount of Schiphol employees, and train and air travelers at Schiphol.

The practical use of the research results will be for Schiphol to have some reasoning and aid for opting for a particular layout or design of the bus station in the 2025 Master Plan and for pushing towards this option in the decision making process, which involves many more parties. Already within Schiphol airport there are different views and interests concerning the landside infrastructure and the added value of this research will specifically aid the department of Traffic & Transportation in the discussion.

The scientific relevance of this research can mainly be found in the methodology of obtaining the performance figures of the bus station. Since the research focuses on a specific case there is no actual scientific relevance of the performance figures themselves. The research methodology will have the ability to at least provide performance figures in current and future (prognosed) scenarios of Schiphol's bus station. The rate of genericalness of this method partly determines the added value to science of this research method. Also it requires capabilities, or a combination of capabilities that is not yet available anywhere to be scientifically relevant. Chapter 3 will discuss the chosen methodology and in Chapter 10 the conclusions are drawn of the research and it will be explained whether the research or research methodology is scientifically relevant.
1.5 OUTLINE OF THE REPORT

This report is built up according to the structure of the research and follows largely the chronological order. Chapter 1 provides the introduction to the whole research, including its structure, the problem definition and research questions. It forms the basis of the report further exploration.

Next chapter, Chapter 2, provides a further introduction into the subject of the research: Amsterdam Airport Schiphol and in particular its bus station at Plaza. It serves as background information for the succeeding chapters.

Now that the path is known and the goal of the research is clear, the methodology for achieving this goal can be determined in Chapter 3. It will also provide the answers for the first research question on the definition and techniques for scoring a bus station on capacity, safety and quality. Chapter 4 provides further explanation of the main element of the methodology, the simulation tool.

Now that the methodology for obtaining the results are known, some preparation is required before starting to perform the result generation. The simulation tool requires input, which has to be collected and analyzed. The data will be filtered for the relevant elements and set in the right format. This process is explained in Chapter 5. Also, for generation results for future moments in time a set of scenarios is required. This will provide numbers of bus users for each year, given for multiple scenarios, so that prognoses on the bus station performance are covered for a wider range of prognoses outcomes. The scenarios are provided in Chapter 6.

The actual results following from application of the tool to Schiphol Plaza's bus station start in Chapter 7. These are the results of the current layout for the different scenarios discussed in the previous chapter. The bus station is scored on the criteria that are determined earlier in the report in Chapter 3. The next chapter, Chapter 8, provides alternative design concepts that potentially remove the bottlenecks or breaches of criteria limits. They are selected from three sets of proposals, which are tested on their expected performance. In Chapter 9 the three selected alternative design concepts are tested using the simulation tool and using a Multi-Criteria Analysis the best scoring alternative is indicated. The result from this chapter is the proposal for a design that ensures Schiphol's goal of having a bus station with sufficient capacity, safety and quality now and in the future.

The implications of the results from Chapter 9 lead to conclusions on the research and implications for the different stakeholders. Recommendations are made for further steps resulting from this research and for enhancement and improvement of the methodology used in the research. The conclusions and recommendations are provided in Chapter 10.

Figure 1.1 shows the relationship between the chapters and the various phases of the research. This flow diagram in combination with the text from this paragraph serves as a guide for the rest of the document.
FIGURE 1.1: AN OVERVIEW OF THE FLOWS THROUGH THE CHAPTERS
2 INTRODUCTION TO AMSTERDAM AIRPORT SCHIPHOL AND ITS BUS STATION

In this chapter the subject of this thesis is introduced: the bus station at Amsterdam Airport Schiphol. In paragraph 2.1 an introduction of the airport itself is given. This is provided to introduce the surroundings of the subject and to give an insight in the situation in which the bus station exists. Paragraph 2.2 provides more information about the bus system in general, while paragraph 2.3 discusses the Schiphol Plaza bus station, the subject of this thesis.

2.1 INTRODUCTION TO AMSTERDAM AIRPORT SCHIPHOL AND ITS ACCESSIBILITY

Amsterdam Airport Schiphol is one of the busiest airports of Europe and a major hub for transfers around the world. It is responsible for an annual passenger number of 45.2 million (2010), which ranks Schiphol as 14th busiest airport in the world and 5th busiest in Europe [Airport Council International website, 2011]. It is situated in the Haarlemmermeer polder, just a few kilometers southwest of Amsterdam, in the middle of the Randstad agglomeration. Since the location is amidst several large cities in one of the densest populated areas of the world, infrastructure is surrounding it, including the A4, A9, A5 freeways and direct rail connections to Amsterdam, Leiden and Utrecht. Figure 2.1 shows that the airport is situated directly next to the A4 freeway, one of the main connectors in the Randstad, which also connects the airport to the freeway network. The A4 almost immediately leads to the outer and inner ring of Amsterdam, which connects to several directions all around the Netherlands. Besides the road infrastructure, the airport has its own train station as well, which is lying on the north-south route from Amsterdam to The Hague, Rotterdam and further. There is a bus station that connects both airport passengers, train passengers and Schiphol area workers to and from the main entrance of the airport, Schiphol Plaza, with the regional bus network, the local Schiphol bus network and the train network.

Next to the public transportation connections there is also easy access to taxis, coaches and shuttle services through the access road passing the Terminals on two levels: the departure halls (level 1) and the arrival halls (level 0). Table 2.1 provides some key figures about Schiphol and its accessibility.

<table>
<thead>
<tr>
<th>Schiphol information:</th>
<th>Value:</th>
</tr>
</thead>
<tbody>
<tr>
<td>Area</td>
<td>2787 ha</td>
</tr>
<tr>
<td>Passengers per year</td>
<td>45.2 million</td>
</tr>
<tr>
<td>o Of which arriving / departing (purely) by public bus</td>
<td>1.5 million</td>
</tr>
<tr>
<td>o Of which arriving / departing by train</td>
<td>15.9 million</td>
</tr>
<tr>
<td>o Of which arriving / departing by personal car</td>
<td>20.7 million</td>
</tr>
<tr>
<td>o Of which arriving / departing by taxi</td>
<td>7.1 million</td>
</tr>
<tr>
<td>Employees in Schiphol area</td>
<td>~60,000</td>
</tr>
<tr>
<td>o Of which arriving / departing by public bus</td>
<td>5.200</td>
</tr>
<tr>
<td>o Of which arriving / departing by train</td>
<td>12.000</td>
</tr>
<tr>
<td>o Of which arriving / departing by personal car</td>
<td>34.000</td>
</tr>
<tr>
<td>o Of which arriving / departing by other mode (bicycle, carpool, etc.)</td>
<td>8.800</td>
</tr>
</tbody>
</table>
Schiphol is considered to be one of the leading airports when considering quality. This can be in the form of available facilities, ground personnel service, but also public transportation connectivity. On this field the airport scores at least four out of five stars for all public transportation factors at the official Skytrax airport ranking. For these factors Schiphol is only outscored (slightly) by Frankfurt and Zürich airport, which both have 4.5 stars for the downtown express [Skytrax website, 2011]. A high quality bus station with high frequencies and connections to all around the Schiphol area and the outer region contributes to a high airport performance.

2.2 AN INTRODUCTION TO THE PUBLIC BUS SYSTEM OF SCHIPHOL

The public bus system in and around Schiphol is extensive in the sense that it combines a local (Schiphol area) network, a regular regional network with connections to surrounding towns and cities and a high quality regional network, Zuidtangent, that mostly consists of dedicated bus lanes. Besides that, it is extensively used, in particular by employees throughout the Schiphol area, which is the area owned by Schiphol and can be seen in grey in Figure 2.1. The modal split of all employees using public transportation is measured to be about 35.5%, with about 8.6% of all employees travelling the largest distance by bus [SOAB Adviseurs, 2011]. In paragraph 2.2.1 the bus system will be explained, whereas in paragraph 2.2.2 a comparison is made with other airports to indicate competitors of Schiphol and to see how their public transportation accessibility, in particular the bus connections, perform.
2.2.1 THE BUS SYSTEM IN AND AROUND SCHIPHOL

There are three network levels of bus services involved when considering the public bus alone: local buses for travel around Schiphol-area, medium haul regional buses that travel to nearby towns and cities and the so-called HOV-network (‘Hoogwaardig Openbaar Vervoer’, High-class Public Transportation).

The local bus company is Schiphol Sternet, which is aimed at traveling within the Schiphol area, mainly for employees of Schiphol and other companies based in the area, as well as travelers to and from more distant parking spaces for the airport. This service started in 2000 with the goal of integrating public and private (employee) transportation within the Schiphol area and to neighboring towns. In this area the frequencies are high, about one bus every 2.5 minute, and there are additional connections to neighboring towns every 30 minutes outside and 15 minutes during rush hour. In total there are 14 lines, including one night service. Eleven of the lines are serviced by major bus company Connexxion and three are serviced by the Amsterdam public transportation company GVB. Through this network Schiphol is connected to Amstelveen bus station and the train stations of Amsterdam Sloterdijk, Amsterdam Zuid and Hoofddorp [Schiphol Sternet website, 2010].

Besides the services for Sternet Connexxion also has its own lines that include Schiphol in the trajectory. These lines are not part of the Sternet and not specifically aimed at employee transportation within Schiphol, but more at connecting nearby towns to Schiphol and each other. For Connexxion these are lines 60, 177, 208, 215, 216, 256, 277 and 370 which connect (amongst other places) Haarlem, Leiden, Alphen a/d Rijn, Almere and Noordwijk. Next to Connexxion there is one other line that is served by GVB, line 245 between Schiphol South and Amsterdam North, which only serves during rush hours. An overview of all lines in the region of Schiphol is found in figure 2.2 [Connexxion, 2011].

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FIGURE 2.2: OVERVIEW OF BUS ROUTES IN AND AROUND SCHIPHOL [SOURCE: CONNEXXION, 2011]
The highest network level of bus services at Schiphol is that of the HOV-network, a high quality, high frequency bus network with mainly dedicated lanes in its network. The service, offered by Connexxion as well, is called the Zuidtangent. These services are performed by articulated buses that have a higher quality than other services in terms of interior spacing, seating and leveled exits. Also, thanks to the dedicated lanes the average speed that can be achieved outside the city centers and Schiphol Plaza is considerably higher. The service consists of two tangential connections: line 300 and 310. Line 300 leads from Haarlem station to Amsterdam Bijlmer Arena station and passes through Hoofddorp, Schiphol and Amstelveen. Line 310 follows largely the same route, but starts in Nieuw-Vennep and ends at Amsterdam Zuid station. [Goudappel Coffeng, 2010]

![Current Zuidtangent Routes](source: Website Provincie Noord-Holland)

The popularity of the Zuidtangent and the increasing importance of Schiphol as a major hub of the Amsterdam region are the main reasons that these services are to be expanded in the future. One expansion that is already planned is a new HOV service: the Westtangent. This service will connect Schiphol with Amsterdam Sloterdijk station. This connection is already served by many lines, but the quality and travel time could be significantly improved by providing it with a dedicated bus lane. [Gemeente Amsterdam Dienst Ruimtelijke Ordening, 2010].

An overview of the Zuidtangent lines is found in Figure 2.3.

2.2.2 Schiphol Public Transportation Compared to Other Airports

The layout of Schiphol is unique in the sense that public transportation is very close to the terminals. If the layout is compared to other main European airports the differences can be noticed:
Paris-Charles de Gaulle has a central train station, but the only available buses are shuttle buses to Paris centre, some nearby train stations and other airports.

London Heathrow does have connections to local and regional bus lines, but has no train station. It does however have a metro station and the light rail link to London: Heathrow Express. [Heathrow Airport website, 2009]

Frankfurt Airport does have two railway stations and is therefore well connected to the rail network. There are however few bus connections to the airport, which is reflected in the fact that only 5.3% of the passengers arrive at the airport by bus, of which only 0.5% is considered public transport, the rest being airport and hotel buses. [Fraport website, 2010].

2.3 DESCRIPTION OF THE BUS STATION

The main bus stop in the Schiphol area is at Schiphol Plaza, the main entrance to the airport. This is also the location of Schiphol’s central bus station, which means that the bus stop is used by people transferring from train to bus and vice versa (both regional and local), employees working at Schiphol Plaza living in the region and travelers from the airport that use the bus for the access to and from Schiphol. The daily amount of movements is about 37000.

This is one of the three main types of bus stations as distinguished by De Boer (2010):

- Conflict-free type, or street side bus stations: the passengers have a direct connection to the train station or other central access building. There are no pedestrian-bus conflicts.
- Concentrated conflict type, or double streetside bus station. Usually this type consist of a single elongated island. The pedestrian-bus conflicts are concentrated at clearly distinguishable bus platform access locations.
- Diffuse conflict bus station types, where the bus station consist of multiple smaller islands. These are bus stations with more complex dynamics of buses and pedestrians. This is the reason for the term ‘diffuse’ when considering the bus-pedestrian conflicts. Pedestrians have no concentrated location of crossing the roads and it can get somewhat chaotic on the roads of this type of bus stations during peak hours. There are many different layouts possible. Usually it consists of several parallel islands, usually diagonally oriented compared to surrounding infrastructure.
Schiphol Plaza bus station has bus stops on both street sides, but is more comparable to the concentrate conflict type. Although the buses do not stop at both sides of the island, there is a clear conflict between pedestrians and buses at the zebra crossings that have to be taken to get to the western side of the bus station.

Still the layout is not complex, as can be seen in figures 2.4 and 2.5: one dedicated road with one lane in both directions, and platforms on each side. This is one of the four parallel roads (lanes):

- **A-lane**: used by taxis and occasional tour buses, only accessible through a barrier.
- **B-lane**: the dedicated bus lane.
- **C-lane**: open road, mainly used for short stops for picking up passengers and through traffic.
- **D-lane**: open road that leads to the parking entrance of P1.

At the points where the bus lane leaves the bus station area the roads join the access roads for the departure halls in the terminals from the second floor, the dedicated bus lanes. At the south side the buses join the open road network towards Schiphol south and southeast. On the northern end the bus continues on a dedicated bus lane until the far end of northern Schiphol area.
The relevant dimensions of the bus station are given in table 2.2, which contains those numbers that are used as input in the simulation.

**TABLE 2.2: BUS STATION MAIN DIMENSIONS**

<table>
<thead>
<tr>
<th>Dimensions</th>
<th>[m]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Length between taxi lane crossings</td>
<td>330</td>
</tr>
<tr>
<td>Bus lane width</td>
<td>6</td>
</tr>
<tr>
<td>Width including bus stops</td>
<td>12</td>
</tr>
<tr>
<td>Bus platform width</td>
<td>6</td>
</tr>
<tr>
<td>Zebra crossing width</td>
<td>4</td>
</tr>
</tbody>
</table>
2.4 Stakeholder Analysis

For this research it is important to take into account the influence and desires of the most relevant stakeholders. Decisions that potentially follow the result of this research, for instance the change of the bus station infrastructure, affect a range of stakeholders. Its role in the research subject explains how and if it affects certain factors in the system. The importance shows the interest of the stakeholder for the subject. This should be taken seriously as problem owner and therefore indicates the importance of this stakeholder. Finally, the influence the stakeholder has in decision making on the subject is given. This is something that should be taken care of when creating new designs or ideas. If a highly influential stakeholder has no interest in the outcome of such a proposal, there is already a potential conflict. Table 2.5 provides the stakeholder analysis.

**TABLE 2.5: STAKEHOLDER ANALYSIS OF THE STAKEHOLDERS INVOLVED WITH THE SCHIPHOL PLAZA BUS STATION**

<table>
<thead>
<tr>
<th>Stakeholder</th>
<th>Role</th>
<th>Importance</th>
<th>Influence</th>
</tr>
</thead>
<tbody>
<tr>
<td>Schiphol Group NV</td>
<td>Owner of the land and infrastructure (including bus station), initiator of Schiphol Sternet, employer of most of the users.</td>
<td>Highly important: most affected by the bus station as it is a quality feature of the airport and most employees are users.</td>
<td>Highly influential: decision maker on the infrastructure, source of the users (both employees, air travelers and train transit passengers).</td>
</tr>
<tr>
<td>Schiphol area employees</td>
<td>Largest group of users of the bus system, mainly the Schiphol-local Sternet network. Some arrive by car or train and need the bus system for transit, others use only the bus, mostly if live in the region.</td>
<td>Since the Sternet service was specifically created for the enormous amount of people working in this area, it can be said that the importance goes beyond ‘user’. Surveys are often performed to test the satisfaction of the users: High importance.</td>
<td>Medium influence: mainly through satisfaction queries. But as the main client of the Sternet buses and the influence through Schiphol’s involvement with Sternet there are more possibilities for this group to have some influence.</td>
</tr>
<tr>
<td>Air travelers</td>
<td>Users of the airport, of which about 3% uses the bus alone to reach the airport.</td>
<td>Medium / low: a very low percentage uses the bus to get to Schiphol, however this part of the airport ‘experience’ is important in the perceived quality of the airport. Require high quality in infrastructure and services</td>
<td>Medium / low: though the numbers are low, air travelers are highly important to the airport and their quality perception has a great influence on policy.</td>
</tr>
<tr>
<td>Other travelers using the bus system</td>
<td>Users of the bus system that either: transfer from/to the train station, or travel to/through Schiphol by bus only</td>
<td>Medium: are affected by the Schiphol bus station if they transfer, board or alight here and thus require high quality in infrastructure and services.</td>
<td>Medium: many quality assessments are done each year to ensure the satisfaction of the bus users, so their influence is substantial.</td>
</tr>
<tr>
<td>Connexxion</td>
<td>Bus company that serves most lines at Schiphol, some under the name of Schiphol Sternet and Zuidtangent.</td>
<td>Medium: is affected by all infrastructure decisions and any change may affect their services. Is interested in high infrastructure quality and high service quality (as little delay as possible).</td>
<td>Highly influential: their services affect the quality of the bus station as perceived by the users (punctuality). Many decisions, especially on information supply, are taken together with the bus service providers.</td>
</tr>
<tr>
<td>GVB</td>
<td>Amsterdam regional bus company that serves a few bus lines, but may provide more in future. Some include a part of the Sternet lines.</td>
<td>Medium: same as for Connexxion, though it be on just a few lines.</td>
<td>Medium: similar to Connexxion, only serves less lines than Connexxion and is not involved in the often used Zuidtangent.</td>
</tr>
</tbody>
</table>
The general outcomes of this stakeholder analysis are that:

- Schiphol Group as problem owner and most influential stakeholder on landside infrastructure at Schiphol is to be satisfied by the outcome of the research. Its interest lies mainly in the outcomes of the score for the bus station for now and in the future, as well as the design concepts for the bus station. For the design concepts costs will be the most important factor.
- The interest of the users is mainly at the current situation, which will not change directly as a result of this research. However, it is important to think ahead and take future customer satisfaction into account and especially take good care of the quality factor of new bus station proposals.
- Connexxion and GVB are not so much influential in any decision making that could follow the results, but are affected by the outcomes. In particular the interest of the users is of equal interest for these transport companies as the users are their customers. As this is a similar interest as the problem owner, few conflicts of interest are expected concerning this research.
- The governmental stakeholders are less interested in the current score of the bus station itself, but more in general accessibility of the region. However, as main financers they are an important stakeholder when creating new proposals for the bus station in future, especially through the factor of costs.

For every step in this research the interests and implications for the stakeholders need to be taken into account. Any decision that is made might influence a stakeholder in an unacceptable way. These decisions can therefore not be made without checking on the implication for those stakeholders. Also their
interests influences the decisions. For Schiphol the outcome of this research may be a decision making assistance as well.

2.5 CONCLUDING REMARKS OF THIS CHAPTER

An introduction into the subject of this research is given in this chapter. What has become clear is that Schiphol scores high on a European and worldwide level when it comes to accessibility and its public transportation connections. It has an extensive bus network of multiple levels (regional and local) that connects with the centre of the airport operations as well as Schiphol's train station at Schiphol Plaza bus station. This indicates the importance of the bus station for local, regional, national (train network) and even international (through high speed rail connections) connections.

The next step will be to connect the knowledge about the system that is being dealt with to the research problem in order to come with a method to solve the research problem and answer the research questions. Requirements and scope of the methodology are determined by the information given in this chapter. Chapter 3 will provide these requirements and scope and explain how this leads to a research methodology.
3 RESEARCH METHODOLOGY

In this chapter the methodology for the different phases of the research is explained and supported. The research will consist of a literature study, data collection, analysis and design. Sources for data and reasoning for methodology are part of the information given in this chapter. Paragraph 3.1 provides the requirements which sets the path and boundaries for the research and the creation of the tool. Paragraph 3.2 defines the scope from which the level of detail and type of simulation can be deducted. The type of detail is further explained in paragraph 3.3, which deals with the input and output that the simulation should be able to handle. This paragraph also answers the first research question:

RQ1: What are the standards and scoring techniques for bus throughput (capacity), quality and safety for a bus station?

Finally the type of simulation is discussed in paragraph 3.4. After this chapter a choice is made on what the functionality of the tool should be, what the scale of the research and simulation is, and which method is used to create the tool that itself will be the chosen method to answer the remaining research questions.

3.1 GENERAL METHOD DECISION

There are several methods possible for obtaining the required performance figures. Numerically calculating the delay a certain situation on the bus station creates is already a complex calculation. Also determining a safety and quality score requires a different calculation. It can for example be performed by measuring the current situation in terms of delays of the buses and customer satisfaction and processing the results analytically. The desire is to have these calculations for any given time of the day, but also for future scenarios.

To have the ability to test a non-current situation, or a scenario with adjusted bus station characteristics or dimensions, there is a need for a simulation of this hypothetical scenario. This interaction is too complex to analytically assess for each scenario, meaning it demands a simulation tool that is able to test a variation of the bus station.

3.2 USER AND FUNCTIONAL REQUIREMENTS OF THE SIMULATION TOOL

The formulation of the research questions and the conclusions drawn from the stakeholder analysis in paragraph 2.4 lead to a selection of user and functional requirements. The requirements guarantee the (possibility of) answering of the research questions and the best possible fulfillment of the stakeholders’ desires.

User requirements:

- The format of the tool should be able to be adjusted easily. Making a generic tool that can be used for similar but other situations, either at other airports or other bus stations, increases its value and generalizes this project. Adjustments could be: other bus types, new bus stops, other bus stop locations, other / more zebra crossings or different walking routes for the pedestrians.
The tool should be able to read input files easily, preferably also cell values in time format (i.e. arrival and departure times). Generally spoken, the user should not have great difficulty changing the input in order to test other scenarios.

The method should be able to provide a continuous visualization of modeled processes of bus and pedestrian movement in the designated area.

**Functional requirements:**

- The tool should be able to calculate running times of the buses from entering to exiting the area in order to determine the delay. Delay is one of the key factors on which the bus station needs to be scored, in interest of Schiphol, the bus service providers and the users.

- Pedestrians should be ‘generated’ from each bus stopping at the corresponding bus stop where a number of passengers alights. Reversely pedestrians that need to enter that vehicle are generated as well and enter the area from the border. This guarantees the relationship between buses, pedestrians and the bus timetable, which is essential for the simulation to be realistic.

- Pedestrians behavior that should be covered includes their route and their walking speed, which should vary in a realistic manner. These two factors should be determined for each pedestrian individually, so that consequently each pedestrian is modeled individually.

- Pedestrians should behave realistically, meaning that they choose the nearest zebra crossing, walk at varying speeds and occasionally cross somewhere else than a zebra crossing.

- Bus behavior that should be covered includes their route, acceleration and speed. Also all buses should be linked to the corresponding bus number which in turn determines their size, planned arrival time and stopping location.

- There should be an interaction between buses and pedestrians: pedestrians are generated from the buses and buses are held up at zebra crossings when they are occupied. This influences both safety and throughput, meaning it is in interest of particularly Schiphol, the bus service providers, the users and the government bodies (since safety is involved).

- The bus timetable should be read as input, altered according to a normal distribution of delay and early arrivals and then used to generate buses in the simulation. Again this is to ensure a realistic simulation. The tool should be able to include stochastic arrivals of touring cars with large groups of passengers at the other side of the bus lane (C-lane), independent of the general bus process.

- Pedestrians should also be generated independent of the bus (or touring car) process, representing random non-bus users that cross the road.
3.3 DEFINING SPATIAL SCOPE AND LEVEL OF DETAIL

The spatial scope is a collective term for the bordered area that is taken into account within the research and the relevant elements of the infrastructure within this area. Since the study is purely on the infrastructure at Schiphol Plaza the scope is within Schiphol area. The largest scale considered is the Schiphol area and surrounding towns, which is the furthest area that the bus system has a direct effect on.

Boundaries of relevant area

The determination of the spatial scope depends on the desired scale level and relevant areas. By distinguishing different scale levels, levels of detail can be related to each scale. Larger scales, like the entire Schiphol area, do not take microscopic elements such as zebra crossings into account, while on the other hand smaller scales like the bus stop only do not include network elements.

To define the spatial scale the level of detail is required and provided in the form of a list of aspects that are relevant in the research.

Table 3.1 shows possible aspects and states their relevance to the research. Green indicates an important aspect that is influential to either the throughput, capacity, safety or quality of the bus station, while red indicates an aspect that has no or a negligible influence on these factors. The green aspects will be taken into account, while the red aspects will be left out of consideration.

The aspects are chosen following the list of requirements of paragraph 3.2. Each aspect that could be relevant in order to fulfill these requirements is given is considered. As the subject is a part of infrastructure the list consists of elements within this infrastructure or which influence the events within this area.

Those aspects taken into account are compared with the proposed options for spatial scale. This comparison is shown in Figure 3.2. In this table again green and red are used for the aspect-spatial scale combinations. Green indicates relevance or influence of the aspect on that particular scale, while red means that the aspect is not relevant for that scale.
### TABLE 3.1: ASPECTS RATED ON RELEVANCE

<table>
<thead>
<tr>
<th>Aspect:</th>
<th>Relevance:</th>
<th>Rate:</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bus lane capacity / throughput</td>
<td>Very important for high quality services</td>
<td></td>
</tr>
<tr>
<td>Pedestrian flow</td>
<td>Affects the bus flow and thus above aspect</td>
<td></td>
</tr>
<tr>
<td>Bus passenger O/D</td>
<td>Determines the amount of passengers per bus</td>
<td></td>
</tr>
<tr>
<td>Service frequencies</td>
<td>Have influence on first aspect</td>
<td></td>
</tr>
<tr>
<td>Individual bus interaction</td>
<td>Can cause delay in more extreme cases</td>
<td></td>
</tr>
<tr>
<td>Interaction with taxi lane</td>
<td>Always right of way for buses, influence is negligible</td>
<td></td>
</tr>
<tr>
<td>Bus size</td>
<td>Influences the design and size of bus infrastructure</td>
<td></td>
</tr>
<tr>
<td>Zebra crossings</td>
<td>Can cause delay and thus influence first aspect</td>
<td></td>
</tr>
<tr>
<td>Bus platform design</td>
<td>Influences capacity, routes and bus station quality</td>
<td></td>
</tr>
<tr>
<td>Dimensioning of bus stop (road)</td>
<td>Influences the throughput of buses</td>
<td></td>
</tr>
<tr>
<td>Traveler information supply</td>
<td>Connections outside of Schiphol area, due to dedicated bus lane (Zuidtangent) no known bottlenecks affecting the bus station. The goal is to assess the bus station effects on throughput and its capacity, earlier delays are irrelevant to that.</td>
<td></td>
</tr>
<tr>
<td>Connecting freeways</td>
<td>Negligible influence as most of the route is dedicated bus lane. Traffic density very low at the ‘mixed’ infrastructure.</td>
<td></td>
</tr>
<tr>
<td>Connecting public roads</td>
<td>Negligible influence as most of the route is dedicated bus lane. Traffic density very low at the ‘mixed’ infrastructure.</td>
<td></td>
</tr>
<tr>
<td>Touring cars</td>
<td>Very irregular, but can interrupt flow for a while</td>
<td></td>
</tr>
<tr>
<td>Kiss &amp; Ride</td>
<td>An extra supply of pedestrians</td>
<td></td>
</tr>
<tr>
<td>Design of Jan Dellaertplein</td>
<td>Only the bus infrastructure will be influential, not really part of the square</td>
<td></td>
</tr>
</tbody>
</table>

### TABLE 3.2: RELEVANT ASPECTS VERSUS THE SPATIAL SCALES

<table>
<thead>
<tr>
<th>Spatial scale:</th>
<th>Relevant aspects (levels of detail):</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>capacity of bus lane</td>
</tr>
<tr>
<td>1. bus stop(s)</td>
<td></td>
</tr>
<tr>
<td>2. bus lane at Plaza up until taxi lane crossings</td>
<td></td>
</tr>
<tr>
<td>3. bus infra within terminals proximity</td>
<td></td>
</tr>
<tr>
<td>4. bus infra of Schiphol Center</td>
<td></td>
</tr>
<tr>
<td>5. bus infra of total Schiphol area</td>
<td></td>
</tr>
<tr>
<td>6. bus infra of Schiphol + surrounding towns</td>
<td></td>
</tr>
</tbody>
</table>
When taking the first three levels of scale all the aspects are taken into account but one. Only the interaction with lines not stopping at Schiphol Plaza or elsewhere in Schiphol area is not taken into account, but otherwise it would have meant that the entire Schiphol area were the spatial scope and focusing on microscopic aspects as well as the whole Schiphol network would mean a research that is far too extensive for the given time and complexity of programming.

On the other side, the main aspect that scale 3 adds to the research is the interaction with other traffic and it should be questioned whether this is a valuable addition. The first and only point of interaction with other traffic is at the south side where the bus lanes merges with the Havenmeesterweg. Traffic density on this road is relatively low and due to double lanes in both directions and priority for buses a conflict here is not very likely. As the dedicated lanes go beyond the boundaries of the Schiphol area before they reach important intersections and access to the freeway, the effects of spillback on the infrastructure at Schiphol Plaza is minimal when entering the Schiphol terrain. Delays before Schiphol centre area are common, but they are taken into account when determining the throughput of the bus station and not of influence. Also the fact that bus lines take different routes at a certain point is not of any influence for the congestion. Therefore it is decided that scale 1 and 2 are sufficient for a thorough analysis of the infrastructure's performance. A rough indication of the four lowest spatial scales is given in Figure 3.1. Scale 1 is indicated in blue, scale 2 in red, scale 3 in green and scale 4 in purple. Scale 5 is the grey area in Figure 2.1 and scale 6 can be seen as the total area depicted in Figure 2.1.

FIGURE 3.1: SPATIAL SCALES OF THE RESEARCH AREA
At the area near the terminals the spatial boundaries need to be determined as well. The following options are possible:

- Only the bus stop and the platforms.
- Including the Jan van Dellaertplein: so up until (and including) the entries / exits of Schiphol Plaza.
- Up until and including the train platform entries / exits.

For the first option the interaction with Plaza is not present. This is not very realistic as virtually all bus passengers enter and exit Plaza on their route. The question is whether the link is made with arriving trains and consequently with the arrival and departure patterns of potential bus users. This is however a complex aspect to analyze as no data are available on the mix of train passengers in terms of destination (the terminals, or elsewhere at Schiphol). What is essential in this research is those pedestrian accessing the bus station, of which data is available through analysis of the Schiphol worker's mode choice and available train-to-bus vv transfer data which is exactly the data that are needed for modeling the pedestrians to and from the buses [De Lange, 2011]. The actual movement at the train platforms can be left out for that purpose. Therefore it is chosen that it is sufficient to place the spatial scope boundaries at the entries / exits of Schiphol Plaza.

**Relevant elements of the infrastructure**

Now the decision is made to focus on the area within the terminals' proximity, it needs to be clarified which elements of the infrastructure in this area are relevant. The bordering of the considered area is now known. This means that potentially all elements within this area can be considered, however, using the list of relevant aspects in Table 3.2, it will be limited to:

- The bus lane itself between the two crossings with the taxi lane (A-lane), without interaction with the taxis.
- The bus stops.
- The zebra crossings, all three along the bus station and including the crossing of the A and C-lane.
- The bottleneck just past the passenger viaduct, where only one bus can pass at the same time.
- The layout of the bus stop platforms.
- Touring car arrivals (only the passengers who become pedestrians at the zebra crossings).

**Types of bus stations that need to be considered**

Following paragraph 2.3 three types of bus stations are distinguished. It is wise to narrow down the options for the eventual design concepts to only the feasible types of bus stations. The available space is very limited at the terminals and many parties, mostly within Schiphol Group, are fighting over their preferences at this transport hub. The limitation can mean that not all bus stations will be suitable. Also the fact that it is a place with two-way (dedicated) traffic for buses, but one-way for the rest of the vehicles makes it a complex location to fit anything else than a two-way bus lane with curbside bus stops. To have an island platform more space is required than available, unless all other traffic has to make way for the bus station. Turning circles, especially for the longer Zuidtangent buses, make this a difficult option. Multiple parallel islands in diagonal orientation could be an option, but this will also require the other two lanes to be
removed as the diagonal orientation and the length of the buses demand this size of a bus station. It is a capacity friendly solution, but only if bus stop capacity is really the main bottleneck, this option will be taken into account.

3.4 Time Frame for the Research

The time frame for this research will lead from 2011 to a certain year in the future. This year is determined the predictability of the input and relevance for the research and the available prognoses data for this range. Also boundaries need to be set for the total amount of computing, which is limited. Figure 5.3 shows a timeline for predictions and major events. The list of relevant plans and prognoses is given below:

- **Schiphol Group: 2025 Master Plan.**
  - The first upcoming plans for major changes at Schiphol Airport, with 2025 as target year.
  - Still under construction.
  - Relevance to the subject: outcomes of this research may be influential in decision making for the design of the infrastructure at the terminals, in particular the bus station.

- **Schiphol Group prognoses.**
  - The prognoses for both the number of air travelers and the number of Schiphol Area employees are made for up to 2030. The consequent bus use for these groups are processed using these numbers and ready for use in determining future numbers of bus users at Schiphol Plaza. [De Lange, 2011].
  - Relevance: these prognoses are used for determining future bus passenger demand and supply in future scenario's. In other words, this is a time frame in which prognoses on the most important growth figure for this subject exist.

- **OV-Bureau Randstad: Randstadnet 2028.** [OV Bureau Randstad, 2010]
  - Provides the projected public transportation network of the Randstad in 2028
  - This is based on a planning that precedes the creation of the HOV-network.
  - Relevance: indicates future plans for extension of the HOV-network. Relevance is low, however, since prognoses for this time frame are already made.

- **Dutch government: Luchtvaartnota ('Aviation note'), April 2009.**
  - Title: ‘Competitive and sustainable aviation for a strong economy’.
  - Contains prognosis of annual flight number restrictions until 2020.
  - Contains flight movements prognosis for Schiphol for 2020, which are estimated to be between 570,000 and 675,000 movements per year.
  - Relevance: low, this only influences the number of bus users amongst the air travelers, which is a very low number. It does affect the number of employees around Schiphol to some extent, but also for these figures prognoses already exist and are used.

- **Provinces of Noord-Holland and Flevoland and municipalities of Amsterdam and Almere: MRAnet, an HOV-system for the metropolitan region of Amsterdam.**
  - HOV (High-quality public transportation) network for the metropolis of Amsterdam.
  - The goal of this project is to form the backbone of the public transportation in the region, including bus, tram, metro and train.
  - The target year for realization of this network is 2020.
Relevance: contains an overall plan for public transportation in the Amsterdam region, which includes Schiphol. However, these plans are external influences and no major plans have been set in stone that in any case should be taken into account.

The biggest milestone of the list above is 2025, the year where the next master plan is projected on. Since major changes in the infrastructure should preferably become part of this master plan, the time frame at least has to surpass 2025.

For both the analysis on the current bus station and the generation of a design concept for the bus station the time frame is important. The solution for appearing bottlenecks needs to create a robust situation for the future. A new master plan might be expected after the next 15 year period, so in this case in 2040. This could be a suitable end year for the time frame, although the predictability of situations in 2040 is very low. A wide variety of scenarios would then be required.

It is not necessary to hold on to population prognoses for the time scope or the plans of the Randstad 2040 Action Plan, as most of these plans are in very early phase of exploration. It is wiser to hold on to given prognoses and make sure that the span is beyond the important 2025 Master Plan. To be able to deliver a view of the performance in that year and up to 5 years beyond the Master Plan’s 2025 the furthest prognoses known for passenger supply and demand at Schiphol are for 2030. As this is five years past the Master Plan aim, this year is appropriate and therefore chosen as end date of the time span.
3.5 TYPES OF INPUT AND OUTPUT FOR THE SIMULATION

In this paragraph the types of required input and output for the simulation of the bus station are discussed. Not all input and output are necessarily related to the simulation tool. In particular some of the output values (or ‘scores’) cannot be determined by simulating bus and pedestrian flow. Therefore these should be seen as input and output of the research, where a large part is determined by simulation.

3.5.1 INPUT

The elements that will be part of the input depend on the aforementioned relevant elements of the infrastructure and the goal of the research. Since the goal is to test the performance of the bus infrastructure at Schiphol on capacity, quality and safety, all that has its influence on these factors should be considered, unless its influence is expected to be negligible.

The input mainly consists of the factors ‘buses’, ‘pedestrians’ and ‘infrastructure’. All that can be assessed beforehand about these factors can be used as input. The following variables should be adjustable and therefore be able to be used as input for the simulation:

Bus input variables are:

- Time of arrival following the time tables [hr:min:s]
- Realistic distribution of delays and early arrivals, according to existing data: mean and standard deviations. [s]
- Maximum speed on the bus lane [m/s]
- Normal acceleration and deceleration (and maximum for emergency stops) [m/s²]
- Length / width (per bus type) [m]
- Stop location per bus line [m].
- Number of boarding and alighting passengers for each bus, according to supply and demand (see below).

Pedestrian input variables are:

- Supply and demand [numbers /quarter an hour per bus line]
- Numbers of non bus related pedestrians [numbers /quarter an hour]
- Walking speed, including mean and standard deviation [m/s]
- Alighting and boarding rate [pax/s]
- Route over the bus station [m]
- Optional: train timetable and walking distance between train and bus station

Infrastructure input variables are:

- Length of bus station, or assessed area [m]
- Dimensions and locations of bus stops [m]
- Dimensions and locations of zebra crossings [m]
- Dimensions, locations and number of lanes [m]
- Specifications of special features, such as the road narrowing at Schiphol Plaza
3.5.2 **Output**

The output values of the research will be the main stimulators for an improvement to the infrastructure or the introduction of traffic management measures. They form the combined score of the bus station infrastructure performance. The score is split into a capacity/throughput, quality and safety score. The scoring methods are explained below:

**Bus throughput / capacity score**

Infrastructure capacity represents the highest possible traffic volume that can be conveyed by a particular road during a specific time period [Lakshamanan & Anderson, 2001]. In this particular case a special type of road is considered, a dedicated bus lane through a *bus station with multiple berth curbside bus stops*. Though the basic definition of the capacity is the same as mentioned above, the quantification of the values is different from regular roads. The fact that there is dealt with a bus station introduces another complication of determining the capacity. One can think of conflicts between buses entering and exiting the parallel bus stop and interference of pedestrians using the zebra crossings. The punctuality of buses is influenced at the instance when the bus station gets more crowded and buses are delayed due to these conflicts. What will be measured through the simulation is this effect on punctuality, in other words: the (additional) delay suffered through the simulated area, which is generally the bus station. Earlier delays are taken into account, so that the effect of the bus station throughput can be distinguished. The capacity will be quantified as maximum (simulated) throughput of buses in a fixed peak hour period (hour, or x minutes), whereas the punctuality of the buses are quantified as the amount of time a bus needs from entering to exiting the area, compared to the time for this trajectory without any delays.

**Safety score**

The criterion of safety of the bus infrastructure involves the interaction between pedestrians and buses. The main concentration of potential danger is at the zebra crossings. Some accidents have occurred in the past where buses have hit a pedestrian. One can imagine that the risk increases when the frequency of buses increases or when the amount of pedestrians increases.

Safety is a factor that very much interacts with capacity and quality. There exists a tradeoff between capacity on one side and the risk at zebra crossings on the other side. If the traffic volume increases, the amount of users on the platform will be larger as well, thus decreasing the quality perception from the user point of view. The solution in the design phase such that this interaction changes for the better.

To quantify the safety using data is rather difficult in this matter. The existing empirical data are summarily and consists of a small number of collisions of which one has been fatal. It also only represents the current (or recent) scenario and layout of the bus station. The only fatal accident was also not directly related to the layout of the infrastructure. Therefore the safety score is not a value that can be generated purely by the simulation, but with the help of simulation it is assessed for every situation or design. It is quantified by amount of bus-bus interactions and bus-pedestrian interactions per (peak) hour. Less interactions will lead to a higher safety score. The speed of the bus is of importance as well in case of an actual collision, which is why the speed at every interaction is recorded as well. The average of the speeds determines the ‘severity’ of the total number of interactions in the simulation period [Várhelyi, 1997].
Quality

The quantification of the quality of a certain bus services and infrastructure is the most vague of all criteria. What is meant by this criterion is the perception of the user of the bus services. According to dell'Olio et al. (2010) the main variables to test the quality of bus transits on, according to their given weights, are:

- Waiting time
- Journey time
- Comfort during journey
- Service reliability

As this research is only on the infrastructure, factors that are outside the influence of the infrastructure and only determined by bus service quality are not considered. Therefore already comfort during journey is left out. Waiting time will vary when the frequencies change, although this is generally not directly related to the infrastructure. Journey time will also increase when the traffic volume increases and congestion occurs, or when zebra crossings get busier. In the case of a bus station like Schiphol Plaza, bus stop location is less of an influence, but when it gets more complex, this also has to be taken into account. The amount of stops for zebra crossings however will have its influence. Service reliability depends directly on the occurrence of bottlenecks, presence of traffic lights and crossings and other sources of congestion.

When reviewing the general bus transit quality variables, most of these are dependent on capacity and traffic volume. Next to dell'Olio, Jansen (2011) states that the following factors are to be considered concerning quality of bus infrastructure (service-only factors filtered out):

- Waiting comfort
- Curbside safety
- Walking distances
- Findability modality

Waiting comfort can be translated into (amongst other things) quality of platforms. The quality or presence of seating etcetera is left out of consideration, but the spacing of each passenger while waiting is a clear and quantifiable quality factor. Combining the above mentioned factors that will be considered, while making sure to have more independent variables within the quality criterion, the following ones are proposed:

- Quality of platforms (size, average no. persons per m²)
- Complexity of bus stop for the user (easy to navigate through, or not)
- Connectivity to Schiphol Plaza: location, visibility, accessibility

Combining all variables leads to seven in total, with the first four not entirely independent of the other criterion: capacity. Therefore they will not be assessed within the quality scoring and only the bus platform size, people density, connection with Plaza and the complexity of the infrastructure will be used in the quality score. The amount of pedestrians per m² can be assessed using the simulation, however the complexity of the bus station and its connectivity are determined outside the simulation. Quantification for complexity is difficult, but will be expressed in the amount of possible routes for pedestrians. Quantification of the connectivity will be in meters to Plaza entrance for each bus stop and the amount and kind of
obstacles before the bus stops can be reached. This is however not something that has to be simulated and is therefore no simulation output.

The only factor that can be quantified by simulation is the quality of the platforms in persons per $\text{m}^2$. Each run the average occupancy of the bus platforms is given. Simply dividing by the area leads to the available space per person, or reversely the people density.

The interaction between the three ‘scores’ is visualized in Figure 3.2. Quality and capacity are related through the user perception of the situation at the platform (chaotic, or orderly), as well as the travel time through the bus station. The relation between capacity and safety are, as discussed above, the situations at zebra crossings and platforms: higher pedestrian density combined with a high flow of buses will create more interaction between buses and pedestrians and thus decreases safety.

3.6 Methodology for input data collection and interpretation

The proposed simulation tool requires a set of data to be inserted as input. The input consists of data on buses as well as pedestrians crossing the B-lane. This paragraph describes the methods used to obtain the data and how it is interpreted.

Below an overview is given of the types of data that need to be collected and the chosen methods. The collection of pedestrian data is explained in further detail in section 3.5.1.

Arrival time of buses including delays and early arrivals:

- Source: timetables of bus service providers. The distribution (average, standard deviation) of delays and early arrivals is taken from Probit (2011).
- Description: planned time of arrival including realistic deviations with actual arrival times.
- Method of collecting: collecting timetables, applying the right format and storing into one Excel-table. Within the tool the actual times will be generated according to the distribution of delays and early arrivals.

Pedestrian flow:

- Explained in section 3.5.1.

Bus & pedestrian behaviour:

- Description: Typical behaviour variables of both buses and pedestrians, including:
  - Passenger flow through doors of the bus
  - Average walking speed of pedestrians along platforms and zebra crossings
  - Average speed and acceleration of the buses along the B-lane
  - Average safety gap (in time) between crossing pedestrians and bus
  - Average safety gap between buses
- Source: camera images and / or visual observation.
- Methodology: manual analysis of camera images, manual observation or use of available data only.
3.6.1 Choice of methodology for collecting pedestrian data

For the research on the bus station performance there is an important factor that requires additional data acquisition: pedestrian flows crossing the bus lane. No research has yet been done on the flow at this particular location. The flow consists of bus users walking to or from the platform between the B- and C-lane and pedestrians walking to other destinations such as buildings across the streets and coaches or personal cars picking up and dropping off people at the C- and D-lane. As the flow occasionally disrupts the bus flow on the bus lane itself this might be a deciding factor when optimizing the bus station, since a growing queue on the bus lane can cause chaotic situations and therefore reduce the perceived quality of the bus station.

The following aspects of the pedestrian flow need to be determined:

- Amount of pedestrians crossing the zebra crossings per time unit / distribution over time.
- Relation of pedestrians with buses at the stops (how many persons from/to each bus)
- Walking speed (average, standard deviation)
- Choice behaviour of crossing location
- Percentage non-zebra users

The difficult task in this matter is to measure the frequency and amount of crossing pedestrians while identifying whether they are actual bus users or not. This is of particular importance when a solution is found in relocating the ‘destination’ of either of these groups. In other words, if for instance the coaches or ‘kiss and ride’ will be relocated to the access roads at the departure halls, one level up, then the model should provide the effective change at the bus station activities. This is only possible if the distinction can be made between the bus users, coach passengers and other pedestrians crossing the B-lane.

Below the options for collecting the desired data are provided.

Method 1: Camera image processing

With the use of camera images pedestrians crossing the B-lane can be easily ‘spotted’. Strategically placed cameras will give an overview of the zebra crossings and will help to identify pedestrians only crossing the B-lane and pedestrians walking further crossing the C- and D-lane. The images can also be used to measure walking speed, boarding and alighting time and count the amount of passengers per bus.

For a complete image of the situation two cameras need to be placed: each viewing both of the two main zebra crossings from the top, keeping track of the A,B and C lane. The third zebra crossing is significantly less busy, but to get an indication of the frequencies a basic camera is placed from the Traffic & Transportation office that is directly linked to a laptop. This is done to save costs for this operation, as a simple camera can be used and no external party needs to assist here.
Method 2: Data-based estimations

In case that pedestrian detection is not possible automatically, or costs run too high, the data should be collected otherwise. This can be done by relying purely on available data. This means that the amount of crossing pedestrians will be directly linked to the estimated amount of passengers per bus. When this number is known the moment when they cross the roads is also known, i.e. the moment of arrival plus alighting time and walking time to the nearest zebra crossing. The downside is that the accuracy is not as good as automatic counting as the numbers are not based on real life measurements.

However, more data are available to get to a realistic estimation of the crossing pedestrians. By analyzing figures on Kiss & Rides, including a distribution over day, week and season, and estimating the amount of coaches arriving each day or hour the number of crossing pedestrians not related to the buses will be more realistic. Assuming that the amount of remaining pedestrians walking towards or from the Sheraton or WTC is low and can be easily estimated makes that the data are complete. The figures are added to the estimated number of bus users and all pedestrians can be simulated without the use of expensive camera imaging.

Method 3: Manual counting

The task of the cameras can be taken over by humans in the form of manual counting. Even when hiring multiple students for several hours per day during a random week will keep costs significantly lower than placing cameras and letting data be analyzed.

The downside is that simultaneous counting is needed to get to the same results as the camera option. Both directions, three zebra crossings and both the B- and C-lane need to be monitored simultaneously. It will be a difficult task for a low number of people to keep track of different groups of people, or an extensive operation with a larger number of counters. In either way the counting will not be as accurate as with the use of cameras. Next to that, data will have to be inserted by hand and various analyses still have to be done to get to the right input format. This will require more total work hours than method 1 and 2. The actual counting work can be outsourced, but this will add to the costs and the processing of the data will still have to be done.

Method 4: Combination of method 1 and method 2 / 3

Another alternative for making a distinction between the different types of crossing pedestrians is to combine camera images and either data based figures or manual counting. The combination will lead to accurate numbers and a check on the estimated or counted numbers. The tasks can be divided over the different methods, for instance by using the camera images to monitor the bus passengers and using manual counting for keeping track of non-bus users. It is also possible to monitor the non-bus users with cameras and estimate the bus users with the available data.

This is however the most expensive and most time consuming option as both the cameras and extra work on the other method are required.
Multi-criteria analysis

To come to a decision for the applied method a multi-criteria analysis (MCA) is performed on the four options. The criteria are: work load, costs, data completeness and accuracy. It is chosen to make this decision using a multi-criteria analysis since some of the criteria are in conflict with each other: for instance, a more thorough method with high data accuracy might induce higher costs. The form of this MCA is relatively simple, with three possible scores: green (good), orange (medium) and red (bad). This scale is chosen because of the low variation in some of the criteria and because the decision is not one of the leading ones in this research. Time is valuable and results need to be as good as possible, so work load is included. Costs are relative and more related to the company, Schiphol Group, and their willingness to invest in valuable data. Accuracy of data is important although the results will still be valuable even at a more rough estimation, contrary to the absence of some of the data. Therefore data completeness is given a ‘medium’ weight and data accuracy a ‘medium/low’ weight. The analysis is found in Table 3.1.

<p>| TABLE 3.1: MULTI-CRITERIA ANALYSIS FOR PEDESTRIAN DATA COLLECTION METHODS |</p>
<table>
<thead>
<tr>
<th>Work load</th>
<th>Costs</th>
<th>Data completeness</th>
<th>Data accuracy</th>
<th>SCORE:</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Weight:</strong></td>
<td>2</td>
<td>3</td>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td>Camera</td>
<td>3</td>
<td>1</td>
<td>3</td>
<td>18</td>
</tr>
<tr>
<td>Data based</td>
<td>3</td>
<td>3</td>
<td>3</td>
<td>23</td>
</tr>
<tr>
<td>Manual count</td>
<td>2</td>
<td>3</td>
<td>2</td>
<td>16</td>
</tr>
<tr>
<td>Combination</td>
<td>1</td>
<td>1</td>
<td>3</td>
<td>14</td>
</tr>
</tbody>
</table>

From the multi-criteria analysis it can be deduced that the best option is method 2, since it scores only medium at the least important criterion, contrary to all other methods. This method scores high on work load, costs and data completeness, and medium on data accuracy. The data accuracy is lower due to the lack of actual measurements, but many factors can be taken into account to get to reasonable accuracy, so the score is not very low. Costs scores are very low for methods 1 and 3 due to the camera installations, where method 2 is free of costs. However, method 1 requires the least amount of work and is therefore rated ‘green’. How the available data is used to get to the desired input values is explained in paragraph 3.6.2.
3.6.2 Methodology of Collecting Pedestrian Data Further Explained

The method for collecting data on how many passengers use the bus station and their distribution over the individual buses is the collection and analysis of the passenger demand and supply data as available from Schiphol [De Lange, 2011; Probit, 2011] and combining these with walking speeds of the passengers.

First the Mobility Research 2010 presents all information on the employees working within the Schiphol area. What can be extracted is (amongst other things):

- Travel mode
- Starting time, work days
- Living area
- Parking location (if applicable)
- Working location

These data are very accurate since there is a participant number of over 12,000 employees out of a total of 63,000. It distinguishes, amongst many other things, between pure bus users, train+bus users, car users and car+bus users (when parking at a remote parking lot).

Combining and filtering using the aforementioned factors results in a specification of employees traveling by bus per direction per time unit, which is specified per 15 minutes. Dividing these amounts on the arriving buses from that direction within the given time frame of 15 minutes results in the amount of employees per bus. These steps are performed by the bus related calculations within the simulation and only need to be performed once at the start of each run.

Next to employees within Schiphol area, there is also a group of passengers transferring from/to train or other bus lines and air travelers. Transferring passengers can come from / go to Schiphol Plaza by / to either the train or another bus line. The availability of data at Schiphol is insufficient to deduce numbers of transferring passenger per bus line from. The solution lies in acquiring check in/out data from the bus companies, most importantly Connexxion. Since the public transportation pass is mandatory in buses this data will contain all users that are not employee in the Schiphol area, as they can travel freely with their Schiphol pass and do not need to check in.

The other pedestrians that do not board or alight any bus can have three different destinations or origins:

- Cars stopping at the C- or D-lane for ‘Kiss-and-ride’

These pedestrians can be estimated using data of periodic counting around the airport access roads [Witteveen & Bos, 2010]. In this report the average daily and hourly users of the C- and D-lane are mentioned. Of all air travelers from Schiphol 29% is dropped off by car, while this number is 27% for picking up travelers. The numbers of drop off / pick up passengers for any given hour can be randomly distributed over that hour and in this way incorporated in the model. [MRI, 2010]

- Group travel coaches.

The number of pedestrians coming directly from or going to a coach is the most rough figure of all pedestrian data. Using an estimation of average numbers of coaches per day and ditto number of
passengers per coach, these values can be distributed randomly over the day. Assumed is that this group will cross the roads in a flow similar to that of the public buses. This will interrupt the B-lane bus flow for a longer period since these local pedestrian flows can get rather long and uninterrupted. A boarding coach can create a single line of walking passengers that takes over a minute to cross the road.

- Buildings on the other side of the terminals, mainly the Sheraton Hotel, Hilton Hotel and WTC offices.

This group of pedestrians is relatively small, because the Sheraton and WTC can also be reached through a bridge from the terminals. Next to that, they will virtually always use the most southern zebra crossing. Manual counting of this crossing can give a rough estimation of this group. However, the influence of these pedestrians will be minimal.

**Connecting pedestrian data with bus data**

Next to pedestrian data there is also the bus data that is required as input for the model. The data required are amount of buses and their arrival and departure times. From these data actual delays can be easily calculated.

The bus data relies mainly on the time table, which can be found on the bus companies’ websites. The times are put in correct format for the simulation tool so they can be read. Other required bus data consists of standard deviation of the arrival time and movement parameters (speed, acceleration). There will be a separate standard deviation for early arrivals and delays, since in reality they differ as well. The values of standard deviations are provided by Probit (2011).

For obtaining a connection between specific buses (line and arrival time) and the amount of bus users crossing the bus lane, the users per bus are analyzed through the available data. This is done with the use of the available data from the Mobility Research. The data on the transit passengers not working within the Schiphol area are less accessible and less thoroughly available. The figures that are known on this group are the numbers of transfer passengers from and to the train station each day as well as the air traveler movement from and to the terminals. However, no distribution over the day is available and these are assumed to match average Schiphol area employees distribution, since this one matches regular peak hours and also consist mainly of commuters.
3.7 METHODOLOGY FOR THE MODELING PHASE

Since a computational tool will be the end product, modeling is chosen as the main research method. More detail will be given on the methodology of this so-called ‘modeling phase’. This phase of the research is the most extensive and important part of the process. For the modeling phase the goal is to create a tool that can model a basic bus station and provide performance figures of this bus station in terms of capacity, quality and safety. The description of the tool itself will be given in Chapter 4.

3.7.1 TYPES OF SIMULATIONS

A distinction is made between different types of simulation, such that the right type of simulation tool and programming software can be selected. The main distinctions are between microscopic and macroscopic simulation and between continuous and discrete event-based simulation.

Microscopic or macroscopic simulation

The choice of spatial scale and required detail determines the scope of the model. In general the choice is between a microscopic and a macroscopic model. Where a microscopic model includes details such as individual vehicles and pedestrians, a macroscopic model analyzes generally the traffic flow as a whole. This will depend on the list of requirements as given in paragraph 3.2. This is a microscopic modeling tool, since the details involved are most importantly individual buses and pedestrians that interact with each other. Also the aforementioned spatial scope is relatively small. The network aspect is less involved in this problem since only the origin and destination of passengers are considered in order to be able to assign them to a specific bus line. These are the main reasons to create a microscopic model. [Fernandez., 2010].

Continuous or discrete event-based simulation

The difference between continuous and discrete-event based simulation is timing between variations in variables and the consequently the actions taken by the tool to simulate. In event based simulation there is a list of ‘events’ that will checked when the time of a certain event matches current time. Continuous simulation will simulate each time step, regardless the presence of an event. In this simulation the event would be for instance the arrival of a bus. In that case a discrete simulation would seem appropriate. However, bus and pedestrian movement are continuous processes. This leads to the conclusion that continuous simulation is more suitable when a ‘real time’ simulation needs to be visualized. However, the simulation will still require time steps (even in the order of 0.1 seconds) and thus is technically discrete, but without skipping between events. [Özgün & Barlas, 2009].

Deterministic or (stochastic) agent-based pedestrian simulation

For the simulation of the pedestrian movement there is the choice between stochastic and deterministic simulation. The most realistic simulation is stochastic, in particular agent-based simulation. Stochastic indicates that there is a high level of randomness to the movement of pedestrians, while deterministic simulation defines are predetermined path and behavior of each pedestrian. The definition of agent-based simulation in which elements or groups of elements behave autonomously according to a regime of behavior. This behavior cannot be determined beforehand and evolves as the simulation runs. Though this is more realistic than deterministic simulation, it requires a considerable amount of programming and computing. The question is whether it is essential to the simulation of the complete bus station process.
Observation shows that most pedestrian behavior is ‘predetermined’. The reason is most likely the knowledge that most types of bus users have of the bus station. The largest group is commuters who make use of the bus station twice a day. Therefore it is chosen to simulate the pedestrian deterministically. There is a level of randomness in the choice of different paths, like which zebra crossing will be chosen. Also the walking speeds differ according to the normal distribution from literature [Daamen, 2007].

3.7.2 CHOICE OF PROGRAMMING SOFTWARE

A choice of software needs to be made in which the tool will be written. The software needs to comply to the requirements of the tool, as given in paragraph 3.2. Following paragraph 3.7.1 it is known that using the software it should be possible to make continuous microscopic simulation. There are several options, some are numerical computing environments that require a start ‘from scratch’, others are complete traffic simulation software that provide building blocks for the infrastructure. From a large range of (traffic) simulation software a selection is made using comparative study by Hoogendoorn et al (2009). Based on information from this study it becomes clear that from the available options three software packages offer more advanced microsimulation: VISSIM, Aimsun and Paramics. Next to those options there is the option of creating a new simulation tool through more generic computing software. In this case MatLab is chosen as the only basic numerical computing software in the list as it is easily accessible and knowledge about it is already present. A combination of a MatLab simulation tool and a visualization through an existing traffic simulation program is a fifth option.

The question that needs to be asked is: In what way will the tool distinguish itself from existing tools or simulation software? Creating a model in any of the traffic simulation programs will not create a new tool, merely a new product of an existing tool. Also this software might not offer the exact set of functionalities that is required for this research, even though the functionalities it does have are more advanced. Of the three software packages mentioned only the latest versions of VISSIM can simulate the passengers boarding and alighting the buses through an additional pedestrian module [VISSIM website, 2011]. Cortés et al. (2010) show that until recently most of these software are based on the movement of the vehicles in a system and not so much on the public transportation system, let alone the generation of pedestrians from the public transportation. So far only VISSIM has been able to provide this feature [Aimsun website, 2011; Paramics website, 2011].

Another reason not to use a traffic simulation program is that one of the requirements is that the tool should be easily adjustable. Having a traffic simulation in VISSIM or similar software first of all requires access to that software when the simulation needs to be run. Adjusting variables or even more so, the infrastructure, requires easy access and knowledge of the software.

It would be wiser to create a more simplified and generic simulation tool that can be used by anyone with a little knowledge of the bus infrastructure and when a standalone executable is created no other software is required. In other words, using a standalone MatLab tool does not require any knowledge of MatLab or even a license to the software.

The advantages of creating a new simulation tool specifically for bus stations of the type of the Schiphol Plaza bus station (multiple berth curbside bus stops along a dedicated bus lane) are:

- Easier to use
Performance study for the Amsterdam Airport Schiphol bus station

- Can be more generic due to the lack of limitations of existing traffic simulation software
- It does not require expensive software license as an standalone executable can be made.

There are some disadvantages that need mentioning as well:

- The functionality is less advanced, especially in terms of visualization and types of infrastructure.
- The process of creating the tool demands more time than making a model with commercial traffic simulation software.

But considering the advantages, which emphasize the research relevance and value of the tool more, the choice is made to create a new simulation tool using numerical programming software of MatLab.

3.8 CONCLUDING REMARKS

What becomes clear from Chapter 3 is that it chosen to create a tool for microscopic continuous simulation to obtain the current and future performance of the Schiphol Plaza bus station. This tool will be created from scratch using MatLab because of the desired flexibility in additions and the ease of using it without making or changing the model in a commercial complex traffic simulation program, which also requires access in the form of a license. The simulation will be limited to the area as determined by the spatial scope and the relevant aspects as determined in Table 3.2.

Now that the requirements, the type of simulation tool that needs to be created and the nature of its input and output are determined in this chapter more information on the tool needs to be provided. This is done in Chapter 4, where an extensive description of the tool and its functionality are given.
4 **BUS STATION SIMULATION TOOL DESCRIPTION**

This chapter describes the simulation tool for bus stations well type. The tool performs a set of functions: the main simulation of buses and pedestrians on the bus station and some specific functions that support the main simulation computation and provide input, which enables the main function to perform a set of calculations, each element will receive its separate explanation. First, the theory behind in paragraph 4.1, followed by the general set-up of the tool, including the connection between the elements in paragraph 4.2. The central function of simulation is explained in paragraph 4.3, while the processing of input is discussed in paragraph 4.4, showing which form it has and how it can be used in the rest of the software. Paragraph 4.5 gives the explanation of the bus operations, whereas section 4.6 provides the pedestrian simulation function of the tool. These sections go further into detail on the dynamics of the buses and pedestrians in the simulation. Paragraph 4.8 follows with an explanation of the practical application, or how the tool can be used and for which types of examples. Finally given in paragraphs 4.9 and 4.10 are respectively the necessary validation and calibration of the tool and the concluding remarks.

4.1 **SIMULATION TOOL THEORY AND ASSUMPTIONS**

According to the methodology as discussed paragraph 3.6 the type of simulation selected there is a microscopic traffic simulation with small time steps. The time steps are variable and can be as low as 0.1 seconds while still maintaining up to 4x real time speed including visualization. Without visualization 10x real time speed is achievable with this time step. The simulation runs continuously, though with small time steps, but not event-based, as explained in paragraph 3.6 as well. Also the simulation area is called in through irrational values, not discretely. This means the model is both space-continuous and time-continuous.

The bus behavior is based on the Intelligent Driver Model, which will be further explained in paragraph 4.7. Their routes through the bus station are predetermined according to the assigned stop location, but a 'last minute change' can occur when this spots is indicated as occupied. Several spots per group of bus lines, mostly grouped by network level, are available. The pedestrian behavior is based on more straightforward simulation, not based on any method from literature, with the assumption of constant walking speed, but introducing a stochastic aspect by varying the walking speeds according to typical walking speed average and standard deviation from literature. This is further explained in paragraph 4.6.

A list of assumptions and limitations is given below that simplify the simulation and programming of it, or that appear from the absence of certain data:

- Pedestrian behavior is limited to constant walking speed (varying speeds between different pedestrians, though) and a predetermined walking path.
- No interaction is simulated between pedestrians, other than waiting times for boarding and alighting. Also the pedestrian congestion is not simulated, as this is a more complex process. It is left out solely for simplicity.
- Pedestrians that cross the roads at another place than the zebra crossings are not taken into account for bus-pedestrian conflicts. In other words, buses will not stop for them. It is assumed
that in reality the pedestrians will wait for a relatively safe moment for them to cross the road and not influence any buses by slowing them down, let alone induce an emergency stop. This is not simulated as such, since this action does not influence any of the outcomes.

- Buses are assumed to drive not faster than the maximum speed. They cannot leave their path unless their stopping location appears.
- The tool is limited to the Schiphol Plaza-type of bus stations: road side bus stops along a bus lane with (optional) zebra crossings. Fishbone types of bus stations require a different type of simulation that is even more based on the pedestrian behavior since in most cases the bus platforms are islands to which usually no zebra crossing is present. Walking paths depend are highly variable and the interaction with bus routes is more complicated. It could however be an extension of the simulation tool to accommodate for this type of bus stations as well. For the application to Schiphol’s bus station the current version is sufficient.

4.2 GENERAL SET-UP OF THE SIMULATION TOOL

The simulation tool consists of separate functions with one function combining calculations and delivering the final output. This composition is due to the fact that different types of input are to be processed through the various functions and it will be less complex to separate those functions, than to perform all the tasks through one large function. From the main function there is a complete and clearly structured overview of all related functions. The simulation tool seen as a black box with its input and output is visualized in figure 4.1.

![Diagram of the simulation tool]

**FIGURE 4.1: SCHEMATIZED OVERVIEW OF THE INPUT AND OUTPUT FOR THE SIMULATION TOOL**

On the one hand there is the input related to the buses: timetables and bus behavior in terms of acceleration, deceleration and speed, designated bus stop. The timetables will be transformed as a
function of the mean (scheduled time) and the standard deviation of both early arrivals and delayed arrivals, which is described in paragraph 4.4, whereas the other variables will be used as is.

The motion of the buses themselves is modelled in a separate function, the bus simulation function, which is described in paragraph 4.5. For each run of the main loop (main file) the current state of the buses is given as input and this function will return a new state for the current moment.

On the other hand there is the input related to the pedestrians. The data on the passengers are predetermined in the pedestrian demand input data file, which is described in paragraph 4.3.

Pedestrians will be modeled individually, but with predetermined behavior using these variables. Their location of crossing the bus lane (whether or not at a zebra crossing), their actual walking speed and the path to their destination are determined in the tool. The walking speeds depend on the data available on walking speeds, while the paths are determined by the layout of the bus station, pedestrian destinations and choice behaviour. This is further described in paragraph 4.6. Also coach arrivals and the remaining pedestrians following their path to or from the other side of these roads are modeled similarly. When crossing at a zebra crossing the bus flow will be held up, a signal to the bus dynamics function will indicate that approaching buses will apply sufficient braking deceleration. The pedestrian dynamics, both from the buses, to the buses and elsewhere, are described by the pedestrian dynamics function, as is discussed in paragraph 4.6.

The central part of the tool has the function of gathering the combined inputs from the above mentioned files, all linked to a time and date, and putting them into a simulation. The file also contains the necessary processes and data on the infrastructure. The infrastructure data is read by the software, as described in paragraph 4.3 as well.

The main function combines the input data after processing by the sub-functions and puts this through a time loop. During the simulation it provides the required output of the bus arrival and departure times (and corresponding delays), the bus platform situation (number of people present on the platforms), the bus – pedestrian interaction on the zebra crossing in terms of ‘braking-seconds’ times the number of braking buses. This is discussed further in the description of the bus dynamics in paragraph 4.5.
4.3 THE MAIN FUNCTION: THE CENTRAL SIMULATION

The basis of the tool lies in its main function. Here the output of the bus dynamics function and pedestrian dynamics function are combined to be used in the time loop for the simulation of both. Here these functions are called after new buses are ‘generated’ if the (rounded) current time (in seconds) matches with an actual arrival time. Figure 4.2 shows an overview of the processes within this part of the software, with the main function processes indicated in green. The rectangles indicate the sub functions that are called from the main function.

At first, there is the option of determining the duration, start and end time of the simulation. The selection can be every hour and minute of the day. Next, a growth factor can be inserted for scenarios with an increased passenger demand and increased bus frequency. A distinction is made between passenger and bus frequency growth. This factor should be for the year or season that is to be simulated with respect to the base scenario: the current situation for an average week day. For instance, when a yearly growth factor of 1.1 is projected, a simulation of an average day for two years in the future would require a growth factor of 1.21. When there are different timetables for different days, seasons or scenarios this will also be the place to select which timetable is to be used. Dimensions of the bus station are defined in an input sheet, which is read by the software. Length of the bus lane(s), number of bus lanes, position of the bus stops and the zebra crossings along the bus lane(s) are defined here.

The next step is to start the simulation. All is contained within a for loop that runs from \( t_0 \) (set beforehand) until \( t_0 + t_{\text{duration}} \) with steps of \( \Delta t \), also set beforehand. Experience has shown that for this simulation a \( \Delta t \) of 0.1 seconds is short enough for smooth visualization at at least real time speed while keeping up with calculation time. Lower time increments might slow down the simulation to speeds below real time speed. Though accuracy increases, an accuracy of 0.1 seconds, or when considering a driving bus at 10 m/s, an
accuracy of 1 meter is sufficient for such a microscopic simulation. For quicker results (up to 15x real time speed), the visualization can be switched off. This is most practical when only the results are required and more runs need to be performed.

Bus generation

When time equals the bus arrival time of one of the buses in the system, as provided by the bus timetable function, a new bus is generated in the simulation. A number of characteristics of this bus is given by the bus timetable function as well, including:

- Direction on the bus lane
- Number of passengers that will exit at the bus stop
- Position of the doors
- Bus length

Before the bus can be given a position according to the dynamics, it is important to first generate the pedestrians at that time, since the bus dynamics are for a part determined by the pedestrian position when they use the zebra crossing.

Pedestrian generation

Pedestrian positions are determined every run of the loop of the simulation. First the pedestrians are called from the pedestrian dynamics function, which is described in paragraph 4.6. This function provides the position of each pedestrian in the system in x- and y-coordinates. The main function checks these positions on whether they are at one of the zebra crossings, both in parallel direction and perpendicular direction. If this is the case, with a margin for reaction time taken into account, the zebra crossing is set to ‘occupied’. This occupation will be used in the next step of the simulation, where the bus locations are determined.

Bus movement

The bus movement is the result from calling the bus dynamics function. The current time and zebra crossing occupation are entered into this function, as well as the list of buses known at that point in the simulation. What it receives is the renewed positions of the buses in the system. If any of them left the area and the related passengers have left the boundaries of the simulated area, the bus can be removed from this list. Since each arriving pedestrian (from one of the buses) is linked to that bus, the bus has to remain in the list in order for the related pedestrians to be simulated.

Plotting

In the plotting part of the main file the positions of all buses and pedestrians need to be drawn. For every time t the output contains a figure window with each bus drawn as a rectangle with curved corners and the pedestrians visualized as small dots. With a ∆t of 0.1 seconds, the image moves smoothly, at about half the refresh rate of regular television. Screen dimensions depend on the length of the bus station and width and number of lanes and platforms. The running speed of the whole simulation, which determines the speed of the actual movement in relation to real time, depends on the built-in pause in the software. This
pause can be adjusted and provides real time simulation at a value of about 0.03 seconds. The visualization, without background image (this is optional and has to be created for each bus station individually), is shown in Figure 4.3.

FIGURE 4.3 EXAMPLE OF THE VISUALIZATION

Output data

The last part of the process is processing internal data into output that is provided to the user in the form of an Excel file. The output data provides the scores of the bus station for the selected time period in terms of bus throughput, safety and quality as perceived by the user. They are given in the following formats:

- The bus throughput of each bus is provided through an overview of times for each phase of the bus stop process:
  - Entering the simulation area
  - Stopping at the bus stop
  - Leaving the bus stop
  - Exiting the simulation area

The total time of being in the simulation area is not sufficient to describe the throughput score of the bus station, because it depends on the number of boarding and alighting passengers as well as the waiting time at the bus stop in case of an early arrival. Therefore the delay is provided as the difference between the first two moments and the last two moments: the standstill time at the bus stop is left out of consideration. Subtracting the undisturbed driving time through the bus station yields the delay that is solely caused by the bus station. Delays caused by the amount of passengers, due to their boarding or alighting times, are not taken into account as this too is a factor not directly related to the infrastructure but merely the supply and demand at that moment.

- The safety score is provided in the form of amount of ‘braking seconds’ caused by zebra crossings for all buses. The time a bus needs to brake when approaching the zebra crossing is the moment with the highest risk of collision between bus and pedestrian. The number is accumulated for all buses and not divided by the number of buses, since a higher frequency on the bus lanes does in fact increase the risk. Therefore giving the risk per bus is not sensible.

- The quality score for the bus station is stated as the density of pedestrians on the platforms. The format in which it is provided is a table of pedestrian density (pedestrians per m²) per second for each half of each bus platform. The location of the split between the two halves can be defined in the software. These values can be easily processed into an average per desired time unit by the user.
This concludes the cycle of the simulation: $\Delta t$ is added to the time and the cycle starts over again until $t = \Delta t + t_{\text{duration}}$.

### 4.4 INPUT PROCESSING

The main file and function files need to read different sets of input. Some of the input requires processing. The input consists of:

- **Bus (timetable) input:**
  - Bus timetables
  - Bus characteristics
  - Bus station dimensions and characteristics

- **Bus passenger input:**
  - Passenger demand per bus line or group of bus lines at the given bus station within a time frame (for instance per 15 minutes).
  - Passenger supply from each bus line to the given bus station within a time frame.
  - Share of passengers not making use of the zebra crossings (crossing the lane(s) elsewhere).
  - Average walking speed.

- **Other pedestrians’ input:**
  - Distribution over the day per zebra crossing.
  - Average walking speed.
  - Optional: train timetables and (average) walking distance between train and bus station

- **Bus station infrastructure:**
  - Dimensions of the bus lane(s)
  - Number of bus lanes
  - Locations of bus stops
  - Dimensions of bus stops
  - Dimensions and locations of zebra crossings

The input that needs the most processing in the software is the bus timetable. While the other input is provided by the user as ready-to-use, the bus timetable is changed to make it more stochastic. This starts off with an table of bus lines with corresponding planned arrival times in hours and minutes, thus being two columns per line. There is a different page for each direction and there can be different versions of the timetable, for instance when lines are excluded, or a busier timetable needs to be tested. These are read from an Excel file of which a small part is shown in Figure 4.4.

![Figure 4.4: Example of representation of the bus timetable](image-url)
The hours and minutes are transformed into seconds and processed according to a normal distribution of this arrival time with a standard deviation on the upper side (delay) indicating the arrival time and on the lower side (early arrivals). These values are part of the input file and read from there by the software. The function describing the actual arrival times in the simulation is (within a loop):

\[
\begin{align*}
t_{act} &= t_t + \sigma_{delay} \cdot norm(l) - t_{buf} \\
t_{act} &= t_t - \sigma_{early} \cdot norm(l) - t_{buf}
\end{align*}
\] (4.4.1)

All times are rounded to the whole second. The distribution of early and delayed arrivals is determined by the available data: for example 60\% is later than the timetable time and their actual arrival time will be calculated by the first of 4.4.1, while the other 40\% early arrivals will be transformed using the second equation of 4.4.1.
4.5 THE BUS TIMETABLE FUNCTION

The bus timetable function performs the processes that create (or read from input) the characteristics of a newly generated bus in the simulation. This not only includes the dynamic characteristics, but also the amount of passengers boarding and alighting at the bus station. These numbers are determined by combining the bus time table, the bus characteristics, the arrival time and the passenger demand. Figure 4.5 explains the structure of this function.

Only at the first run a definitive timetable is made using the input processing as described in paragraph 0. Also within this function the number of alighting and boarding passengers for each bus is determined. In the input the demand of passengers is given in numbers per quarter of an hour per line or group of lines. A group of bus lines can be for example the set of lines going to the center of the nearest city. Grouping may be necessary if data on passenger demand is only available for certain connections and not for each bus line. If the data available is only giving demand/supply per hour or any other longer time period, an average per quarter of an hour should be used.

The passenger demand of each quarter of an hour is divided over the quarters that need to be simulated. Every passenger receives an arrival time at the bus platform through random determination within these 15 minutes. It also receives information on the bus stop location and which zebra crossing will be used.

The passenger supply, or number of alighting passengers, at the bus station is the passenger supply distributed over the number of buses for this (group of) bus(es) in these particular 15 minutes.

Optionally, if the required data are available, there can be chosen to distinguish between train-bus transfer passengers and the rest. By coupling the daily train timetable to the program and combining it with the share of supply from the train station, walking time is determined using the normally distributed walking speed and the average distance between bus and train station. This way there is more clustering.

FIGURE 4.5: OVERVIEW OF THE PROCESSES WITHIN THE BUS TIMETABLE FUNCTION
introduced in the arrival of bus passengers, where without this option the arrival time is evenly distributed over each quarter of an hour.

Finally, the bus time table function provides this information for the arrived bus to the main function as output.

### 4.6 Pedestrian Dynamics Function

The pedestrian dynamics function provides locations for all pedestrians in the system. It accumulates the information on time, scheduling of buses and the corresponding passenger demand and supply. The structure of processes within this function is visualized in figure 4.6.

![FIGURE 4.6: PROCESSES WITHIN THE PEDESTRIAN DYNAMICS FUNCTION](image)

**Theory**

The theory behind the pedestrian simulation is less complex than commercially available pedestrian simulation. The complexity in this tool is mainly the computation of their moment of arrival and the generation directly from or to the buses. For simplifying reasons it is also chosen not to make it an agent-based simulation. It is assumed that each pedestrian’s path is known when the pedestrian is generated, therefore this part of the simulation is deterministic. The pedestrians will not interact, but will differ in walking speed following a normal distribution based on research data from literature. According to a comparative study of walking speeds by Daamen (2004) the average walking speed, as found across literature, is 1.34 m/ with a standard deviation of 0.37 m/s. These values will be fixed in the tool. Optionally they could be input variables for the tool, but that is outside the scope of the research in this case.
In the simulation tool

All buses are checked for their boarding and alighting passengers and the pedestrians not making use of the bus system are added as well. The portion of non-zebra users (pedestrians crossing the roads elsewhere), average walking speed and the standard deviation the walking speed are single variables used in this function. The portion of non-zebra crossing users is an input variable from the passenger demand input. The average walking speed is more general and set inside the software.

The first part of the function is only run once as that specific bus appears for the first time. The passengers are evenly spread over the amount of doors the bus contains. This is an assumption for simplicity and it determines the location where each pedestrian starts to walk. Each of the pedestrians is given a walking speed and exit time. The exit times for each door are determined to be 1.4 seconds apart between each passenger for each door, an average following comparable average dwell times through bus exits [Daamen, 2004]. Each pedestrian is then given a walking speed that is determined following a normal distribution and using the average speed and standard deviation mentioned before.

As soon as the $t > t_{exit}$ for a certain passenger, the route starts and it first walks parallel to the road until it has reached the crossing location as determined at moment of generation through the choice of either one of the two closest zebra crossings, or at a random location. The share of random location crossing is determined through measuring and is found to be about 40%. A random pick of 40% of all pedestrian will choose a random location between them and the nearest zebra crossing.

The routes for an example of a bus station are given in figure 4.7.

![Figure 4.7: Typical walking routes on a bus station. The red arrows are the walking routes towards the bus stops.](image)

Depicted in are red the walking routes, here they are for pedestrians towards the bus stops. The yellow dots are the collection spots where they will wait for oncoming buses. Each set of bus stops, or collection of bus lines designated to a set of stops, has its own collection spot. Since there is no interaction in this simulation, the fact that all people are at one location is not influencing the simulation results. Boarding of the bus will depend on the number of people waiting at that point and given a set boarding time per passenger. This happens after passengers have alighted at the bus stop. They walk the same path.
reversed. When there are more choices for zebra crossings, the choice behavior determines the route of each passenger. This distribution is different for every situation or layout of a bus station, so this is also given in the input file.

As soon as all pedestrians have exited the boundaries of the simulation area, [xmin xmax] by [ymin ymax], the function returns to the main function that the bus can be removed from the list (only if the bus itself has left the simulation area as well).

For the reverse process of pedestrians walking towards the bus, the same procedure is used, only in reversed order and direction. Their arrival times are determined by the bus timetable function and are communicated to the pedestrian dynamics function. Next to the bus users, the pedestrian dynamics function also includes a random generator for non-bus users that lets the pedestrians only make use of the zebra crossings. This also includes a random arrival time of a coach once in a while. Daily frequencies of coaches are part of the bus timetable input. The coaches are treated as regular buses, but without the arrival at a bus stop and with a relatively large number of passengers. These pedestrians are generated at the side furthest of the general walking direction at a given position as prescribed in the infrastructure input or otherwise at a random location.

A complete list is now created of all the pedestrians in the area, which can be used by the main function to visualize them in the simulation and perform the rest of the simulation.
4.7 BUS DYNAMICS FUNCTION

This function generates the movement of all the buses in the simulation. The input consists of time $t$, delta $t$, xybus (all current positions), zebra occupation and the array bus_overview for all information about the buses. After setting some fixed characteristics of all buses in the main function, like maximum speed and normal acceleration, and importing those into the bus dynamics function a loop starts to run for all the buses in the system. Typical variables like maximum acceleration $a_{\text{max}}$, maximum deceleration $d_{\text{max}}$, comfortable deceleration $d_0$ and maximum speed $v_0$ are provided through the input of the simulation.

The dynamics part is split up into three categories:

- Normal dynamics
- Checking distance to preceding bus(es)
- Checking for occupied zebra crossings

Figure 4.7 explains the working of this function through visualization of the processes.

![Diagram of bus dynamics function](image-url)
The processes are as described below:

**Normal dynamics**

The purpose of this part of the tool is to provide the dynamics of the bus, including the stopping process at the allocated bus stop. The requirements of the normal dynamics include:

- No lane changing, except when entering the bus stop berth.
- Fixed route through the bus station, except when the allocated bus stop appears to be occupied. The bus will then line up behind this bus at the next bus stop. Groups of bus lines can be allocated to a set of multiple bus stop locations, so that multiple buses from the same group can stop simultaneously. If all of these spots are occupied the bus will wait behind the last bus.
- Normal dynamics occur with the use of a maximum speed, which can be set in the program. Assumed is that all buses keep driving this speed as long as they are able to drive this speed.
- During braking for the bus stop use is made of a leading braking distance, which is calculated according to the speed at that instance and comfortable braking deceleration $d_0$. This way at all times there will be enough distance for the bus to brake normally and comfortably and situations where the bus has a lower speed, for instance after braking for a zebra crossing, it will brake accordingly.
- If the bus has reached the bus stop location the waiting time at the bus stop starts to run, in order to check whether the process has ended or not by comparing the time with the predetermined waiting time at the bus stop, which depends on the number of passengers boarding and alighting plus buffer time:

$$t_{\text{wait}} = t_{\text{exit}} n_{\text{pax}} + t_{\text{buf}}$$

If waiting time as well as the planned departure time according to the original timetable has been surpassed and the bus will accelerate again using standard acceleration and steering towards the main bus lane.

(4.7.1)

**Theory**

To ensure the above requirements a modeling theory for the acceleration of the bus needs to be used. Only calculating the acceleration at every run is sufficient for determining the dynamics in longitudinal direction since the new speed and consequently the new location can be calculated using:

$$v_i(t) = v_i(t - \Delta t) + a_i(t) \Delta t$$

$$x_i(t) = x_i(t - \Delta t) + v_i(t) \Delta t$$

(4.7.2)

There are several car-following models that can provide the dynamics variables in a microscopic time- & space-continuous simulation without lane changing like this one. There are also Cellular Automation models, but they make use discrete division of the road length and time, where in this simulation it is desired to have time- and space-continuous modeling for more accurate simulation. This accuracy is needed since the involvement of pedestrians, which have a higher detail level [Nagel & Schreckenburg, 1992].
Performance study for the Amsterdam Airport Schiphol bus station

Of the best known car-following models, the Intelligent Driver Model (IDM) from 2000 by Treiber et al. (2000) is the most recent. According to Treiber et al. the model is an improvement on the Gipps’ model from 1981, which loses realistic properties in the deterministic limit. Also this older model is time-discrete, since at that time computing speed was more an issue with this type of calculations. Since computing is nowadays no problem for the more advanced IDM and this model provides exactly what is needed in this case, the Intelligent Driver Model is chosen for computing the bus dynamics. The description reads:

\[ a_i(t) = a_0 \left( 1 - \left( \frac{v_i(t)}{v_0} \right)^d - \left( \frac{s^*}{s_a} \right)^2 \right) \]

\[ \text{with } s^* = s_0 + v_i(t)T + \frac{v_j(t)(v_i(t) - v_j(t))}{2\sqrt{a_0d_0}} \]

(4.7.3)

In this equation \( v_i(t) \) is the current speed of the specific bus, \( v_j(t) \) the current speed of the preceding bus, \( T \) the headway, \( s \) the current spacing between the buses, \( s_0 \) the minimum spacing and \( d \) the acceleration exponent (usually set to 4).

How this model is used for behavior amongst other buses and approaching bus stops and zebra crossings is described below.

Checking distance to preceding bus(es)

It is important that when a bus drives too close to a preceding bus that the braking action that is needed to maintain a safe gap has to overrule the acceleration determined in other steps of the process. The gap is included in the used car-following model described below. This is also the reason why only acceleration is determined for the x-direction, because in this way the actual movement of the bus can be determined at the end of all loops and checks when the definitive acceleration is known. Changing the speed before other checks have been performed would require a difficult change back.

The distance between two buses interfering in the same lane, or partly on the same lane, is to be a maximum of two meters plus braking distance, maintaining a headway of two seconds at all time. The IDM provides the dynamic variables for safe behavior of the bus when approaching other buses. The desired spacing is set to two meters in the equation.

A previous acceleration induced by the approach of a zebra crossing or bus stop might overrule the one calculated here since the highest deceleration necessary always overrules any other action.

Checking for occupied zebra crossings

When the zebra occupation input tells the bus dynamics function that the approaching zebra crossing is occupied at time t, it will engage braking similarly to braking for the bus stops, leaving a distance of two meters between bus and zebra crossing. Comfortable braking is used from the calculated braking distance at the current speed (see equation 4.1.2). Only if the zebra crossing turns to ‘occupied’ after the braking distance maximum braking of 3 m/s² is engaged [Vuchic, 2007].
4.8 PRACTICAL APPLICATIONS AND GENERALNESS OF THE TOOL

Now that the use of the simulation tool is known, its practicality for the range of applications becomes clear. Also the limitations should be noted here to give a complete view on what the tool can and cannot be used for.

Generality

As the tool has an aforementioned list of input variables, applications will at least require that those input data can be provided. That means that dimensions of the bus station, bus characteristics and passenger demand should be known. Since the tool can process and link actual passenger numbers to each bus, this information does not have to be present. If no distribution over the different bus lines is known, a uniform distribution will be chosen. Also when the accuracy is not per quarter of an hour, the demand and supply can be evenly distributed over the time span that is the accuracy available.

Limitations

The limitations in the tool are mainly on the bus station complexity. As the tool is originally designed with the example of the Schiphol bus station in mind, the only type that can be simulated is a dedicated bus lane, with a built-in maximum of two lanes, that has parallel bus stops on both sides and driving in two directions. No fishbone structures are allowed, this requires a more complex simulation.

Pedestrian behavior is limited to a stochastic walking speed, which is realistically based on literature, and stochastic road crossing behavior in terms of the location. Interaction between pedestrians is not taken into account and routes are fairly basic with only straight lines. This is sufficient for the goal of the tool, which is to model for the effect of the pedestrian-bus interaction on zebra crossings. An advancement of the tool would however be useful to obtain more realistic results.

4.9 VALIDATION AND CALIBRATION OF THE TOOL

After finalizing the tool it needs to be validated and calibrated according to the real situations through measured values. The following measurements have been performed to test the tool's validity:

- Measuring delay of buses that is suffered on the roads of the bus station by clocking braking and standstill time for buses other than at the bus stop, e.g. at zebra crossings or due to congestion on the bus lane within the bus station. The same braking time summed for all buses provides the validity of the safety score of the tool.
- Counting of platform occupancy at various moments to validate the right order of magnitude of the quality scores of the tool. On average over a period of time (like an hour) the values from the model should be near the measured values.

From the validation test follows that at first the values of the simulation delays and braking seconds were higher than the results from the measurements. For measurements in the hour period of 17:00-18:00 average delays as suffered on the bus lane were ~13.2 seconds, while the simulation average was ~21 seconds. This meant that the buses were more hindered by the crossing pedestrians than in reality. Observation showed that the reason is that in reality bus drivers react more ‘aggressively’ when
approaching zebra crossings than they did in the simulation. When pedestrians approach the zebra crossing at the curb side, most bus drivers will not stop already. There is still three meters of ‘berth area’ before the actual roads starts, which gives the buses a small buffer.

The aggressiveness of the can be adjusted in order to calibrate the tool to improve the results. This is done by changing the area of zebra crossing ‘occupancy detection’ and consequently changing the aggressiveness of the bus drivers. After moving the border of this area to 1 meter before the actual bus lane, this improved the results to more realistic averages of 14.1 seconds. For buses coming directly from the bus stop in front of the crossing the zebra crossing is set to occupied, however. Also for the morning peak the measured 16.5 seconds average was realistically close to the simulated 18.2 seconds now.

4.10 CONCLUDING REMARKS

The bus station simulation tool has been created to provide performance figures for Schiphol Plaza’s bus station. The elements that are required in this tool have been thoroughly discussed in this chapter: bus movement, pedestrian movement, their interaction and the relation to bus timetabling. Next step is to start using the tool for this bus station and perform various runs. In order to do that first the required input needs to be collected and generated from the available data. This is done in Chapter 5, which will lead to the creation of future scenarios in Chapter 6 and the actual simulation results in Chapter 7.
5 Collection and Analysis of the Input Data

The simulation tool as described in chapter 4 has been designed to be applicable to the case of the Schiphol Plaza bus station. If the input values for the tool are found for this case, the results should represent a near realistic situation. Paragraph 4.2.1 provides the analysis of the required data. Appendix B provides a more thorough overview of the (processed) data that is used for input in the simulation.

As can be read in chapter 4 the required input data is comprised of:

1. The bus time table for the Schiphol Plaza bus station
2. The passenger supply and demand at Schiphol Plaza on every moment of the day.
   a. The number of employees within Schiphol Area making use of the bus system (parking-bus, train-bus, bus only)
   b. The number of transfer passengers to/from the train station to/from the bus station, that do not work commute to/from Schiphol Area.
   c. The number of air travelers arriving/departing by bus at Schiphol Plaza.
3. The number of pedestrians not related to the bus station.
4. Bus infrastructure variables
5. Other fixed variables

The data that are processed and collected are as follows:

1. The bus time table can be found on the Connexxion and GVB websites [Connexxion, 2011]. The most important result from analyzing these data is the distribution of the buses throughout the day, as is shown in Table 5.1. This table shows the total number of buses per hour per direction rated by the busiest hours of a normal week day.

<table>
<thead>
<tr>
<th>hour:</th>
<th>stops:</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>8:00 - 9:00</td>
</tr>
<tr>
<td>2</td>
<td>7:00 - 8:00</td>
</tr>
<tr>
<td>3</td>
<td>17:00 - 18:00</td>
</tr>
<tr>
<td>4</td>
<td>16:00 - 17:00</td>
</tr>
<tr>
<td>5</td>
<td>18:00 - 19:00</td>
</tr>
</tbody>
</table>

2. a) The number of employees within the boundaries of the Schiphol owned area is a known figure. Modalities of the employees, including the parking space that is commonly used, starting hours for work and location of work are all deducted from the Mobility Research 2011. Categories are combined: for instance, employees within Schiphol Centre that park their car at either P30 or P40 will always make use of the Sternet buses to get to Schiphol Centre. Depending on which of the two parking locations it is deducted from which direction they will arrive: P30 is south of Schiphol Centre, so they will arrive from the south in the morning and depart to the south in the afternoon. Together with the number of train-bus combinations of employees and their exact working location this leads to table 5.2 that indicates numbers of bus users with their work base
within Schiphol Area. Following the Mobility Research (2011) the number of average annual work days for day shift workers, corrected for presence, is 198 (220 x 90% presence rate). The majority of the workers around Schiphol, especially at the terminals, have no distinction between weekends and week days, meaning an average of five work days per week would indicate five arbitrary days. Therefore the number of work days can be divided by the 365 days in a year. This leads to an average daily presence rate of \( \frac{198}{365} \times 100\% = 54\% \). Similarly the presence rates of irregular shift workers (flight and non-flight) is determined. The numbers of workers travelling each day are multiplied by these factors. The daily average of Schiphol Area workers boarding and alighting at Plaza are given in Table 5.3.

**TABEL 5.2: THE DAILY AVERAGE OF WORKERS WITHIN SCHIPHOL AREA MAKING USE OF SCHIPHOL PLAZA BUS STATION**

<table>
<thead>
<tr>
<th>Schiphol Area workers</th>
<th>Movements:</th>
</tr>
</thead>
<tbody>
<tr>
<td>Centre workers</td>
<td></td>
</tr>
<tr>
<td>Car+bus day shifts</td>
<td>4300</td>
</tr>
<tr>
<td>Car+bus irregular shifts</td>
<td>8300</td>
</tr>
<tr>
<td>Total car+bus</td>
<td>12600</td>
</tr>
<tr>
<td>Bus only</td>
<td>2200</td>
</tr>
<tr>
<td>Non-centre workers</td>
<td></td>
</tr>
<tr>
<td>Train+bus</td>
<td>6600</td>
</tr>
<tr>
<td><strong>Total daily users Plaza:</strong></td>
<td><strong>21400</strong></td>
</tr>
</tbody>
</table>

b) For the non-Schiphol workers that arrive and depart from Schiphol station and transfer to/from the buses there is a clear number that is provided by the Mobility Research (2011): 13400 movements per day between the train station and the bus station.

c) The same applies to air travelers. However, the number of daily air travelers arriving by bus is very low: only 1900 movements vice versa per day.

The total number of users of the Schiphol Plaza bus station is given in Table 5.3.

**TABEL 5.3: THE DAILY AVERAGE OF USERS OF THE SCHIPHOL PLAZA BUS STATION**

<table>
<thead>
<tr>
<th>Plaza bus station users</th>
<th>Movements:</th>
</tr>
</thead>
<tbody>
<tr>
<td>Schiphol Area workers</td>
<td>21400</td>
</tr>
<tr>
<td>Non-Schiphol transfers</td>
<td>13400</td>
</tr>
<tr>
<td>Air travelers</td>
<td>1900</td>
</tr>
<tr>
<td><strong>Total number of users:</strong></td>
<td><strong>36700</strong></td>
</tr>
</tbody>
</table>

The distribution of these users over the day is determined by:

- The data from the Mobility Research (2011) on starting times.
- The Schiphol flight pattern for irregular flight workers.
- Regular working times distribution (peak hours).
3. For the number of pedestrians not making use of the bus system, but using the zebra crossings, there are merely data on Kiss & Ride users, coming from C-lane and D-lane, and the number of average daily coach arrivals per day from the Mobility Research (2011): 20. Using the average occupancy of 50 passengers [Brouwer's Tours, 2011], this leads to about 1000 crossing pedestrians to travel coaches. Coach arrivals are randomly determined in the simulation (between 8:00 and 17:00) and Kiss & Ride numbers are related to Schiphol flight pattern. The total number of Kiss & Ride movements between the (arrivals) terminal and the C- & D-lane per day is about 400 persons collecting air travelers and 500 collected air travelers [De Lange, 2011].

4. The fixed bus infrastructure variables that are part of the input are:
   - Length of bus station/lanes: 300 meters, between each crossing with the taxi (A-)lane.
   - Width of the lanes: each bus lane and berth lane has a width of about 3 meters.
   - The locations of the bus stops and zebra crossings.

5. Other fixed variables:
   - Share of the pedestrians not using the zebra crossings: 30%, as found after on-site counting at the peak hours.
   - Bus characteristics:
     - Length: 12 m (18 m for the Zuidtangent buses)
     - Width: 2.6 m
     - Normal (maximum) speed on the bus lane: 10 m/s, as the maximum speed is 30 km/hr on the bus lane, with a rounding up following speed measurements on-site. Speeds are generally in the 35-40 km/hr region in reality.

The bus types that are taken as standards are depicted in figure 5.1.

For the bus dimensions the length and width of the Mercedez Benz Citaro (Citaro G for Zuidtangent) is used, as this is a common bus type for the lines at Schiphol Plaza. The Zuidtangent buses are always Citaro Gs. [Mercedes Benz website, 2011].

FIGURE 5.1: THE USED STANDARDS FOR BUSES AT SCHIPHOL PLAZA: THE MERCEDEZ-BENZ CITARO (LEFT) AND THE CITARO G (RIGHT)
6 SCENARIOS FOR FUTURE BUS PASSENGER DEMAND AT SCHIPHOL PLAZA

To run simulations of future situations at the bus station, various scenarios are created. The scenarios are based on variations in moment in time, demand and distribution of demand. The latter is translated as different distributions over day, number of buses (for instance due to different sizes of buses). The moment in time and passenger demand are related through the projected growth. There are data on the projected growth of O&D (Origin & Destination, no transfer passengers) air travelers at Schiphol and the amount of workers within the Schiphol Area. Using the Mobility Research of 2011 [SOAB Adviseurs, 2011] the distribution of the number of workers over the day and the different bus lines can be estimated, in the same manner as is done with the data on current figures. Using the prognoses as provided by de Lange (2011) the distributions can be scaled to future amounts.

For the share of passengers that are not a Schiphil-based employee or air traveler, but that do make use of a bus transfer at Schiphol Plaza the prognoses are provided by De Lange (2011) as well. They are based on NS (Nederlandse Spoorwegen, “Dutch Railways”) prognoses for future amounts of users of the Schiphol Airport rail station as an start or end station (train transfers are not relevant for the bus station). Subtracting the number of Schiphol Area workers that do not work within the terminal area (and do have to use the buses) and the number of air travelers leaves the intermodal transfer passengers that use Schiphol Plaza as a transfer station.

The following assumptions have been made for the trends upon which the scenarios are based:

- As there are no data on the distribution of the non-Schiphol Area workers over the bus lines it is assumed that they have an even distribution over the Zuidtangent lines and an assumed 10% makes use of the Schiphol Sternet. These lines are slower and restricted in most cases to Schiphol Area and are not likely to be heavily used for commuting.
- It is assumed that throughout the years the frequency of the buses grows proportional to the demand of passengers. Specific cases may describe otherwise, if the solution is in the use of larger buses.

Tables 6.1 provides the basic scenarios in terms of bus users from/to Schiphol Plaza. The data processing calculations on which these figures are based can be found in Appendix B. Table 6.1 shows the cumulative numbers of passengers per category for scenario 0 in a graph.

<table>
<thead>
<tr>
<th>Average daily number of travelers vv</th>
<th>2011</th>
<th>2015</th>
<th>2020</th>
<th>2025</th>
<th>2030</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bus only Schiphol Area workers</td>
<td>5000</td>
<td>5700</td>
<td>6200</td>
<td>7000</td>
<td>7900</td>
</tr>
<tr>
<td>Parking - bus Schiphol Area workers</td>
<td>16600</td>
<td>18800</td>
<td>20500</td>
<td>23200</td>
<td>26200</td>
</tr>
<tr>
<td>Train - bus Schiphol Area workers</td>
<td>6600</td>
<td>7600</td>
<td>8900</td>
<td>9500</td>
<td>10200</td>
</tr>
<tr>
<td>Train-bus transfer passenger (non-Schiphol)</td>
<td>13400</td>
<td>15600</td>
<td>17500</td>
<td>19000</td>
<td>20600</td>
</tr>
<tr>
<td>Air Travelers</td>
<td>1900</td>
<td>2200</td>
<td>2500</td>
<td>2700</td>
<td>2900</td>
</tr>
<tr>
<td>Total</td>
<td>43500</td>
<td>49900</td>
<td>55600</td>
<td>61400</td>
<td>67800</td>
</tr>
</tbody>
</table>
This scenario, Scenario 0, is based on the prognoses as mentioned earlier, the other scenarios diverge from this scenario with a difference in growth with respect to 2011 of +20% and -20%. The list of scenarios is:

- **Scenario 0**: Schiphol Plaza bus use growth according to prognoses
- **Scenario 1**: Growth according to prognoses +20% ➔ high growth
- **Scenario 2**: Growth according to prognoses -20% ➔ low growth

The 0-scenario represents the scenario obtained by summing the prognoses of Schiphol workers, number of air travelers at Schiphol and NS user prognoses [De Lange, 2011]. This is the base scenario of which two variants are based.

The first variant, Scenario h1, presents a 20% higher growth (e.g. a growth 120% of the 0-scenario growth). This scenario is based on possible changes in the passenger demand that are unforeseen in the 0-scenario and they include:

- The inclusion of trams instead of buses for some of the bus lines. The quality perspective in terms of comfort factor for trams are higher than for buses in general (1.0 versus 1.2) and an initial growth of around 20% may be expected for those lines that are converted to trams [Pot, 2011].
- Even more success for the HOV-lines. The high quality bus transport is being expanded in Schiphol region [APPM & Goudappel Coffeng, 2010] which makes it probable that more travelers than expected will change their main transport mode from car or train to these regional bus lines.

The second variant presents a 20% lower growth (e.g. a growth 80% of the 0-scenario growth). This scenario includes the following elements:

- Schiphol's growth is restricted further. Both the number of air travelers and Schiphol workers grow less than in the 0-scenario.
The cause of this disappointing growth could also be the further development of the recession in The Netherlands and Europe. Recovery time expands well into the lengths of the proposed time span and therefore the growth on average may be expected to be at least 20% lower than in the basis scenario.

For the growth factors the total passenger supply and demand changes, but so do the number of buses, as is assumed, since the bus size is assumed to remain the same. The timetable is ‘compressed’ equally over time such that the order of buses and distribution over bus lines remains the same. Appendix B gives more specific information about the scenarios and the related numbers of passengers in this situation. Figure 6.2 shows the three scenarios in relation to time (in years).

**FIGURE 6.2: ALL SCENARIOS GIVEN WITH THE NUMBER OF BUS USERS PER DAY FROM 2011-2030**

**Implication on stakeholders and their influence**

The choice of the scenarios is important for many stakeholders. Even more so, the stakeholders are influential in the eventual realization of the scenarios. Many choices that will be made by amongst others the local and regional governments such as Stadregio Amsterdam together with Schiphol can influence the demand and supply of the bus system. As mentioned in section 2.2.1 there are plans for the introduction of a Westtangent, an HOV connection to Amsterdam West. This decision is not made however, meaning the supply and demand growth is still uncertain. Even national government has its influence in case they introduce new restrictions on Schiphol’s growth. The choice of Schiphol to change their landside layout can also include a higher or lower focus on the accessibility by bus. Reversely in case
of higher growth the impact on Schiphol might force a change in focus. For example, if parking availability cannot cope with the growth, Schiphol could push for a mode shift towards public transportation.

Concluding remarks of this chapter

Using these scenarios the future performance figures of the bus station can be generated by the simulation tool. The input values for passenger demand will be scaled according to the corresponding future numbers from these scenarios. Chapter 7 provides the current and future performance for all scenarios as it reports on the results from the simulation.
7 PERFORMANCE SCORES FOR THE CURRENT LAYOUT

In this paragraph the simulation results for each scenario in the current layout of the bus station are discussed. Results are given in terms of distribution of bus delays as a result of the bus station throughout an average work day. Also quality ratings are given in terms of bus platform occupation and safety ratings are determined in terms of bus-pedestrian interactions.

Before the simulation can be used for obtaining useful results, first the number of runs needs to be determined. The equation for determining the required sample size reads:

\[ n \geq \frac{Z^2 \sigma^2}{d^2} \]  

(7.1)

Where \( Z \) is the desired reliability in terms of standard deviation from the mean value (\( Z = 1 \) means the probability of being within one time the standard deviation), \( \sigma \) is the standard deviation of the data and \( d \) is the accuracy that you want the reliability for. After several test runs \( \sigma \) is found to be 1.4 seconds. An accuracy of 1 second is desirable as values for runs of different scenarios could lie close, within several seconds. A reliability of 90% is chosen that the values are within one second deviation, resulting in \( Z = 1.6 \).

The number of runs therefore is:

\[ n \geq \frac{1.6^2 \cdot 1.4^2}{1^2} \approx 5 \]  

(7.2)

7.1 THRESHOLD VALUES

To have a guideline how to interpret the results from the simulation for every criterion threshold values need to be determined. It is a quantitative method to calibrate the final scores of the bus station’s performance, also used when analyzing the design concepts.

- **Throughput / capacity:**

This criterion is measured in average delay first. This gives a more overall idea about the performance. However, the 10 second delays are not influential in anyone’s perception of the infrastructure, it is the more extreme delay that causes a perception of lower quality of the infrastructure. Therefore additionally a graph with the percentage of buses above the threshold value is given. Since the bus companies have a penalty system for delay, every whole minute will cost the company money as described in the tender, there is a threshold of one minute delay that should not be suffered. When taking into account the guidelines from the product specifications of the tender for the Schiphol regional buses, the aim is to have at most 5% delays of over one minute on average throughout the day [Probit, 2011]. However, specifically the peak hours are taken into account in this research and from the same quality review it follows that ‘only’ 90% stays under the boundary of delay. Therefore it is chosen that 20% less than half a minute delay suffered purely at the bus station is a reasonable scoring mechanism for this case.

- **Safety:**

When speaking in more general terms, safety thresholds are usually quantified in numbers of injuries or deaths, but as this is a single node in the network with very little accident history, there is chosen to
measure in a easier quantification method: measuring total braking seconds of all buses caused by crossing pedestrians. This is not a common method and there is no example of a suitable threshold to be found in literature. Therefore the threshold is set at twice the current values, since a potential 100% increase of the risk of accidents is a serious decrease of safety.

- Quality:

For quality it is determined to measure the occupancy of the bus platforms in spacing per pedestrian. The reverse can also be calculated, which then becomes the people density, but personal space is a unit that can related to more easily. According to literature thresholds for personal space in public transportation are distances of 1.2 meter, or \( \sim 5 \text{ m}^2 \). This is taken as the threshold for which the average possible spacing per person gives the bus user an unpleasant feeling, resulting in a lower perceived quality of the infrastructure.

7.2 RESULTS FOR THE CURRENT SITUATION (SCENARIO 0)

The simulation for scenario 0, the situation in the year 2011 for an average work day in the year, leads to results that are most similar to the current situation. Bus time tables for a work day are used as they are. Figure 7.1 shows the distribution of average delays of a single bus solely caused by the bus station process and interaction with crossing pedestrians. These are the results from five runs with various actual bus arrival times (determined by normal distribution using the measured standard deviation) for each hour during peak hours, as determined by Table 5.2. All results are for both directions on the bus lane.

![Figure 7.1: Results for average delays caused by the bus station in scenario 0](image)

As expected the delays are highest in the middle of the peak hour periods, when the number of buses and passengers (pedestrians) is highest. The average delay shows no drastic situation, no average delay is near one minute.
The next step is to see how these figures evolve when the use of the bus station increases throughout the years. In scenario 0 the growth is taken as predicted by Traffic & Transportation for Schiphol. For every five years a set of five simulations is run for the two highest peaks: 8:00-9:00 and 17:00-18:00. The evolution of the average delays provides an insight into the capacity of the bus station and in which year an overload of this capacity may be expected. The graph in figure 7.2-1 shows the average delays for both peaks from 2011 to 2030, while figures 7.2-2 and 7.2-3 indicate the safety score in accumulated braking seconds and the average pedestrian density on the most heavily used part of the bus platform: from the zebra crossing south of the traverse to the southern end of the platform. The bus platform here is about $70 \times 6 = 420 \text{ m}^2$.

**FIGURE 7.2-1: AVERAGE DELAYS FOR TWO PEAK HOURS FROM 2011-2030**

**FIGURE 7.2-2: AVERAGE PEDESTRIAN DENSITY FOR TWO PEAK HOURS FROM 2011-2030**
What can be seen from the results when comparing the different scoring criteria is that the safety score, in terms of braking seconds of buses, is in line with the bus throughput score.

The quality score has a less steep gradient, the gradient is more comparable to the passenger supply and demand growth. This is a logical outcome as the number of passengers on the platform determines this score. This number is also dependent on the bus frequency. Assumed is that the frequency grows with the supply and demand, so only large disturbances can cause overly crowded bus platforms. The results for scenario 0 show no signs of such disturbance.

### 7.3 Results for all scenarios compared

From the graphs in paragraph 7.1 it can be deducted that the time span of 8:00 – 9:00 is leading, when taking the most severe peak hour. Therefore, for combining the scores of the different scenarios this hour is taken as standard. For these computations the same amount of simulation runs for each five years is performed. The distribution of average delay across the time span is visualized in Figure 7.3,
As expected the high growth scenario delivers the highest delays for this peak hour. To get more insight in the distribution of the delays there is also looked at the percentage of buses having a delay larger than 30 seconds. This is shown in Figure 7.4.

![Figure 7.4: Percentage of Buses Suffering >30 Seconds Delay at the Bus Station](image)

Figure 7.5 shows the simulation results for the quality score for all three scenarios, where Figure 7.6 provides the safety scores.

![Figure 7.5: Average Pedestrian Spacing for 8:00 – 9:00 for All Three Scenarios from 2011-2030](image)

This graph shows little relation with the pedestrian supply and demand of the scenarios, other than a slight decrease. Still, an average of 12 m² available per person indicates that there is far enough outlet space in case of more severe peaks, when comparing it with the threshold of 5 m². The values in figure 7.6 also do not seem to spiral out of control. The increase is roughly comparable with the increase in average delay. The amount of braking in the low growth scenario, scenario 2, seems to increase just slowly for the first 15 years. The impact of the pedestrian numbers is clear from this graph. In the higher scenario in 2025 the
threshold of twice the ‘risk’ of today’s situation is expected. For the lower scenario though this moment appears to be well past the time frame and after 2035. This is a serious threshold though, meaning also here action should be taken as both for the base and the high scenario breaching of the threshold occurs within the time frame.

![Average Braking Seconds for 8:00 – 9:00 for All Three Scenarios from 2011–2030](image)

**Figure 7.6: Average Braking Seconds for 8:00 – 9:00 for All Three Scenarios from 2011–2030**

### 7.4 Concluding Remarks of This Chapter

The conclusion of this chapter is that the found scores indicate that, though not being an actual bottleneck, the throughput of the bus station is an issue. This can be a capacity issue, though acting on the pedestrian-bus interference is not a solution through capacity change. Chapter 8 provides further information on steps that are necessary to be taken in the form of providing alternatives to the current layout.
8 DESIGN CONCEPTS FOR THE BUS STATION

To overcome the future problems in capacity overflow, various changes can be made. At first the distinction is made between different types of measures. For each type of measure the effect is tested through simulation. For each measure a practical solution in the form of a new bus station layout or any other new alteration in the bus system is chosen from a list of realistic proposals. The choice of alternative design concepts follows from variations of layout and routes of pedestrians. Another factor on which to vary the bus station concept is the allocation bus stops. This could for instance be fully dynamic. However, the current concept comes close to dynamic bus stop allocation: each group of bus lines with similar characteristics, network or destination have a series of bus stops. When the first one is occupied the bus driver can switch to the second available spot and so on. Although this is not fully dynamic, given the layout of this particular bus station this concept comes close to fully dynamic allocation.

The final choice for a design concept is made after scoring the proposals on:

- Effectiveness of the measure
  - Tested through simulation, as is given in paragraph 0.
- Estimated costs for the proposal
- (Other) Benefits for the most important stakeholders

Results from Chapter 7 have stated that the first appearing main bottleneck lies in the capacity of the bus station. The flow is heavily disturbed and delays are unacceptably high. To overcome these issues the following types of measures are proposed:

1. **Capacity increase**: expanding the bus station in terms of number of lanes, or making better use of the available space.
2. **Rerouting of pedestrians**: without changing the bus lane, making sure that there is no more interaction between buses and pedestrians.
3. **Decreasing the pedestrian flow**: removing sources of pedestrians and/or partial rerouting of pedestrians without touching the capacity of the bus station.

All of these options are given the assumption that the amount and types of buses is not subject to change, which is considered an external factor.

Each of the possibilities is used to come to a new design concept for the bus station. First they are discussed in paragraphs 8.1 to 8.3, where a decision for a proposal in this ‘category’ is made. They are scored on the same criteria as the final choice for a proposal, only with an expected effectiveness, since simulations will only be run for the selected proposal from this category.

For all the decisions on the proposal design concepts it is chosen to use a simple version of a Multi-Criteria Analysis. This is a fitting way to compare expected scores while considering different weights of the criteria. As some of the criteria are contradicting and different in importance, it is a benefit to have a scoring system with weights and scores. It provides and open and explicit way of choosing between variants. The most fitting scoring for these MCAs is found to be 1, 2 or 3 points, 1 being a low score, 2
medium and 3 means a good projected score. This is a very rough scoring scale, but these are only projections of the performance and therefore this is sufficient.

There criteria and corresponding weights are:

- **Projected capacity / throughput score:**
  - This is not yet a result from simulation, but an estimation is made on how good this proposal will score compared to the other proposals.
  - Since throughput also influences the quality of the bus station as perceived by the users for a significant part, the importance of this criterion is high. It receives a weight of 3.

- **Projected safety:**
  - Scored through accumulated seconds of braking. But since this is a projection there may be looked qualitatively as well.
  - Although safety is always an important criteria, since it deals with human lives, scoring for safety quantitatively is limited and it also has a direct correlation with the throughput, since it is quantified through braking seconds of the buses. Therefore it has a weight of 2.

- **Projected score on quality:**
  - Quality scores from the simulation are quantified by available area per person. This is an easier criterion to estimate.
  - Quality is in interest of the users at first instance. However, as both Schiphol and the bus service providers are more than just interested in satisfied customers (and employees), quality is for them a significant factor.
  - Also this criterion is limited in capabilities for quantitative scoring, it is mostly a qualitative criterion. However, for the decision here other qualitative estimations may be taken into account as well. A medium score of 2 is taken for this criterion as well.

- **Estimated costs:**
  - Rough estimations, but extremely important as it highly influences the feasibility of the option.
  - Costs are a factor in interest of many of the stakeholders. Schiphol and the regional authorities are generally financers of landside projects, and for them costs are the largest burden towards new design concepts.
  - A weight of 3 applies here.

- **Other benefits or drawbacks:**
  - This criterion includes all benefits and drawbacks that are not covered in each of the above scores. This could be in the form of the relocation of other activities, building difficulties or user drawbacks.
  - Other stakeholders like construction companies might be introduced here. Also the elements suffering potentially from new design concepts may involve new stakeholders. One can think of influencing the taxi business at the same square if the bus station needs to expand.
  - Since the term is rather vague and not always clear side effects can be noted, the weight given here is 1.
8.1 DESIGN CONCEPT 1: CAPACITY INCREASE

Given the limited space in front of the terminals there is not much room for expansion of the bus station. In a new master plan there could however be a change in the use of lanes. If either the A- or C-lane would be transformed into a bus lane, this could increase capacity sufficiently. However, as the bus lanes are in both directions and boarding can only take place at the right side of the bus, one lane needs to cross the other at both ends. This will create some disturbance, but it is down to the simulation to see how large the disturbances are and what the benefits can be for the future. The following ideas for capacity increase are proposed:

- Transforming the C & D lane into second parallel dedicated bus lane with an equal number of berths as the existing bus lane. This requires the C- and D-lane activity to be moved elsewhere. This could be a move of Kiss & Ride to the Departures access roads only and the exits of P1 moved to the other side of the building, around the corner. This is a proposal that requires a large amount of construction work and relatively high costs.

- Maintaining the C and D-lane and transforming the A-lane for taxis into the second dedicated bus lane. The taxis can be moved to the upper departure hall road, which is a common taxi stand for departing passengers. Combining both is possible, but there is a high chance of congestion and lack of taxi stand space on this road. The projected costs for this option are marginally lower than the first option, as the parking building do not require construction, but still a second bus lane including facilities is to be constructed.

- Combining flows of taxis and buses on the A-lane, while maintaining the B-lane as it is. It will be transformed into a bus lane, but for only a limited part, as taxi stands are necessary as well. Part of the taxis can still be rerouted towards the departure hall road. Costs are similarly high as for the second proposal.

These three proposals are combined and scored on the criteria as described in paragraph 0 and the results are shown in Table 8.1.

<table>
<thead>
<tr>
<th>Criteria (projected):</th>
<th>Weight</th>
<th>C &amp; D --&gt; bus lane</th>
<th>A --&gt; bus lane</th>
<th>A --&gt; taxi + bus</th>
</tr>
</thead>
<tbody>
<tr>
<td>Score on capacity / throughput</td>
<td>3</td>
<td>3</td>
<td>3</td>
<td>2</td>
</tr>
<tr>
<td>Score on safety</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td>Score on quality</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>Costs</td>
<td>3</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Other benefits / drawbacks</td>
<td>1</td>
<td>2</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Total score:</td>
<td>22</td>
<td>21</td>
<td>16</td>
<td></td>
</tr>
</tbody>
</table>

The projected scores on capacity are good for all proposals. A doubling of the amount of berths should provide about twice as much capacity, which should be sufficient for far into the future. Cost are high for all proposals, as well as the score on safety when combining taxis and buses on the same lane. The results from the simulation will be similar for this option, but the fact that two types of vehicles with different kind of behavior share the bus station infrastructure is another factor that decreases this score. The score on quality is medium as it is expected that there be sufficient space per person on the platforms, as is the...
case now. Another factor that is not in the simulation, but does affect quality, is the accessibility of the bus station. With two busy bus lanes to cross, this is a slight drawback and causes the score to be medium. The A-lane alternative scores badly on the drawback that the taxis are to be moved to the already crowded departures hall road.

The implication of both the C&D-lane removal as the A-lane removal are similar, in both cases the current users will not favour the option. For obtaining the scores from the simulation, this close call is not necessarily a problem since the resulting design concept is practically the same. Though they are very comparative scores, the slightly better score of the C- & D-lane alternative leads to the selection of this proposal for this category to be simulated by the tool.

**How the tool is used for this proposal:**

The option will be chosen for a lane to be added. Giving the crossing locations of the two lanes will create a yielding regime between conflicting buses. It is convenient to use the existing crossings with the A-lane (taxis). As there will be only the current length available, the total length of the bus lane will be kept unchanged. Bus stop locations can be chosen to be the same as for the current bus lane. Buses are now divided up into twice as many bus stop locations. The result will be half as many per bus stop, while the type of lines per bus stop (either lane) are kept the same.

**8.2 DESIGN CONCEPT 2: REROUTING OF PEDESTRIANS**

An alternative for altering the bus station layout is altering its access points for pedestrians. The main advantage of this measure is the removal of any pedestrian-bus interaction. This will to a certain extent enhance the bus flow on the bus lane, without changing the lanes or bus stops. However, this is an extensive construction that involves high costs. The results of the simulation might account for this construction. Only options for no more pedestrian-bus interaction are to let the passengers either access the middle platform from above or underneath. The most basic option is a staircase bridge across the bus lanes. However, this was the situation years ago at the bus station and proved to be very unsuccessful and the bridge was largely unused. Pedestrians are not willing to opt for up and down movement when the clear alternative (crossing the roads anyway) is there for grabs. Therefore this is not considered as a proposal in this category.

Three proposals are based on the three possible (realistic) new access points:

- **Since a large group of the pedestrians comes straight from the train station underneath and the fact that there can be a direct connection between the bus platform and the train station platform, an escalator/staircase between the two is a potential solution to the pedestrian flows. Especially the train-bus connection is optimized in this way.**

- **Creating an escalator/staircase from the traverse crossing all the lanes that connects Plaza with P1, Sheraton Hotel and the WTC building. The existing access to this traverse from Plaza is wide and thus capable of handling large pedestrian flows. The zebra crossings will be removed and crossing the streets at Plaza will no longer be possible or allowed.**

- **The most extensive proposal is to move the bus lane upwards to a higher level. Pedestrians can now access the bus station from underneath and this way too all pedestrian-bus interactions are**
removed. The additional benefit here is the creation of new space for infrastructure underneath the bus station.

The scores for these three proposals are given in Table 8.2.

**TABLE 8.2: SCORING RESULTS FOR THE PROPOSALS IN THE CATEGORY ‘PEDESTRIAN REROUTING’.**

<table>
<thead>
<tr>
<th>Criteria (projected):</th>
<th>Weight</th>
<th>Train station</th>
<th>Traverse</th>
<th>Bus lane raised</th>
</tr>
</thead>
<tbody>
<tr>
<td>Score on capacity / throughput</td>
<td>3</td>
<td>3</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>Score on safety</td>
<td>2</td>
<td>3</td>
<td>3</td>
<td>2</td>
</tr>
<tr>
<td>Score on quality</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>Costs</td>
<td>3</td>
<td>1</td>
<td>3</td>
<td>1</td>
</tr>
<tr>
<td>Other benefits / drawbacks</td>
<td>1</td>
<td>2</td>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td>Total scores:</td>
<td></td>
<td>24</td>
<td>30</td>
<td>23</td>
</tr>
</tbody>
</table>

Figure 8.1 shows the winning design concept of having a rerouted pedestrian flow through the traverse.

![Figure 8.1: Design concept 'Traverse Access'](image)

**FIGURE 8.1: DESIGN CONCEPT ‘TRAVERSE ACCESS’**

Again, all proposals for rerouting the pedestrians should have a largely positive effect on throughput. Only the bus interaction and capacity of the actual bus lane can now cause a bottleneck. Safety in terms of the pedestrian-bus interaction is also very high, since this interaction is removed completely. Another factor introduced however is the raised level of the bus lane, which introduces the risk of incidents at the ramp or at the edges of the bus platform. The main drawback of the train station and traverse proposals is that in
some way the bus station should be closed off at street level, so that crossing the roads is made impossible. This also means that crossing the roads past the bus station should now be using the traverse as well. However, this is a minor group. A drawback for the train station option is that the flows through such an entrance can get congested as the train station platforms are very crowded during peak hours. Space is only limited here. The access to the traverse however is wide with two large access tunnels each containing a staircase and three escalators. This route is less congested for pedestrians and the already present route upward with escalators reduces the unattractiveness of a slight detour to the bus station. The most important advantage of the traverse option is the ever important cost criterion. Creating a staircase with escalator from the traverse will involve a substantial investment, but it will be incomparable to creating a vertical passage towards the bus stations. Even more, the train station has three platforms, meaning that for completeness all three would need such a passage. The option of the traverse access point is therefore chosen, as the raised bus lane option will require an investment many times that of an escalator combination down from the traverse to the bus station as well.

Figure 8.2 visualizes the access points from the rail platforms concept.

![Access Points from Schiphol Station](image)

**FIGURE 8.2: DESIGN CONCEPT ‘ACCESS POINTS FROM SCHIPHOL STATION’**

How the tool is used for this alternative:

Pedestrian flows are rerouted. The simulation gets only more straightforward, as the bus-pedestrian interaction is removed and no longer a zebra occupation determination is required. Pedestrians still need to be simulated in order to determine the number of people waiting for each bus to board, this is still dependent on how the buses and pedestrians are simulated and cannot be left out of consideration.
8.3 **DESIGN CONCEPT 3: REDUCING THE PEDESTRIAN-BUS CONFLICTS**

Another alternative is to simply reduce the pedestrian flows. There is looked at the different sources of pedestrians and each proposal treats one of those sources such that the pedestrian flow crossing the bus lane is reduced:

- There are more sources of pedestrians than only the buses vice versa. Some of the production is from the Kiss & Ride and the coaches arriving each day. Since especially the coaches produce a long string of pedestrians, this can have a large effect on the bus flow. This will be only a minor reduction in the total pedestrian flow, however.

- The pedestrians are rerouted as in the previous set of concepts through the traverse, except that the zebra crossings are not removed. The reason for not removing the zebra crossings in this alternative is that it might prove to be difficult to force a closed off bus station, unless a valuable construction around it is created as well. Also the people coming directly from/to the terminals to the bus station will not prefer to be rerouted up to the traverse and down again, or down to the trains station and up again, even though that is a minor detour. This is also a significant group and leaving the zebra crossing option open is a distinct alternative compared to the previous concepts.

- The pedestrians are rerouted through the train station access, but again also leaving the zebra crossing open for pedestrians toward or from Schiphol Plaza, who do not have the train station as origin or destination. This removes the group of pedestrians coming from the train station whilst keeping the option of crossing the roads open for other pedestrians.

The scores for these three proposals are given in.

**Table 8.3.**

<table>
<thead>
<tr>
<th>Criteria (projected):</th>
<th>Remove groups</th>
<th>Traverse + zebra c.</th>
<th>Train station + zebra c.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Score on capacity / throughput</td>
<td>3</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>Score on safety</td>
<td>2</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>Score on quality</td>
<td>2</td>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td>Costs</td>
<td>3</td>
<td>3</td>
<td>2</td>
</tr>
<tr>
<td>Other benefits / drawbacks</td>
<td>1</td>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td>Total scores</td>
<td>18</td>
<td>21</td>
<td>25</td>
</tr>
</tbody>
</table>

The scores, benefits and drawbacks are based on the proposals from the pedestrian rerouting design concepts, but with the difference that the impact on throughput and safety is less, but there is no drawback of a closed off bus station at street level. Quality scores are reasonably good, since there is no forced detour anymore. The removal of the small groups from coaches and Kiss & Ride is expected to have little effect on the throughput, safety and quality scores as this group insignificantly small. Costs are very low for this option on the other hand. The traverse option will be unlikely to be very popular as most people will opt for the easier route, which gives them a bad score in the last criterion. This is purely based on choice behavior: when the easier way is available, most people will opt for that. The costs might be high when breaking through the tunnel where the train station is. But mostly for its effectiveness, especially in
improved quality for train-bus transfer, the best choice in the category of reducing the crossing pedestrian flows is the **train station access point** option, with maintaining the zebra crossings.

**How the tool is used for this alternative:**

In this concept the bus users coming from the train station can be left out. Since this is a separate group indicated and separately analyzed in the data analysis, it can simply be left out of the calculations. The group will still arrive at the bus platforms, but the pedestrian flow crossing the roads will now only consist of the other bus users.

### 8.4 CONCLUDING REMARKS

For each of the three categories of performance-improving design concepts one proposal is chosen. This is done in order to have a varied and distinguishable set of concepts that can be analyzed using the simulation tool. Now that the three options are known they are scored using the simulation tool. This is further explained in Chapter 9.
9 PERFORMANCE SCORES FOR THE DESIGN CONCEPTS

For each alternative the simulation tool is run in the highest scenario and for the busiest hour of the day, which was found to be 8:00 – 9:00. The results are compared to those of the original layout and situation of the bus station. This leads to a comparison of all three concepts and conclusions on which is the best option. As a reminder, these are the three selected design concepts:

- Capacity increase by transforming the C & D-lanes a second dedicated bus lane with stops.
- Pedestrian rerouting: an access point from the traverse to the bus platform furthest of Plaza, while closing off the other accesses and consequently removing all pedestrian crossings.
- Crossing pedestrian flow reduction: access points from the railway station platforms, thus rerouting all the bus users transferring from and to the trains.

9.1 SIMULATION RESULTS OF ALL THREE DESIGN CONCEPTS

When providing expectations, for the capacity increase concept a better score on the throughput is expected as capacity has doubled. The same can be said about the traverse access point concept, where the bus flow disturbing pedestrians are no longer crossing the bus lane. Because the zebra crossings still exist in the train station access concept, the effect is expected to be lower than for the other two. Figure 9.1 shows the results of simulating the new alternatives in the highest scenario (scenario 1) for the throughput score in terms of average delay, the most important factor as was determined in Chapter 7. This is supported also by the graph of the percentage >30 seconds delay buses. Figure 9.3 provides the safety score of the three selected design concepts and the basis scenario.
As can be seen the bus flow for the traverse concept is nearly undisturbed for the current situation and earlier prognoses, and only slightly disturbed further into the future. Still the improvement on this part compared to the standard situation is very significant, with a maximum of just 14 seconds. This tells us that the layout of the bus station this way does not need urgent capacity expansion if the pedestrians can be rerouted elsewhere than the zebra crossings. When looking at the values for bus throughput of the train access point concept in the graph it is clear that the effect is not as large as for the other two alternatives. However, there is still an improvement compared to the current situation.

The safety score is not produced for the traverse design concept in this run of the simulation, since there is no more bus-pedestrian interaction on the roads. The score for this alternative is simply set to maximum,
or in this case zero braking time. The other two alternatives are tested on its safety and the results can be found in figure 9.3.

The third alternative, which has a reduced pedestrian flow crossing the bus lane, is expected to have mediate results for all criteria compared to the other alternatives, since this is a ‘middle of the road’ alternative. In this case the convenience of having the zebra crossing option still open means that the scores as will be shown here are sacrificed for that convenience.

The quality scores are somewhat misleading, since the location of the train station access point of the train station access concept in the bus platform determines the density of pedestrians on the location for that design. It is however not yet known where exactly this will be and whether it will be taken into account for the given part of the bus platform. In the simulation it is assumed that it is within the bus platform and therefore yields low scores on quality in terms of pedestrian spacing. Next to that, the density of the capacity expansion concept is not comparable either as it depends on the layout of such a new expanded bus station. Therefore the quality score will not depend on simulation outcome, but be determined considering the proposed layout and ideas.

9.2 SCORING OF THE ALTERNATIVES AND FINAL CHOICE FOR NEW BUS STATION LAYOUT

The final choice for a new bus station design proposal is made after comparing the simulation results and scoring other characteristics of the proposal. The same technique is used as in Chapter 8, with the same weights for the criteria, except that for this analysis the quantitative scores are known and more precise scores can be given. The scores for all criteria are in the range of 0 to 4 (five choices), except the costs score, as only rough estimations can be given on this subject. The following ranges determine the score 0 to 4 for all the criteria and are based on the earlier mentioned thresholds:

- **Capacity / throughput:**
  - 0: exceedence of 30 second average before 2025
  - 1: exceedence before 2030
  - 2: exceedence before 2035
  - 3: no exceedence within the time frame
  - 4: no exceedence and no more than 20% >30 sec. delays within the time frame (fulfillment of goal for complete time frame)

- **Safety score:**
  - 0: >100% increase in risk in 2040 (with respect to current level)
  - 1: 50-100% increase in 2040
  - 2: 0-50% increase in 2040
  - 3: 0-50% decrease in 2040
  - 4: >50% decrease compared to current situation in 2040

- **Quality score (qualitative due to change in platform):**
  - 0: significant worsening of platform quality
  - 1: worsening
  - 2: light improvement in situation
  - 3: strong improvement
  - 4: strong improvement including other qualitative benefits
Performance study for the Amsterdam Airport Schiphol bus station

- Costs:
  - 0: Requires large scale construction. >€10 million costs
  - 2: Estimated costs €2 - €10 million
  - 4: Estimated costs <€2 million

- Other benefits / drawbacks:
  - 0: Many drawback, doubtful feasibility
  - 1: Some drawbacks
  - 2: No drawback, or a balance of benefits and drawbacks
  - 3: Some benefits
  - 4: Many or very significant benefits

Table 5.9 presents the scores depicted in colors again for all the aforementioned criteria. Also the zero-alternative of having no changes at all is included in this MCA.

**TABLE 9.2: ALL ALTERNATIVES FOR A DESIGN PROPOSAL SCORED ON THE GIVEN CRITERIA**

<table>
<thead>
<tr>
<th>Criteria:</th>
<th>Weight</th>
<th>Zero-alternative</th>
<th>Capacity expansion</th>
<th>Traverse access point</th>
<th>Train station access point</th>
</tr>
</thead>
<tbody>
<tr>
<td>Score on capacity / throughput</td>
<td>3</td>
<td>2023: 0</td>
<td>2027: 1</td>
<td>Not &amp; 13% above threshold in 2040: 4</td>
<td>2028: 1</td>
</tr>
<tr>
<td>Score on safety</td>
<td>2</td>
<td>102%: 0</td>
<td>132%: 0</td>
<td>No risk: 4</td>
<td>47%: 2</td>
</tr>
<tr>
<td>Score on quality (no sim- results)</td>
<td>2</td>
<td>No change: 2</td>
<td>Slight improvement: 2</td>
<td>Slight worsening: 1</td>
<td>Worsening, but with benefits for train-bus pax.: 2</td>
</tr>
<tr>
<td>Costs</td>
<td>3</td>
<td>None: 4</td>
<td>&gt;€20 m: 0</td>
<td>€2-10m: 2</td>
<td>€2-10m: 2</td>
</tr>
<tr>
<td>Other benefits / drawbacks</td>
<td>1</td>
<td>None: 2</td>
<td>Some drawbacks: 1</td>
<td>Large drawbacks: 0</td>
<td>Some drawbacks: 1</td>
</tr>
<tr>
<td>Total score:</td>
<td>14</td>
<td>8</td>
<td>29</td>
<td>18</td>
<td></td>
</tr>
</tbody>
</table>

Remarks on the scores of concept ‘Bus station expansion’ are discussed below:

- Impact on throughput by increasing the capacity was moderate, but not as much as might be expected from a doubling of the facilities.
- Safety is gotten worse for those pedestrians needing to cross two bus lanes with zebra crossings to get to Schiphol Plaza or vice versa.
- The quality in terms of accessibility is reasonably good, but finding your way or correct bus stop will prove to be more difficult. Medium score here as well, therefore.
- The costs of transforming one or two lanes into a dedicated bus lane is a large infrastructural project that will lead to an investment of millions of euros.
- The main drawback remains that the destination of the current users of the C- and D-lane is to be moved as well.

The scores of concept ‘Traverse access point’:
This alternative has the best improvement on throughput and safety. A maximum safety score is obtained from the simulation, since no bus needs to brake for crossing pedestrians in this proposal.

The quality is again not determined by simulation results, but merely on its accessibility, which is not perfect, since there is a small detour through the traverse.

Costs are involved, though they are less than creating multiple staircase holes to the train tunnel or rebuilding most of the infrastructure around the bus station to expand it.

The scores of concept ‘train station access point’:

- The throughput increase is moderate compared to the other alternatives. There is still a group of pedestrians making use of the zebra crossings and the capacity of the bus lane itself remains unchanged.
- Safety scores from the simulation are better than the basis and the capacity expansion. Still the possibility of a pedestrian collision on a zebra crossing remains.
- Quality score for this option is relatively high as the connection between the train station and the bus station benefits a large group of users, which will rate the bus station presumably with higher quality marks. It does however have the same pedestrian congestion issues as the traverse concept might have.

The scores in table 9.2 indicate a clear best of the concepts: the traverse-bus station connection.

9.3 IMPLICATIONS OF THE DESIGN CONCEPT CHOICE FOR STAKEHOLDERS

When taking a step back at the stakeholder analysis and the interests of the main stakeholders, it is clear that the most affected stakeholders are those having interest in high punctuality, since the main ‘bottleneck’ appears to be the throughput of buses on the bus lane. The choice for a traverse access for all bus station users will benefit many parties:

- The users will benefit from higher punctuality on the line and a safer bus station.
- Safety will also be a benefit for the authorities as well as the improvement of main hub Schiphol station, which will more and more act as a major regional hub.
- There are no direct implications for the bus companies, but they too will benefit from the fact that their customers too will be more satisfied.
- Last, but not least it will be Amsterdam Airport Schiphol as a company that will now have a more state-of-art bus station and higher appreciation for its accessibility, both from customers and from employees around the area. Therefore it will be recommended for Schiphol to look into further detail on possibilities for a access staircase with an escalator towards the middle bus platform.
10 CONCLUSIONS AND RECOMMENDATIONS

Here the findings of the research, based on the simulation results for Schiphol Plaza bus station, lead to conclusions of this thesis. In this chapter the final conclusions on the thesis are provided in paragraph 10.1. What the implications of the conclusions and findings are for all the stakeholders and Schiphol in general is given in paragraph 10.2. Looking from an even broader perspective, the scientific and practical value of this thesis is, is explained in paragraph 10.3. The recommendations for further research on the subject and improvements to the methods are given in paragraph 10.4. Finally there is the validation of the research question and design goal set in the beginning in Chapter 1.

10.1 CONCLUSIONS

From this research a set of conclusions is drawn. The goal was to find a method to score a bus station, in particular Schiphol Plaza bus station, on its infrastructure performance. The findings give a clear trend from this research: the bus-pedestrian interaction is leading when it comes to both throughput and safety on a bus station's lanes. The situation with multiple zebra crossings providing access to a part of the bus station's platform area appears to be a very common one, but in fact is not so normal. The type of bus stations with concentrated bus-pedestrian conflicts is in most cases an island-type of bus station. Due to the limited amount of space at the terminals and the complex combination of taxis, public roads and parking one of the busiest bus stations in The Netherlands is simply a series of curbside bus stops. In a situation like this improving the bus station's throughput is not as simple as just increasing capacity by expanding the bus station. This calls for smart methods to improve the throughput and safety, while maintaining the same quality as a bus station.

The results clearly show that this is also the most effective solution: reducing or even completely removing pedestrian-bus conflicts is beneficial for both bus throughput and safety. Just increasing capacity by adding another lane might seem like the perfect answer, but the situation of a busy mix of buses and pedestrians is maintained. It might provide buses with more than enough capacity vehicle-wise, but the same amount of pedestrians will have to cross the bus lanes to get to the entrance of its neighboring hub.

The cause of these results lies in the fact that road capacity is not in every case leading for the throughput of a vehicle lane. Instead of focusing on the vehicle flow only, the pedestrian flow proves to be at least as important in some cases. The influence the removal of pedestrian flows crossing the lanes has compared to an increase of capacity on the road is impressive. There are a lot of cases thinkable where this will also be the most inexpensive improvement of the two.

The technique for rerouting pedestrians is not an easy task though. Schiphol has the advantage of readily available structures and buildings above and underneath the bus station. It requires a connection between the two places that initiates the rerouting of the pedestrians. In other cases a bridge will be the only option, which leaves the questions about the pedestrians’ choice behavior.

But what has become clear is that with the luxury of having other potential access points to and from a bus station, it will be worthwhile to examine what rerouting away from bus-pedestrians conflicts can do for the quality of the bus station, since it might be the most cost-efficient and effective measure.
10.2 **IMPLICATIONS OF THE RESEARCH FOR THE STAKEHOLDERS**

The research results can have an implication on the various stakeholders including Schiphol itself. The conclusions from 10.1 might influence policy making on multiple levels.

- For a more cost effective solution to traffic flow problems on the bus station it is wise not to opt for large bus station renovation, since this research has shown that the current layout can cope until 2030 capacity wise, as long as the bus and pedestrians flows are separated. And costs are, especially in current economic situation, a major factor for future expansion plans. This is the primary advice to financers for Schiphol landside projects, including the stakeholders Schiphol Group, Stadsregio and the provinces.

- Rerouting for bus users does not sound attractive for this group of stakeholders at first, but considering the increase in quality on the field of punctuality and safety this should largely please the bus users. If the detour is kept at a minimum, people will soon get used it and the inclusion of sufficient escalators no person needs to worry about the change of levels.

- Having rerouting options to solve congestion problems is a choice that will be favoured by the bus companies as well as this will not hinder any of their activities and it requires little involvement. Building a completely new bus station implicates that it will most likely not be accessible for a part of the construction time, while construction of access point should not necessarily hinder the bus flows.

10.3 **SCIENTIFIC AND PRACTICAL VALUE**

The main scientific outcome of this research is the aforementioned importance of pedestrian-vehicle interaction, in this case at a bus station. It is the influence on safety as well as the traffic flow that leads from the practical example of this subject. If the principle of a bus station with dedicated bus lane and dedicated crossing locations is similar to Schiphol Plaza's example, it might be expected that similar results would follow from performance study on other locations. When the type of bus station is different, e.g. a multiple island system, or a system with no pedestrian-bus interaction at all, the comparison does not comply.

In practical terms this is beside VISSIM the only simulation software as far as can be found in literature that simulates buses together with pedestrians where the bus passengers are generated directly from the buses and vice versa and their interaction with the buses. Other software can simulate both, sometimes also in the same model, but not the pedestrian generation from buses directly, where the bus arrivals are also linked to an external and changeable timetable. Also the train timetable is included, albeit only to ensure more realistic peaks in pedestrian arrivals.

Schiphol now owns both the research results for the bus station performance and the simulation tool that has provided these results. For the department of Traffic & Transportation it is especially useful to make use of the knowledge in the decision making process. There is still all to decide on for the 2025 Master Plan and it is T&Ts desire to have as much focus on landside accessibility as possible. The simulation tool can provide the results again for different scenarios, and input, The effect of large changes to the timetables, for
instance, can be assessed using the tool and therefore the engine behind this research work can provide support to other projects as well.

10.4 **Recommendations**

Recommendations are provided to indicate practical follow-up steps after the results of the research and to improve the methods that are used in order to improve the results of this research.

Steps that could follow up this research include:

- Increasing the amount of (types of) data that is used by the simulation or could be used by enhanced versions of the simulation.
  - There is still little known about the amount of pedestrians not related to the bus station and their distribution over time as well as their distribution over the zebra crossings. Although this is a small group that does not highly affect the results, more data on their numbers and routes could easily be included in the simulation. These numbers can be obtained by more thorough on-site counting, where both numbers origins and destinations are noted. An even easier option is to analyze the Kiss & Ride users.
  - The data on crossing location is limited to a percentage of people that do and do not make use of the zebra crossing. This however depends on the bus stop location. Some spots tend to encourage more ‘incorrect’ road crossing than others. This requires a significant amount of study, but since these pedestrians create a safety issue too this study might be worthwhile. Crossing location will then be directly linked to bus stop location in the simulation tool.
  - The inclusion of the train station timetable is very basic in the model. Differentiating between different platforms with their own walking distance requires additional data collection. It requires the knowledge of the distribution of the travelers over the platforms and their distribution in relation to the bus station. Surveys at every platform could provide the information, including type of traveler (employee, intermodal transfer passenger or air traveler), origin and destination.

- Looking further into the proposed design concepts. The costs, construction work and feedback of stakeholders are fields on which more detailed information can be obtained in order to make an even more founded decision. Organizing meetings with the main stakeholders where the different proposals are offered can lead to fruitful discussions. Also getting quotes of construction companies will provide more insight into the total costs of each alternative and the amount of work and time that has to be spent on the construction.

Since the issue with simulations is, as always, that they do not represent the exact real situation, part of the recommendations focuses on improvement of the simulation. The current tool includes some assumptions and simplifications which can be the focus for improvement:

- The current simulation tool simulates pedestrians with no interact between each other. Congestion due to high pedestrian concentrations, both on the roads and on the bus platforms, is not taken into account. In reality for peak hours this can become a factor that reduces the walking speed and therefore the road crossing process. As an improvement of the simulation tool this
congestion can be taken into account. Walking speed should then be made dependent on the surrounding number of people, for instance within a 5 meter radius. If for each of these pedestrians this calculation is made the flow will behave more realistically.

- Only basic layouts of bus stations can be computed using this simulation tool: multiple-berth curbside bus stops with a two way dedicated bus lane. Though it was estimated that the island types of bus stations are not suitable for the situation at Schiphol Plaza, for a more extreme large-scale redesign of the terminal area it might become a potential option. Also for a wider application of the tool it could be beneficial to extend the functionality into single and multi-island types of bus stations. This does however require more knowledge about choice behavior of the pedestrians when crossing the roads to get to or from these islands. Enhancing the tool this way would then include a more advanced pedestrian simulation element and an expanded data set for input, since there will be many choices for walking routes.
10.5 Validation: answering the research questions

Here the findings of the research, and in particular the simulation results for Schiphol Plaza bus station, lead to validation of this thesis. The conclusions lead to answers for the research questions that were given in chapter 1 and they are given below:

- **RQ1:** What are the standards and scoring techniques for bus throughput (capacity), quality and safety for a bus station?

Bus stations can be scored on its performance through three main fields: bus throughput, or capacity in a more general sense, quality as perceived by the user and safety.

The standard scoring technique for bus throughput is found to be determining (additional) delay caused by the bus station. Delay suffered earlier in the process is not a result of the bus station process, so measuring absolute delay is not appropriate. The most appropriate technique is to determine total throughput time minus waiting time at the bus stop and free flow throughput time. The delay can now only be caused by interference of pedestrians crossing zebra crossings or with other vehicles.

The criterion quality is a wide term, and in this context there should only be focused at quality related to the infrastructure. Also quality is often determined by punctuality of the services, but that factor is already contained in the throughput factor. What does have an influence is the quality of the bus platforms in terms of pedestrians density. Therefore pedestrian density in m/s² is the standard for quality of the bus station.

For safety scoring the appropriate unit to be taken is the accumulated time of a bus braking for a zebra crossing, since at this location is the highest risk of a collision between a pedestrian and a bus. This is modeled in the simulation by adding up this particular braking maneuver in terms of seconds.

This paragraph aims to answer the research questions RQ2, RQ3 and its sub questions. The current layout has been thoroughly examined through the simulations and conclusions following the research questions can be made in order to determine the need for improvements. The first research question that will be answered here is:

- **RQ2:** How does the Schiphol Plaza bus infrastructure score on these fields?

This will follow according to the answers of the subquestions below:

- **RQ2.1:** How does the current bus station layout score on throughput /capacity?

The threshold is set at 30 seconds average delay. If this is the aim, then at around 2022 the guidelines will not be met anymore, in the worst case of high passenger demand and supply growth. In the other two scenarios this point follows 5 to 7 years later. Still within the range of the set 2011 until 2030 time frame to undertake action.

- **RQ2.2:** How does the current bus station layout score on quality?

The quality score in terms of pedestrian spacing, or pedestrian density, on the bus platform appears to change gradually, but not in steep slopes. This is mainly due to the fact that bus frequencies increase in
Performance study for the Amsterdam Airport Schiphol bus station

relation to the passengers. Although disturbances can cause more people to be stuck clotted on one part of the bus platform, the current layout satisfies the needs for personal space by a large margin.

- **RQ2.3: How does the current bus station layout score on safety?**

The safety boundaries are not fixed, since accumulated zebra crossing braking time of all buses is not a common unit to measure safety in. But as the delay increases with higher pedestrian flows, so does the danger. Having zebra crossings for such a heavily used bus lane is not the safest of options. The total numbers show this as well: about 1800 braking seconds for all buses in one peak hour corresponds to a total of 30 minutes braking, or half the time on average one bus brakes for crossing pedestrians. With that in mind the score can be considered to be low (high values) for bus station average.

- **RQ2.4: What is the robustness of the current bus station?**

The results from the simulation have shown that in theory the bus station can handle large amounts of traffic and pedestrians. The interaction between the two, however, causes a significant growth in average delay. Peaks within the range of delays increase as well and though not treated as such in the simulation, the increasing delays affect the quality aspect of the bus services as well. The most important thing that can be concluded is that the bus station is traffic wise robust for even a 67% growth in scenario 1 for 2030, with respect to 2011. This leads to conclusions on the existence of a bottleneck.

- **RQ3: What is the estimated performance of the bus station in future?**

The performance of the bus station is seen through the slopes of the graphs and known guidelines for maximum allowable values. Though for safety score the results show a relation with the pedestrian increase, the growth is nowhere dangerously steep. The throughput score is denoted by a more steep growth in the last phase to 2030, especially for the high scenario, and considering a desired less than 30 seconds average delay, the performance in throughput, or: the capacity of the bus station, is not sufficient until 2030.

  - **RQ3.1: At which point in time does a significant bottleneck appear?**

Nowhere a real bottleneck physical sense is found after simulating all scenarios and scores. The infrastructure seems to cope with the flow, albeit with increasing delays caused by the bus station. Though this is not a literal bottleneck in future in the sense that the flow on the bus lane will be completely congested, the delays become unacceptably high. Therefore the capacity is treated as a bottleneck in future which will have to be removed to maintain a high quality bus station.

  - **RQ3.2: Is the first appearing bottleneck a capacity, quality or safety bottleneck?**

As mentioned above, the issue that will be treated as a bottleneck is a clear capacity bottleneck. This is the field which has to be searched upon to find a measure for improving the bus station.

  - **RQ3.3: What is the severity of the appearing bottleneck?**

The severity of the appearing bottleneck is not very high. Flows still provide throughput from begin to the end of the bus station. Though the increase of the delays predicts an upcoming bottleneck somewhere
past 2030, possibly within five years after that. That does not mean that the quality of services and infrastructure is sufficient up until that point.

- **RQ3.4: Are there more significant bottlenecks projected between now and 2025?**

Following the results of the simulation there is no need for worrying for another bottleneck than a capacity overflow. Safety issues might prove an issue, but the measures taken for improving capacity will most likely improve pedestrian safety by decreasing the interference between the two.

**Main design objective:**

“Creating a design proposal for a new bus stop layout or otherwise score improving concept that meets future requirements in terms of capacity, safety and quality.”

The main design objective is fulfilled by creating the idea of an access to the bus platform from the traverse crossing the roads at Schiphol Plaza to the opposite buildings. Enough space for a wide stream of pedestrians and a possibility to create staircase with an escalator from this height. By closing off the station from other sides this will remove the possibility of crossing the roads from or to the bus station and therefore disturb the flow on these lanes. This will increase the safety, quality and throughput of the bus station. Next to that it will satisfy the main stakeholders: the bus users, bus companies, the (regional) government and most importantly the main problem owner Schiphol Group.
LIST OF REFERENCES


Gemeente Amsterdam Dienst Ruimtelijke Ordening (2010), Verkenning HOV Westtangent


## APPENDIX A: BUS LINES AT SCHIPHOL PLAZA

### TABLE A.1: BUS LINE OVERVIEW

<table>
<thead>
<tr>
<th>Lines:</th>
<th>route:</th>
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<td></td>
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<td>...starts ...ends</td>
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<tr>
<td>300a</td>
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<td></td>
</tr>
<tr>
<td>300b</td>
<td>Haarlem - A'dam</td>
<td></td>
</tr>
<tr>
<td>277a</td>
<td>Haarlem - Schiphol</td>
<td></td>
</tr>
<tr>
<td>277b</td>
<td>Schiphol - Haarlem</td>
<td></td>
</tr>
<tr>
<td>310a</td>
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<tr>
<td>310b</td>
<td>A’dam - Nieuw Vennep</td>
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<td><strong>STERNET</strong></td>
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<tr>
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<td>Amstelveen - Schiphol Z P40</td>
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<tr>
<td>187a</td>
<td>Schiphol N. P40 - Amstelveen</td>
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<td>191b</td>
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</tr>
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<td>Schiphol Z. P30 - A’dam Sloterdijk</td>
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<td></td>
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**OTHER CONNEXXION LINES**

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**GVB**

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### Prognosis jobs around Schiphol area

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<th>noord</th>
<th>zuid</th>
<th>oost</th>
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TABLE B.2: DAILY BUS MOVEMENTS OF SCHIPHOL WORKERS ACCORDING TO WORKING SHIFTS AND TRANSPORT MODE

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<td>0,76</td>
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<td>209</td>
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<td>50</td>
<td>0,14</td>
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<td>0,95</td>
<td>171</td>
<td>0,47</td>
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<tr>
<td>Car as passenger:</td>
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<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
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<td>57</td>
<td>220</td>
<td>0,90</td>
<td>198</td>
<td>0,76</td>
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<tr>
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<td>220</td>
<td>0,95</td>
<td>209</td>
<td>0,57</td>
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<tr>
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<td>220</td>
<td>0,95</td>
<td>209</td>
<td>0,57</td>
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<tr>
<td>Irregular flying</td>
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<td>50</td>
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<td>Car as carpooler</td>
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<tr>
<td>Train (centrum&amp; zuid!!):</td>
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<td>0,95</td>
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### Performance study for the Amsterdam Airport Schiphol bus station

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**Regional bus**

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**Interliner**

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<td>209</td>
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<tr>
<td></td>
<td>0,57</td>
<td>26,0,70</td>
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<tr>
<td>Irregular flying</td>
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<tr>
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<tr>
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<tr>
<td>Irregular others</td>
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<tr>
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<td>bus tot:</td>
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**TOT** 20699 per day