Functionality Improvements of SimBus Pro

Goudappel
MOBILITEIT BEWEEGT ONS

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Bachelor Thesis Civil Engineering

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Preface

This thesis is the final assignment for the Bachelor of Civil Engineering (CE) at the University of Twente and a result of a ten week internship in the field of CE.

The thesis “Functionality Improvements of SimBus Pro” was carried out at the engineering and consultancy firm Goudappel. Goudappel is specialized in Integrated mobility planning and their aim is “to make cities livable and urban regions accessible” translated from Dutch (Goudappel, 2023).

During my bachelor program, I developed an interest in computer and simulation models for traffic and transportation issues. Therefore, my choice for an internship at Goudappel, who has a lot of expertise on these topics. For my CE thesis, I was assigned to a project on public transportation, more specifically on bus lines. A topic which has a combination of both interests, on a civil level as well as on programming.

The project was conducted both at the Hague office, where one of my supervisors, Alejandro Montes was based, and in Deventer, where the other supervisor Geert-Jan Wolters was based. I very much enjoyed working at the office, talking to experienced advisors, and running ideas by them. This however was disrupted, when I had a little accident and tore an ankle ligament which caused some delays and made it impossible to travel to the office. Luckily both Goudappel and the UT were very understanding and granted me an extension to my internship.

The bachelor thesis is an individual assignment, however, I could not have completed it without the valuable feedback and inspiring interviews with the advisors at Goudappel: Ellen van der Werf, Hendrik Bouwknegt, Frank de Winter, and Jeroen Terlouw, who introduced me to the world of SimBus pro. A special word of gratitude is for my supervisors both at Goudappel, Alejandro Montes, and Geert-Jan Wolters, and my thesis supervisor at the University of Twente, Alejandro Tirachini. I learned a lot from each and every one of you. It is a pity that I could not be as much at the office as I wanted to be. Still, I learned a lot both in programming as well as on a personal level. A big thanks to all of you.

It has been quite a challenge to finish the thesis in time. But here it is. I enjoyed working on the project and I do hope some of the recommendations will be useful. SimBus Pro is a very interesting program that has a lot of potential and the use of this model is important for the future of public transport.

Simon Beusen

Enschede, July 16, 2023

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Summary

The assignment for this bachelor thesis was to extensively examine SimBus Pro, a simulation tool for bus terminals. In order to do so, global conceptual models were created for the code of SimBus Pro in order to enhance the possibility to understand SimBus Pro and its processes. During this process, several areas of concern were identified, providing insight into the code and thus enabling reflection on the code. Additionally, four interviews were conducted with four experts from Goudappel. Their feedback combined with the reflection on the code leads to a number of recommendations for improvement in terms of functionality, usability, and output of SimBus Pro as listed in the table below. These recommendations are clarified and discussed in Chapter 5.

Table 1 - Short description of each recommendation

Section	Recommendation
5.1 A	Determine optimal number of simulation runs
5.1 B	Implement a semi-automatic tool for naming the links in the Vissim file
5.1 C	Automate the construction of the timetable file and a checkup tool for irregularities
5.1 D	Reliability per bus line?
5.1 E	Set departure on time as default
5.2 A	Give passengers who miss their bus, the option to enter the next bus
5.3 B	Create a Vissim workaround for passengers that move towards the bus in front of the queue
5.4 A	Reconsider the assumptions concerning bus behavior on the platforms
5.5 A	Display total delays of the simulation
5.5 B	Include electric loading time for electric buses
5.5 C	Include the dwell time percentage of each bus line on each platform
5.5 D	Introduce numeric thresholds to SimBus Pro
5.5 E	Provide information about distribution of bus lines at each platform
5.5 F	Correct the calculation in the “LIJNINFO” worksheet

One of the recommendations, recommendation 5.5 D, which suggests adding numeric thresholds to SimBus Pro, has been successfully implemented in the code in this project. Additionally, a literature-based recommendation for establishing numeric thresholds is proposed.

By addressing these recommendations, SimBus Pro is improved in terms of functionality, usability, and output. The implementation of 5.5 D enables Goudappel to compare different simulations and make more informed recommendations to their clients. The numeric thresholds, that are presented in Table 4, provide the ability to assess the effectiveness and efficiency of different bus terminal scenarios.

Note, that there are two versions of this report. One is publicly available and does not contain specific details of SimBus Pro, and one which contains all information and is available at Goudappel.

1 Introduction

Most bus terminals are an important link between different kinds of public and private transport. Therefore it is important to have a good functioning bus terminal with reliable timetables and clear information for travelers. As the Dutch State Secretary Van Veldhoven stated "Stations are more than ever an important link for travelers. They are the gateways to the city and for a quick and easy transfer between public and private transport. We are therefore joining forces to make these public transport hubs ready for the future in different parts of the Netherlands" (translated from Dutch, Ministerie van Infrastructuur en Waterstaat, 2020) [1].

Simulation software for bus terminals can prove to be very valuable when building new bus terminals. This software can help to optimize public transport services and help to increase the efficiency of the systems.

Optimalization in public transport involves multiple levels, starting with strategic planning and extending up to tactical and operational planning. After creating a public transportation network, there is much to be done before it can be made operational, which is achieved by tactical planning. In tactical planning, the line frequencies, timetables, vehicles, and crew schedules are determined. Finally, operational planning and control come into play. This level deals with unforeseen or unexpected changes in the schedule or the route of the buses (Gkiotsalitis, 2022).

Goudappel, an engineering and consultancy firm, has developed a software plugin based on Vissim, called SimBus Pro. Vissim[2] is a broadly used traffic flow simulation software package. Vissim however lacks some functionality on simulating bus terminals. Goudappel commissioned and built Vissim-based SimBus Pro, which aims at simulating bus terminals. Both strategic planning, tactical planning, and operational planning related to bus terminals can be modeled in SimBus Pro, thus helping clients to design fitting schedules for the bus terminals that are passenger friendly and practical viable. The main feature is the simulation of specific movements of buses at bus terminals. The information generated by SimBus Pro can be used to optimize the public transport services and thus the overall efficiency of the system. In this bachelor thesis, the assignment was to focus on the software Goudappel developed and how to improve this software.

For this project, a structured approach is used to further improve the functionality of SimBus Pro. The project starts by exploring the context of the project, SimBus Pro, and a clear definition of the research objective. Subsequently, the software SimBus Pro is scrutinized to determine whether there are any problem areas. This is achieved by investigating the code of SimBus Pro and by interviewing experts that have used, developed, or worked with SimBus Pro. The thus identified problem areas, which are an outcome of the interviews, are discussed in this thesis. Recommendations for the identified problem areas are made.

Finally, one of the recommendations for enhancing SimBus Pro is implemented in the code. The final chapter discusses the objectives of the project, the problem areas, and the solutions leading to a conclusion for future improvements of SimBus Pro.

Due to SimBus Pro is a program developed by Goudappel, there exist two versions of this thesis: a publicly available version and a confidential version. The confidential version, which is held by Goudappel, provides a more detailed elaboration on Chapter 3 and its corresponding appendices.

1 https://www.rijksoverheid.nl/actueel/nieuws/2020/11/27/rijk-en-regio-bouwen-verder-aan-betere-bereikbaarheid-van-nederland

[2] https://www.myptv.com/en/mobility-software/ptv-vissim

2 Research context

2.1 SimBus Pro

SimBus Pro is a user friendly interface between the user files, generated by the experts of Goudappel, and Vissim. Vissim is an advanced realistic traffic simulation software (*PTV Vissim*, 2023). During a simulation run, SimBus Pro guides Vissim by simulating all the activities in a bus terminal. After each simulation run the output is extracted, and exported in an output Excel file, which summarizes the results. SimBus Pro coordinates and checks the input files of Vissim, the simulation run of Vissim, and the output files of Vissim. Although Vissim can simulate bus terminals all by itself, large bus terminals are known to encounter complications. SimBus Pro can address these complications, by providing detailed information of the buses and their network. By integrating SimBus Pro with Vissim, the simulation can be improved. SimBus Pro gives the possibility to include all the surrounding networks of the bus terminal, hence providing a more detailed and reliable result. The SimBus Pro interface is coded in Python (version 3.9 is required).

SimBus Pro is developed by Geert-Jan Wolters to replace an outdated program of Goudappel called SimBus, which lacked some functionality and visualizations of simulations. To improve the interface Wolters build a new version of SimBus that is based on Vissim. One of the advantages of Vissim is the fact that visualizations can be included in the results. The most recent version of SimBus Pro was released on August 24, 2022.

2.2 Stakeholders

The engineering and consultancy firm Goudappel commissioned this bachelor thesis. Goudappel is specialized in integrated mobility planning. Their aim is to make cities livable and urban regions accessible (Goudappel, 2023). By investing in the improvements of bus simulation software, Goudappel aims to provide their clients with more reliable and constructive results that enable them to make informed decisions and achieve optimal outcomes in public transportation planning. This ensures that existing and new bus terminals are able to provide a good coupling for the public and private transport (Ministerie van Infrastructuur en Waterstaat, 2020).

2.3 Theoretical framework

To ensure a clear research framework for this bachelor thesis, several steps are outlined. The first step involves providing a comprehensive understanding of SimBus Pro through the creation of global conceptual models. The conceptual models capture the fundamental functionalities of SimBus Pro. However, due to the complexity of SimBus Pro, it would not be practical to include every exception in the thesis as it could lead to confusion. Instead, the conceptual models have been designed to provide a generalized overview, emphasizing the fundamentals of SimBus Pro. Following the development of conceptual models, the next phase of the research involves conducting interviews with experts who have experience with the use of SimBus Pro. These interviews are conducted after gaining basic knowledge of the conceptual models. The interviews focus on three main topics: SimBus Pro experience, input data, and output data. The insights and feedback gathered from the previous steps are used to generate a recommendation list for Goudappel, providing the basis for further improvement of SimBus Pro.

Due to the limited time frame of the bachelor internship and thesis, only one recommendation can be selected for implementation in the interface. This selection is made in consultation with both Goudappel and the University of Twente in order to ensure its feasibility and relevance.

The final step of the research process involves drawing conclusions and addressing the research questions outlined in the proposal. The research questions are stated below:

- How does the SimBus Pro program work for a given case study?
- How to improve the input data of SimBus Pro?
- How to improve the output data of SimBus Pro?

2.4 Theoretical studies

Computer simulations, such as traffic simulations, are often used to represent reality and give valuable input for decision making in real life where reality testing is too complex, dangerous, or too expensive. In a simulation such as Vissim for complex traffic problems or SimBus Pro for buses and bus lines, the computer program or algorithm simulates changes through a model, thus simulating different responses to input signals (Ifentaler, 2012)

The main focus of this project is the computer simulation module of SimBus Pro, a specialized module that uses Vissim. The name Vissim is derived from "Verkehr In Städten - SIMulationsmodell" (German for "Traffic in cities - simulation model")[3]. The model was first developed in 1992, currently it is a globally used multi-modal traffic flow simulation software package, which is only available through a (paid) license. Goudappel is licensed to use Vissim. Goudappel commissioned and built Vissim-based SimBus Pro, that aims at simulating bus terminals.

Lindberg (2019) proposes several ways to evaluate the traffic flow performance of a bus terminal. He uses the average queue lengths and the average number of vehicles waiting at the terminal. Next to this, it is also important to take the traveler into account, by evaluating factors such as the average waiting time or transfer time for passengers (Lindberg, 2019). Evaluating traffic flow performance can only be done by also taking these aspects into account.

Analytical modeling of simulations provides a method to mathematically model the behavior of a system using equations and formulas. Three ways to perform analytical modeling are used for bus simulations: the dwell time, capacity formulas, and queuing system. The dwell time method uses the time that the bus spends at a terminal based on the number of passengers boarding and alighting from the bus. In previous bachelor research by Frazer (2022), the relationship between the number of passengers boarding and alighting and the observed stop times was examined. Frazer examined how the boarding and alighting of passengers can be implemented in the code of SimBus Pro (Frazer, 2022). In order to accurately model dwell times, it is important to take into account the opening and closing times of the doors of the bus (Lindberg et al., 2020).

Capacity formulas are another analytical method to model bus terminals. However, there are not many capacity models available for bus terminals see (Lindberg, 2019). Queuing theory is also used to analyze delays and queue lengths. This can be done on simpler bus terminals, as they can be seen as a queuing system. However, when a bus terminal is very large, queuing theory becomes a difficult and time consuming method to use. Therefore, this analytical modeling is only suitable for smaller bus terminals (Lindberg et al., 2020; Lindberg 2019).

Mainly event-based and time-based simulations are used for the simulation of bus terminals. Discrete event simulations are also a suitable method for modeling bus terminals since it can be described based on clearly defined events (Lindberg et al., 2020). A bus terminal model should include the modeling of passengers, their arrivals, dwell times, and departures (Lindberg, 2019). The passenger modeling is

[3]https://www.myptv.com/en/mobility-software/ptv-vissim

included in the SimBus Pro code, where they arrive at the terminal, alight from the bus, board the bus, and the passengers who have just alighted leave the bus terminal. This modeling was discussed in detail by Frazer's bachelor thesis (Frazer, 2022). The relationship between the number of boarding/alighting passengers and the observed stop times as well as the way boarding and alighting of passengers are implemented in SimBus Pro code are discussed. Lindberg adds the importance of considering the opening and closing times of the bus doors while modeling the dwell time (Lindberg, 2019).

Simulation models use common road traffic rules, but it is still important to note that bus terminals operate differently from normal road traffic. As a result, the bus terminal simulation should use other rules to make it more efficient (Lindberg et al., 2020). Although outside the scope of this thesis, the different types of stops (linear, saw-tooth, angle-stop i.e. - drive in, back out) and the way stops are arranged in the terminal can make a big difference in efficiency (Lindberg (2019). For future research, this might be taken into account too.

2.5 The contribution of this thesis

The contribution of this thesis encompasses several aspects that are aimed at enhancing the understanding and functionality of SimBus Pro for Goudappel. This section highlights the contributions that this bachelor thesis has made throughout the course of the project.

Conceptual models

One of the contributions this thesis aims to make is the development of conceptual models for SimBus Pro. These models serve as a comprehensive representation of the software, enabling a better understanding of its functionalities, operations, and exceptions. By creating these conceptual models, the hope is that Goudappel is provided with a model that in the future can be used for gaining insights into SimBus Pro and its processes.

Recommendation list

Another contribution is the compilation of a recommendation list, specifically made for Goudappel. Through research and insightful interviews with experts of Goudappel, areas of improvement within SimBus Pro were identified and explored. The recommendations that followed this action, range from optimizing the input data, taking a different angle at looking at passenger behavior, or to improve the output data. With this recommendation list, Goudappel is able to adapt SimBus Pro according to their specific needs and requirements.

Numeric threshold

The next contribution of this project has been that one of the recommendations is implemented in SimBus Pro. For this, the numeric threshold recommendation has been successfully implemented. This implementation adds valuable output data to the output file of SimBus Pro. The use of numeric thresholds, set in this bachelor thesis, makes it possible to compare different simulations. It enables Goudappel to give more structured and informed decisions towards the client.

2.6 Research objective

The research objective of this thesis is to identify problem areas within SimBus Pro and implement a solution to improve its user functionality.

3 SimBus Pro

SimBus Pro is a tool programmed in Python and works together with Vissim. This chapter aims to analyze the functionality and operations of SimBus Pro, providing a comprehensive understanding of the tool. To analyze SimBus Pro, it can be divided into four main parts: Input, Preparation simulation, Simulation, and Output. All four parts are briefly touched upon in this chapter, since this is the public version of the report. In the classified version, the components where extensively discussed, and conceptual models are constructed to further explore their complexities.

3.1 Input:

SimBus Pro is capable of addressing various aspects of a case study, making it necessary to provide a substantial amount of input. Currently, the software requires users to provide specific parameters next to a Vissim file, that contains the network for the simulation and a timetable file containing the schedule for the buses in the simulation.

To ensure a realistic simulation that reflects on the current of a case study, the bus schedule data is derived from NDOV ("Nationale Data Openbaar Vervoer", translated as National situation Data Public Transport) (*NDOV Loket*, n.d.).

3.2 Preparation model

In this stage, it is important to adapt the Vissim network created for the simulation in such way that SimBus Pro can identify the different components, such as platforms, entrances, exits, and decision points. By ensuring that the Vissim network is properly adapted, SimBus Pro can operate smooth during the simulations.

3.3 Simulation

SimBus Pro simulates multiple buses concurrently, each with predefined actions. These actions could include a variety of the following actions: alighting, buffering, and boarding. These actions can be modified during a simulation, for instance if a bus is running behind schedule, a decision may be made by SimBus Pro to skip the buffering action, or merge the alighting and boarding actions. Platforms are determined by evaluating the platform occupancy. Additionally, buses can move forward within the platform when a bus ahead in the queue departs.

3.4 Output

Once the bus has left the network, its output data is stored, and compiled into a comprehensive and detailed excel file. This output file contain extensive information related to the simulation results. This output file offers valuable insight into various aspects of the bus simulation, such as leaving on time or delays.

3.5 Reflection model

Now that the model has been fully understood, it can be reflected upon. The reflection is divided into four main parts in the coming sections.

3.5.1 Input parameters and files

The input phase of the simulation involves three critical aspects. The determination of the simulation runs and the creation of the “Vissim file” and “Timetable file”.

Firstly, the number of simulation runs is currently determined solely on intuition. This lack could results in impact on the results or the inefficient utilization of time during the simulation progress. Secondly, the creation of the Vissim file poses a labor intensive task. This process involves naming all the links in a specific manner. Which could lead to “small” errors. Lastly, the creation of the timetable file is a time-intensive work and is susceptible to human errors. Given the complexity and the amount of information involved, mistakes in the timetable file are likely to occur. These errors could affect the simulation results.

3.5.2 Passengers

During the simulations the passengers are assigned to individual buses. The model does not yet take into account that passengers who miss their bus, will wait on the next one to come. Passengers missing their bus leave the network in the model. The effect of this is minimal since it occurrence is low.

When more buses are on the same platform the model boards all queuing passengers in the first bus, leaving subsequent buses empty. This error is caused by Vissim, and effects dwell time for the bus(es) in line after the first bus.

3.5.3 Behavior buses

The behavior of buses on the platforms represents another point of reflection -in the simulation . the buses will try to move forward on the platform whenever possible, regardless the remaining dwell time. This approach does not reflect the real-world, where buses will wait for passengers to board in certain cases. For example when there are only two passengers left to board the bus will wait in the real world for these two passengers to board instead of moving forward like currently happens in the model.

3.5.4 Output

The current output generated by SimBus Pro is a large and detailed Excel file. However, due to the size of this Excel file it could be confusing to use.

There is currently an issue with the calculation method used for two time variables in the “LIJNINFO” worksheet. Specifically, one of the column involves using the modulo operation(“Vertrek Vertraging”, Departure delay), while the other column does not (“Aankomst Vertraging”, Arrival delay). While this columns are comparable since they both calculate the delay. This inconsistency in the calculation method can lead to incorrect results when dealing with time values that span across midnight.

4 Interviews

In order to identify the problem areas of SimBus Pro, interviews were conducted with four users at Goudappel. The interviews aimed at gathering insights and different perspectives from users who have experience with SimBus Pro. The interviews evolved around the following three topics:

- 1. General user experience: What is your experience with SimBus Pro? Have you used SimBus Pro or been involved in projects that used SimBus Pro?
- 2. Input data: What is your experience with the input data of SimBus Pro? Are there any missing or unnecessary functionalities within the program?
- 3. Output data: What kind of output would you like to see from SimBus Pro? Additionally, what kind of data would clients prefer to have? Are there any areas in which improvements could be made to the output?

Valuable insights and feedback were gathered through the interviews with experienced SimBus (older version of the current program) and SimBus Pro users. This information forms the basis for future improvements of SimBus Pro. The background of the interviews and the summary for each question is given in Appendix A.

4.1 Main conclusions of the interviews

In total, four interviews were conducted. Two participants were users of the SimBus and the other two were involved in projects where SimBus Pro was used. SimBus had all the functionalities that SimBus Pro currently has, but more functionalities was added. Based on the interviews, it was clear that users of SimBus - the older version of SimBus Pro - suggested some improvements that already have been implemented in SimBus Pro. Thus, some of the statements of the participants are disregarded.

The participants did not provide examples of useless functionality of the input data. However, there were several suggestions for improvement. Firstly, the on time departure of buses should be set on default. This is to create more extreme simulation conditions. Secondly, the reliability of the bus lines inputs could be merged to save time. Lastly, the issue with the manually generated input, which is prone for errors, should be solved. For the last item, a suggestion was made to create a separate program to check the input data on consistency and errors, before starting a simulation.

All participants made the suggestion for adding the total delay of the buses in the output, calculated as the sum of the blok, halt and hinder times. At the same time, the blok, halt, and hinder times should be better explained or named. Another interesting suggestion is to add an extra element to the output with regards to the disturbance rate. Currently, there are no numeric thresholds set for this disturbance rate, which makes it difficult to compare different simulation results. What is a reasonable or acceptable disturbance rate for a good functional bus terminal? Another intriguing proposal was made with respect to electric buses. At the moment the program does not include any special needs of electric buses, like charging time and limited operational time. This needs more research to include the specific settings of electric buses in the model with a good parameterization. The last request was made to include a figure in the output with the percentage of use time of each bus line at each platform.

5 Recommendations

In the previous chapters areas of improvement for SimBus Pro have been identified. In this chapter, these areas are discussed and a recommendation list for Goudappel is provided.

5.1 Input

a. Determine optimal number of simulations

Based on section 3.6.1, it is proposed to conduct scientific research to determine the optimal number of simulations, rather than setting this value solely on intuition. This research would be beneficial for the accuracy and efficiency of the simulations.

b. Implement a semi-automatic tool for naming the links in the Vissim file

Regarding the Vissim file, the process of manually naming the links is time-consuming and error sensitive. In order to save a significant amount of time for the user, it is recommended to implement a semi-automatic tool that can automate the naming of the links in the Vissim file.

c. Automate the construction of the timetable file and a checkup tool for irregularities

Section 3.6.1 and the interviews highlighted the labor-intensive nature of the "Timetable file" and its probability of human errors. To address this, it is recommended to automate the construction of the timetable file using the standardized layout of the NDOV data. Additionally, it is recommended to develop a separate tool that can check this timetable file for irregularities in the time schedule before running the simulation. This would prevent unnecessary simulations due to possible errors in the timetable file. For example, the program could highlight irregularities for a review by an expert, whom can assess their impact on the simulation and make the necessary adjustments. Implementing these recommendations would save time during later stages of projects. This is a good recommendation because of the time saving it will induce.

d. Reliability per bus line?

Assuming recommendation c. is followed, the suggestion of one of the participants of the interviews, to add reliability per bus becomes superfluous. So it would make more sense to assess the reliability of a specific bus line. Therefore, it is not recommended to exclude the reliability of individual bus lines from the lines from the input, as well due to the fact of the previous recommendation to make the generation of the timetable file automatic. In case recommendation c. is not followed, the idea of the respondent can be implemented. Which makes both recommendations, c, and d valuable. Both will not go together: either c or d can be used. Option c can be easily implemented and will save time. For option d, the effect might be less obvious.

e. Set departure on time as default

A suggestion from the interviews pertained to the departure on time parameter in the timetable file (STIPT). It is recommended that the departure on time parameter is default true to make sure that buses are trying to leave as close as possible to their planned departure time. This change would ensure that schedules remain intact, and the bus performance could be better evaluated. As a default, buses should depart on time, only to deviate from this standard in exceptional situations. The bus terminal performance can be better optimized if this suggestion is taken into account and used in the simulation. By doing so, it ensures that extreme situations, e.g. on a day that all buses are early which causes problems with location, are better evaluated and these extreme situations are taken into account in the bus station.

5.2 Passengers

a. Give passengers that miss their bus the option to enter the next bus on the bus line

From section 3.6.2, it is given that passengers will leave the network whenever they miss their bus. This is not realistic. In real life, a large percentage will hop on the next bus. Hence it is recommended to give the passengers the possibility to enter the next bus on the bus line, this could be done by looking at the next bus and take a percentage of passengers that will wait on this bus and will leave the network based on this percentage the passenger will stay for the next bus or leave the network. This will make the simulation way more accurate. In order to make this as realistic as possible, the simulation should be based on real data (observational data) of passengers in stations in the Netherlands. There has to be a caveat here: section 3.6.2, states that the impact on the output of the simulation will be minimal it is still recommended because it will make SimBus Pro more realistic hence adding to the models validity

b. Create a Vissim workaround for passengers that move towards the bus in front of the queue

Another point of attention is the problem caused by Vissim that passengers will move towards the bus in front of the queue, however due to the fact this problem is caused by Vissim it will be recommended to look for a workaround, in such a way that the passengers board the bus that is determined for them. This point also adds to the validity of SimBus Pro making it more realistic. Also, the fact that passengers board the wrong bus, which could lead to differences in outcomes. This should be accounted for.

5.3 Behavior buses

a. Reconsider the assumptions concerning bus behavior on the platforms

The behavior of buses on the platforms represents another point of reflection. When simulating, the buses will try to move forward on the platform whenever possible, regardless of the remaining dwell time. This approach does not reflect the real world, where buses would wait for passengers to board in certain cases. For example, when there are only two passengers left to board the bus will wait in the real world for these two passengers to board instead of moving forward like currently happens with SimBus Pro. Here the model is not as realistic as it could be. Therefore this improvement is suggested.

5.4 Output

a. Display total delays of the simulation, along with blok, halt and hinder times

Based on the interviews, it is recommended to display the total delay of the simulation, along with the blok, halt, and hinder times. Additionally, blok, halt, and hinder times should be renamed to provide a clearer overview and avoid confusion for both users and clients. This is an excellent suggestion for it will bring clarity to the output of SimBus Pro.

b. Include electric loading time for electric buses

A suggestion from the interviews was to include the loading time of electric buses to the output. This can be done by including the characteristics of electric buses in the simulation, including their charging time and their maximum distance. However, this proposal is challenging (van Oort, 2018). Therefore, it is recommended to perform more research on this topic before implementing this in SimBus Pro.

Since we do not know yet how many buses are or will be totally electric in the future, this is an interesting point for further research. The recommendation should be taken into account and SimBus Pro could most likely benefit from adding the loading time of electric buses. This recommendation is as well important as in 2030 the European Union's goal is to have all city buses electric, in 2022 the Netherlands had 27% of all buses electric (Ruiz, 2023).

c. Include dwell time percentage of each bus line on each platform

Another suggestion was made to include a figure in the output with all dwell time percentages of each bus line on each platform. This is however an difficult task due to the fact that the bus terminals would differ each time. However, it is possible to implement a figure with the percentages of bus lines of each platform. The figure with percentages of each bus line on each platform would be recommended as shown in Figure 1 (with imaginary data).

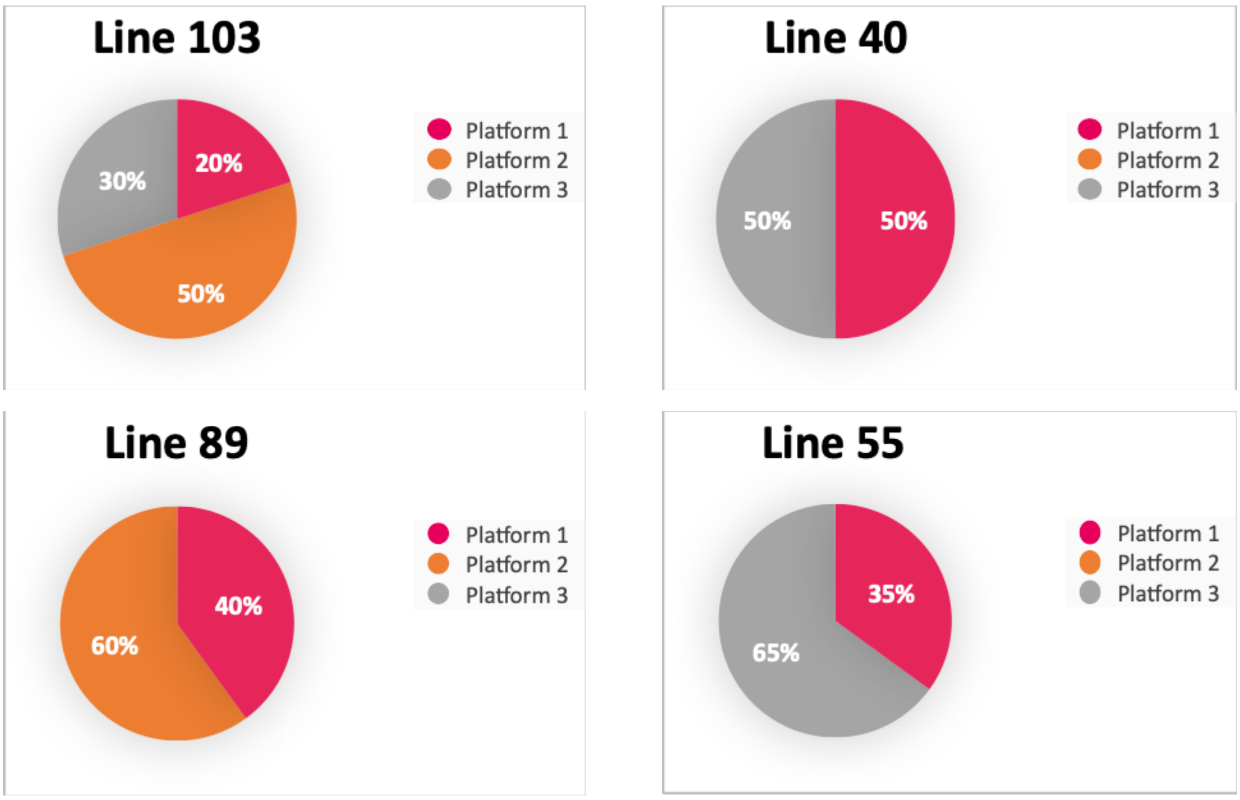

Figure 1 – Use of the platforms for each bus line (based on imaginary data)

d. Introduce numeric thresholds to SimBus Pro

The last suggestion of the interviewees was about the numeric threshold for the disturbance rate. However, it is not clear in this stage if there could be set numeric thresholds for the disturbance rate. Still, the recommendation is made to include numeric thresholds for SimBus Pro so an alternative could be easily identified as a good or bad alternative. This would need literature research towards the numeric thresholds of various aspects of a bus terminal. This recommendation will help with the outcomes of SimBus Pro and as well improve the ability to compare different models, or outcomes with each other.

e. Include and visualize a figure to provide information about the use of each platform of each bus line

Based on the interviews, it has been suggested to include a figure that provides information about the distribution of bus lines at each platform. Specifically, it is recommended to generate a list for each platform, indicating the bus lines that performed their actions at that particular platform, along with the corresponding percentage of time the bus platform was occupied by each bus line. By incorporating this feature, SimBus Pro would offer a visual representation of the usage of platforms by different bus lines. This could provide valuable insights into the efficiency of the platform usage. Since the visual output is very insightful and will help with consulting clients about their problems, it should be implemented. An example of a figure is given in Figure 2.

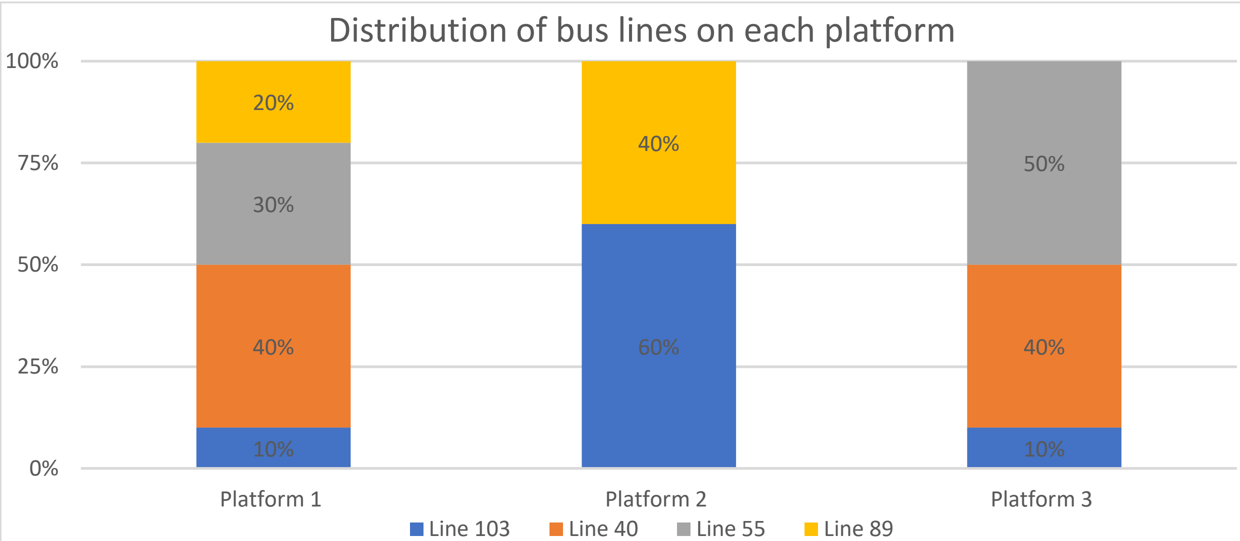

Figure 2 –Distribution of bus lines on each platform (based on imaginary data)

f. Correct calculation in LIJNINFO worksheet

It has been concluded, that whenever a bus arrives before midnight and departs after midnight, it could lead to inconsistency in the results. To address this issue, it is recommended to implement consistent calculation methods for both the “Aankomst Vertraging” (Arrival delay) and “Vertrek Vertraging” (Departure delay) columns. In addition to ensuring reliable outcomes, an exception should be added to the calculation process to handle cases where buses cross midnight. This implementation will ensure that the output is consistent and reliable. This also is a very valuable suggestion that will improve SimBus output.

6 New implementation SimBus Pro

In this chapter, the implementation of a recommended improvement for SimBus Pro will be discussed.

Among the general recommendations, there was a discussion with my supervisors, Alejandro Tirachini, Alejandro Montes, and Geert-Jan Wolters, in order to determine which recommendation should be implemented as part of this Bachelor assignment. The conclusion of this discussion was to implement recommendation 9.4.d. in the code of SimBus Pro. Next to implementation, a literature review towards numeric thresholds is needed to be able to properly interpret the results of this new proposed functionality.

The expectations of Goudappel are stated below. Furthermore, the literature review, corresponding implementation, and description of the case study are presented.

6.1 Expectations of Goudappel

Goudappel has expressed the need to incorporate numeric thresholds for simulations of SimBus Pro. The purpose of these thresholds is to enable Goudappel to compare different simulations and determine the quality of each variant. Currently SimBus Pro lacks a systematic way to compare or evaluate variants of bus terminals. Goudappel would like to classify simulations as either good or not so good, providing a clear indication of the performance of each bus terminal, and thus the performance. The main objective of this implementation is to establish numeric thresholds for SimBus Pro that allows for effective comparisons of multiple variants for the client. By including numeric thresholds for SimBus Pro, Goudappel will gain valuable insights in the simulations and this will enable Goudappel to make well-founded decisions and recommendations for future clients.

6.2 Research on numerical thresholds

In order to establish numeric thresholds for SimBus Pro, a literature review was conducted. The Transit Capacity and Quality of Service Manual (TCQSM), which provides guidelines and standards for evaluating transit capacity and assessing quality of service (QOS), was used (Brinckerhoff, 2013). SimBus Pro is a simulation tool and has its limitations in capturing all aspects of bus terminal QOS. This review explores the quantitative QOS parameters that can be calculated within the simulation.

Das and Pandit (2013) highlight both quantitative and qualitative QOS parameters. Because qualitative parameters, like bus design, driver behavior, and maintenance of a bus stop are not available in a simulation, this review focuses on quantitative parameters such as boarding and alighting time, waiting time, service hours, and on time performance (Das & Pandit, 2013). Out of nine quantitative QOS parameters they discuss, two QOS parameters can be used in SimBus Pro: boarding and alighting time, and on time performance.

Two other QOS parameters: seat availability and crowding level, two passenger-perspective variables, would be interesting to include within SimBus Pro. However, since SimBus Pro currently does not focus on the passenger perspective, no further research is conducted on these two parameters. Future versions as well research might decide to incorporate this perspective too.

The TCQSM provides additional insight into certain quantitative QOS parameters. For example, the on time performance of a bus line. However for this parameter, the definition of “on time” should be explained and determined (Brinckerhoff, 2013). As Yaakub and Napiah (2011) state: ‘on time performance is one of the most used reliability measure.’ Therefore, it has been decided that on time performance will be used for the numeric thresholds.

6.3 Definition “on time”

Considering the simulation context and the availability of input options for specifying bus delays, an appropriate definition of the definition “on time” within SimBus Pro should be established. There are two cases that determine whether a bus is on time. The bus is too early, or the bus is too late. This could be related to the arrival time or the departure time on a bus terminal. But the discussion on time is about the amount of time that a bus is allowed to be too early or too late. The National Railways (NS) has an agreement with the government, stipulating that trains are considered on time if they arrive no more than 3 minutes late and depart no more than 5 minutes late (Ministerie van Infrastructuur en Waterstaat, 2014). However, in this case, it is worth mentioning that it is about trains and not buses. According to the CROW guidelines (Center for Regulation and Research in Earth, Water and Road Construction and Traffic Engineering), buses are deemed on time if they depart between no more than 30 seconds too early or 180 seconds too late (CROW, 2019). Therefore, the definition of “on time” in this bachelor thesis is set as follows: every bus that departs between a time frame of 30 seconds too early and no more than 180 seconds too late, on their planned departure time, is on time.

6.4 Implementation

The on time performance has been implemented in SimBus Pro. It should be kept in mind that SimBus Pro requires pre-determined input regarding which buses will be on time and which ones will not.

Therefore, to ensure a comprehensive analysis, a selection was made for the on time performance calculations. In this selection buses that were running behind schedule were also considered to assess their potential catching up time. This approach aimed to include all buses in the assessment, hence to include the most buses.

For both implementations, only buses with a boarding action are included. Buses that have only an alighting action planned are excluded from the analysis. This exclusion is necessary because buses that only have alighting actions, leave the bus terminal immediately after completing their actions. Including them in the calculations could influence the outcomes in a negative way, as in most of their cases they depart way too early. In Table 2 the two groups are shown, all of these groups include the boarding action.

Table 2 - Bus groups, for implementation. All bus groups include boarding action

Group A	**Group B**
Transitory route and no arrival delay	Transitory route and arrival delay
Non-transitory route, without planned buffer and arrival delay	Non-transitory route, without a planned buffer but has an arrival delay
Buffer action	

For these groups, the arrival delay is compared to the set threshold for on time, where we are interested in late arrivals (180 seconds). The buses that arrive later than 180 seconds are considered to have an arrival delay. The bus groups that are selected for group A, are used to calculate the on time performance for the bus terminal. All buses that are in group A are taken into account for the on time performance calculation. If a bus departs 30 seconds ahead of schedule it is considered too early. If a bus departs more than 180 seconds late on schedule, it is considered too late. If a bus leaves between 30 seconds ahead and 180 seconds too late on schedule, the bus is considered on time. The final format for this parameter is in percentages.

For the implementation of buses that catch up time in their schedule is also important. The two bus groups selected in group B are used. For this implementation, the realized arrival time and the realized departure time of each bus is subtracted. Also, the planned arrival and the planned departure time are subtracted from each other. When the difference of the realized times is smaller than the planned times, the bus is reducing its delay. The final format for this parameter is in percentages and the average time they catch up.

The process that is described above is made for SimBus Pro in Python version 3.9. The accompanying Python code is confidential.

6.5 Thresholds

The on time percentage of the bus station can be translated into a qualitative indicator that provides a clear understanding of the terminal performance. To convert the on time percentage to a qualitative indicator, a table based on the TCQSM is (Brinckerhoff, 2013). 5 presents the conversion of the on time percentages into terminal performance categories.

Table 3 - On time performance converted to terminal performance

On time percentage	**Terminal performance**
>=95%	Excellent
90-94.9%	Good
80-89.9%	Average
70-79.9%	Moderate
<70%	Poor

Using this classification, the terminal performance indicator provides a clear understanding of the quality of the bus terminal variant. An excellent terminal performance indicates the variant is an excellent alternative. A good terminal performance suggests that the variant is a viable alternative that meets acceptable standards. However, if the terminal performance is categorized as average, it is recommended to explore potential changes for the bus terminal. A moderate terminal performance indicates that significant changes are necessary. Finally, if the terminal performance is assessed as poor, the variant should be changed or excluded since it does not meet the required standards for satisfactory operations.

6.6 Case study

For the purpose of testing the implementation in SimBus Pro, a case study was used. This case study is located at the bus terminal of Den Bosch. The case study involved simulating a 24-hour bus schedule. In this particular study, only buses with a transitory route were allowed to use the buffer. The current bus terminal has ten alighting/boarding platforms and nine buffer platforms.

The timetable file for the simulation consisted of 833 buses and was provided by Goudappel. These 833 buses consisted out of four classes. The distribution of the buses on each of those four classes can be seen in Table 4. Additionally, from the 833 buses 469 are arriving too early, 323 buses are arriving on time and 41 buses are arriving later than 3 minutes on the bus terminal. The distribution of the frequency of the buses arriving at the bus terminal per hour is shown in Appendix B, Figure 4.

Table 4 - Distribution of buses for each TYPE of class

TYPE class	Number of buses	Actions
1	356	Alighting – Buffer- Boarding
2	222	Alighting – Boarding
4	181	Boarding
6	74	Alighting

Additionally, Goudappel created the Vissim file for the simulation. This case study is used to see if the outcome of the simulation is a desired outcome. See Figure 3 for the top view of the bus terminal in Den Bosch. Den Bosch[4] is the fourth biggest town in the Noord Brabant region of the Netherlands and has over 150.000 inhabitants. Bus traffic is operated by two big providers: Arriva and Veolia. Den Bosch can be considered a representable town for a case study both in size and in service provisions for buses.

Figure 3 - Top view of the bus terminal in Den Bosch, left google maps view (Source: Google maps), right Vissim view

For this case study, the new implementation was tested, and the results were positive. The bus terminal has an excellent terminal performance according to this simulation data. Out of the 619 buses that arrived on time, 96% of them departed on time. There were 140 buses that arrived at the bus terminal three minutes later than their planned arrival time. These buses were sued to asses catching up time. Remarkably, 91% of these 140 buses successfully caught up more than 10 seconds on the platform. It is important to note that the assessment excluded a total of 74 buses, these buses had only an alight action. See Appendix B, Figure 5 for the output created by the implementation.

[4] https://nl.wikipedia.org/wiki/'s-Hertogenbosch

7 Discussion

In this bachelor thesis, the focus was on SimBus Pro, implementing a chosen enhancement, and running a simulation. During the project, it became clear that there were two points of specific interest regarding the running of SimBus Pro that need to be discussed further: SimBus Pro's Python code and the implementation of the on time performance.

Firstly, SimBus works together with Vissim and uses the VisWalk module (module for pedestrians simulations). However, due to the unavailability of a VisWalk license, the implementation is only tested on SimBus Pro without the input on simulating pedestrians. This limitation needs to be taken into account. Future research is recommended to test if the implementation works as well if pedestrians by using the VisWalk module, are also taken into account in the simulation.

Secondly, the codebase of SimBus Pro is written in Python. Python is a programming language that is very well suited for integrating systems and models. In programming, two problems were identified. Firstly, there is a mixture of English and Dutch languages used, which can lead to confusion. To promote uniformity it is recommended to use one language. Secondly the use of "try" and "except" statements in the code is confusing and makes debugging difficult. Whilst "except" is mostly used to catch general errors, these statements lack the detail needed to solve the problem. To facilitate troubleshooting and debugging, it could be beneficial to implement traceback functions within the except statements. This would provide additional information for error identification. For example "traceback.print_exc()".

Finally, this research only focuses at the on time performance of the overall simulation time. However, it could be valuable to analyze the on time performance of the bus terminal during different periods, such as morning rush hour, afternoon, and evening rush hour. By dividing the on time performance into these distinct parts, it would be possible to identify specific periods where the bus terminal may encounter challenges in maintaining on time schedules. It is possible that around rush hours the bus terminal may encounter more challenges. By using three periods, solutions and adaptations can be made more specific.

As each simulation is a work in progress, the same goes for SimBus Pro. There are a lot of great features in Sim Bus Pro and in this thesis, a small improvement has been suggested and implemented still leaving much more open for further exploration and enhancement. SimBus Pro provides a proper basis for such ameliorations.

8 Conclusion

In this final part of this thesis, the research questions are reconsidered. However, due to the project's taken course not all the research questions that were formulated at the start and written down in the proposal could be fully answered.

How does the SimBus Pro program work for a given case study?

- What are the basic processes and calculation methods of the program SimBus Pro?

SimBus Pro is a software plug-in that guides the traffic simulation software Vissim, it makes use of the basic traffic calculations of Vissim. SimBus Pro implements some functions that help with the simulation in Vissim thus making it more specific, helping the client in making better strategic, operational, and tactical decisions, as is outlined in this thesis. An example of such functionality is the ability in SimBus Pro to assign to each bus a different platform, when the initially assigned platform is occupied during the simulation, SimBus Pro enables to differentiate the bus towards another (free) platform. This capability empowers SimBus Pro to simulate dynamic bus terminals, and thus can help with operational decisions.

- What are the advantages of SimBus Pro over Vissim?

SimBus Pro provides advantages to Vissim by enabling it to handle simulations in greater detail, and on a larger scale. By using SimBus Pro it allows Vissim for a more detailed simulation of a bus terminal. Now that SimBus Pro is thoroughly understood, this sub-question is reframed as: "What advantages does SimBus Pro provide to Vissim?". SimBus Pro enables Vissim to handle simulations in more detail and guidance. Thus enabling the execution of larger-scale simulations and extra functionalities or outputs. For clients, SimBus Pro has the advantage over Vissim to help make more informed decisions on the planning of a bus terminal.

- Detailed description of the case study

The case study used in this thesis is Den Bosch bus terminal. It involved a 24-hour simulation of 833 buses. The bus terminal consists out of ten platforms for alighting or boarding purposes and nine buffer platforms. Of these 833 buses, 74 buses only had an alight action, and were therefore excluded from the assessment of the performances. Out of the remaining 759 buses, 619 buses arrived on time, and 96% of these buses also departed on time, indicating excellent performance of the bus terminal. Additionally, it is worth noting that 91% of the 140 buses that arrived too late, were able to catch up on time. This shows that the bus terminal is an efficient terminal.

How to improve the input data of SimBus Pro?

- What are the problem areas of the input data for the user?

The main problem areas of SimBus Pro are stated here. Firstly, the making of the Vissim and Timetable file are time consuming and error sensitive. Secondly, the departure on time parameter can cause surrealistic situations. Lastly, the number of simulation runs are based on intuition.

- Can these problem areas be improved?

All of these problem areas can be improved, The making of the Vissim and Timetable could be made automatically or semi-automatically. The departure on time parameter should be set on default that buses try to leave on time. For the final problem area, there should be conducted more scientific research towards the optimal number of simulation runs.

- How does this improvement and method effect the (outcome of the) case study?

During this research, it is determined that there will be no implementation done in this project for the input parameters. However, the making of (semi)-automatic tools to produce the input file will make SimBus Pro more reliable, and the departure on time parameter set on default that buses try to leave on time, will cause some more "extreme" situations to simulate and thus enabling Goudappel to base their findings on situations that rarely occur but occur. The last improvement of more research towards the optimal number of simulation runs could lead to less run time and make the progress more efficient.

How to improve the output data of SimBus Pro?

- What are the problem areas of the output data for the user?

Currently, there are some outputs considered missing, such as total delay, the charging time of electric buses and numeric thresholds for SimBus Pro. Additionally, the output parameters: blok, halt, and hinder time, are causing confusion. Moreover, inconsistencies have been detected in the calculation of the output.

Can these problem areas be improved?

These areas can be improved. For example, conducting further research on the loading time of electric buses and their specific characteristics would enable Goudappel to implement the missing output of the charging time of electric buses. Additionally, renaming the output parameters blok, halt, and hinder time, to clear and universally understood names would enhance clarity for all clients and users. Another important improvement would be to include the total delay of the bus terminal as an output. Lastly, conducting research to determine numeric thresholds for SimBus Pro would allow Goudappel to compare and evaluate different simulations more effectively.

- What is the impact of improvements and altered methods on the case study?

The addition of the loading time for electric buses would have significant impact in the near future, considering the European Union's objective to have all public transport buses fully electric by 2030 (Ruiz, 2023). The inclusion of numeric thresholds would have an positive impact for Goudappel, since it enables the ability to compare different simulations. Thus Goudappel could provide more informed recommendations to clients. This will result in more grounded and reliable suggestions for optimizing bus terminal performances. The last improvement of renaming blok, halt, and hinter times would lead to more clarity of these output parameters.

Implementing these improvements would allow Goudappel to provide more reliable recommendations to its clients. If clients follow these recommendations, over time, it would contribute to the gradual improvement of public transport.

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APPENDIX A

Experience with SimBus Pro

The participants experience with SimBus Pro, was the first focus of the interview. Specifically, whether users had personal experience using the program and/or have been or are involved in projects using SimBus Pro. Each participant had previous work experience with SimBus Pro, Ellen van der Werff (EW) and Hendrik Bouwknegt (HB) worked personally with SimBus, an older version of SimBus Pro, and communicated with the clients in their projects. Frank de Winter (FW) worked on the output of SimBus Pro. Jeroen Terlouw (JT), the advisor of Goudappel for Schiphol, worked with the older version SimBus and SimBus Pro for the same project for Schiphol as Project leader. Hence the combined experiences of these four users provide a variety of perspectives for the performance of SimBus Pro.

In summary: all respondents have different experiences with either the new or the old version of SimBus (Pro).

Input data

The second focus of the interview was an, exploration of the participants familiarity with SimBus Pro input data. They were asked to if they missed functionalities or features that were rarely used. Several notable points emerged for this question. For instance, respondent FW highlighted the time-intensive nature of the current timetable file, which is based on publicly available NDOV data consistently presented in the same format. Additionally, HB emphasized two main concerns. Firstly, he mentioned that the current timetable file is likely to consists out of human errors, if the timetable file consists out of any errors this could lead to a lot of time waste for the project because this error will probably, if detected, be detected in a later stage of the project. Therefore this respondent argues that the input should have something of a check before it is used by SimBus Pro, and therefore, a tool should be made for this to check the input data on consistency and errors before starting the simulation. Secondly, HB discussed the simulation itself, pointing out that in the timetable file a parameter "STIPT" what allows for specifying if a bus should leave on its specified departure time or if it is allowed to alter from this time. This makes if this parameter is on "FALSE" that a bus could, in theory, leave too early. He stated that if a bus leaves too early it will be likely to cause no problems, but when a bus arrives way too early than scheduled and stays till its scheduled departure time, it is likely to cause problems in the simulation. Hence he recommends preventing buses from leaving before their scheduled departure time to simulate potential problems. EW stated that the reliability of each bus line at the moment is determined, what seemed for her unnecessary more work, and it could be done according to this respondent for each bus line instead.

In summary: the respondents advised to design the simulation in a way that there is a check on input data for human errors before starting the simulation, prevent buses from leaving before the scheduled departing time, and determine the reliability of each bus line instead of each bus.

Desired output data

The last topic is to get an impression of the desired output of SimBus Pro. Participants were asked about the types of data they would like to see generated by SimBus Pro and the preferences of the client. Next to that, they were asked to identify areas that could use improvements or could be disregarded. All participants shared their perspectives on this matter. One common concern raised by the participants was the lack of clarity of the current output related to the blok, halt, and hinder times. These outputs were in their perspective unclear for both the client as the users. Another common opinion was the missing output parameter of the total delay. FW specifically mentioned that the extensive output file is a good way that every small question of the client can be answered with. Although EW agrees with FW on this matter she adds the opinion that there should come another part in the output or an extra file with a summary of the current output where first can be looked at, think about the total delay in this file another significant parameters that are used a lot. Additionally, FW stated that currently there are no conditions set for the outcomes, for example, de Winter works with the disturbance rate, but this disturbance rate is not yet classified as what is a good disturbance rate, what is a bad disturbance rate. Is a disturbance rate of 5% preferred or 10%? This is now randomly chosen, but as FW and HB stated it is necessary to determine conditions for this disturbance rate both for the client and the Goudappel. EW as well thought it would be interesting for the client to see if electric buses are capable to load during their shift, in the situation where they have time in the buffer, how long they could load. JT mentioned that there is an output missing for how much each bus line is at which platform and would like to see in the output the percentage of each bus line at each platform. Thus there will be an output that bus line 1 uses 50% platform 1 and 50% platform 5 for example.

Another interesting aspect that one of the respondents (FW) mentioned is that projects that use SimBus Pro are time intensive and thus costly, although it is in general the most suitable tool for simulating bus terminals. However, there are a few exceptions where a simplified version, such as a static Excel model could be used to calculate certain aspects of a project. This is less time consuming and more cost effective. Van der Werff specifically mentioned this possibility with an example for a train station and how much each platform was used in the schedule. The possibilities are limited with this kind of models and therefore for most projects SimBus Pro is more preferred.

Additionally, both FB and JT highlighted SimBus Pro's effectiveness in visualizing projects, which in their opinion, is a good aspect of SimBus Pro and in benefit for the project because it gives a client a clear insight into what is really happening.

In summary: the common concern on output data amongst all participants is the lack of clarity of the current output related to the blok, halt, and hinder times, also missing output parameter of the total delay was a shared concern. There is no set disturbance rate and conditions to determine a disturbance rate are necessary. The loading time of electrical buses should be considered in the model too.

SimBus Pro is costlier than a static Excel model but has many possibilities, is more precise, and is effective in visualizing projects.

APPENDIX B

Frequency of bus arrivals per hour for the case study in Den Bosch

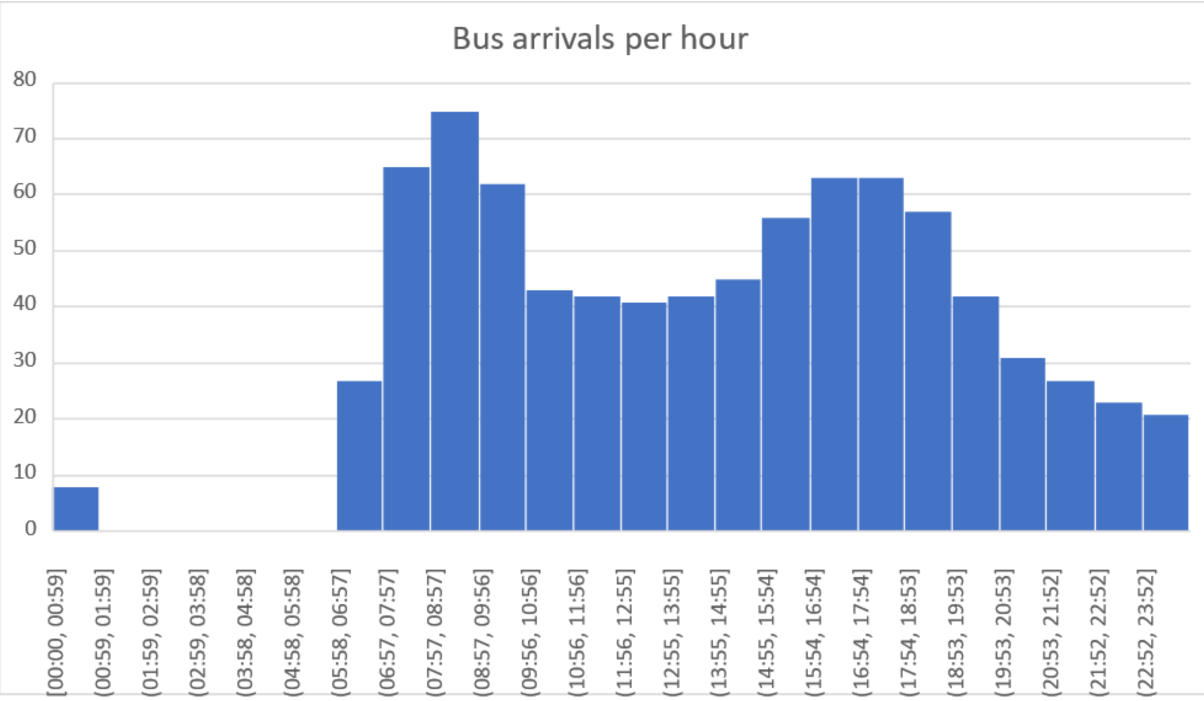

Figure 4 -Frequency of bus arrivals per hour for the case study in Den Bosch

Output of case study for the new Implementation

Totaal aantal bussen	833	
Bussen gebruikt in punctualiteit beoordeling	619	
Bussen gebruikt in tijd kunnen inhalen beoordeling	140	
Bussen die niet worden gebruikt voor deze twee beoordelingen	74	
Totaal punctualiteit	619	
Te laat vertrekken	10	2%
Op tijd vertrekken	595	96%
Te vroeg vertrekken	14	2%
-30 sec. is te vroeg		
180 sec. is te laat		
Bussen die te laat zijn en tijd kunnen inhalen	140	
Tijd ingehaald	128	91%
Tijd bijgekomen	4	3%
Tijd zelfde gebleven	8	6%
-10 sec. minder dan is tijd ingehaald		
10 sec. meer dan is tijd bijgekomen		

Figure 5 – Results of implementation for the case study of Den Bosch