Towards a Digital Twin of Seychelles' Road Transport System

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In collaboration with the Government of Seychelles

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Abstract

Seychelles faces a fast growth in car ownership. Infrastructure improvements cannot keep pace with the grown mobility demand, resulting in an increasing congestion problem during peak hours. This thesis aims to build a reliable microscopic traffic model for Seychelles' main island Mahé. It focuses on motorized private transport. I used openly available map data to build a model in the open-source traffic simulation software SUMO. The traffic demand is based on existing reports, but I refined it following the current change in mobility behavior. I performed traffic counts using drones to calibrate the model to the actual traffic situation. The validation showed a good fit for the current situation. However, the SARS-CoV-2 pandemic may have impacted the traffic counts. Then, I demonstrated the utility of the traffic model in a case study. I assessed the pedestrianization of major roads in the capital city in four scenarios. All scenarios showed negative effects on the road transport network. Nevertheless, pedestrianization also has many positive aspects that a traffic model can not assess. During the entire thesis, I worked in close collaboration with Seychelles' Department of Transport, following a transdisciplinary approach. The authorities should be able to use the developed traffic model to assess infrastructure improvements and prioritize projects based on their benefits.

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Abbreviations

CSV Comma-Separated Values. 39

DLR German Aerospace Center. 3

DoLT Department of Land Transport. 2, 3, 5, 6, 8, 10, 12, 30, 37, 49, 50

GUI Graphical User Interface. 3, 4, 71

GVA Greater Victoria Area. vii, viii, 2, 8–10, 12, 15, 16, 18, 27, 29–33, 42, 63

MPH morning peak hour. viii, 10, 11, 15, 18, 19, 28, 29, 32, 35, 36, 39, 42, 63, 66–68

OD matrix origin-destination matrix. vi, 10, 13–16, 18, 21, 30, 31, 38, 47, 57, 58, 74

OSM Open Street Maps. 11, 12, 15, 30, 51, 71–73

SIDS small island developing state. 1

SLTA Seychelles Land Transport Agency. 2, 3, 5, 6, 8, 10, 12, 18, 37, 49, 50

SPA Seychelles Planning Authority. iii

SPTC Seychelles Public Transport Corporation. iii, 15, 48

SQV Scalable Quality Value. vii, 23–25

SRTM Shuttle Radar Topography Mission. 12

SSLUDP Seychelles Strategic Land Use and Development Plan. 2, 10

SUMO Simulation of Urban MObility. iii, 3–7, 12, 16–18, 30, 32, 39, 49–51, 70, 71, 73, 74

TAZ traffic assignment zone. vi, 13, 57, 58, 73, 74

TdCS Transdisciplinary Case Study. 10, 11

TraCI Traffic Control Interface. 4, 32

veh/h vehicles per hour. vi, 22, 23, 35, 36, 57, 58

XML Extensible Markup Language. 4, 11, 39, 50, 71–73

1 Introduction

With the advent of traffic simulations, powerful new opportunities in traffic engineering have emerged in recent decades. These models' size, complexity, and level of detail could be constantly increased due to advances in computing capacities. The possibility of simulating the road network and traffic behavior provides traffic engineers and decision-makers with a powerful tool to forecast the effects of their measures and test innovative solutions. Experts mainly distinguish between three model types: *macroscopic*, *mesoscopic* and *microscopic* models. *Macroscopic* models describe the transport network based on high-level characteristics, namely flow, speed, or density of traffic streams, in analogy to fluid mechanics. *Mesoscopic* models focus closer on the system, simulating platoons of vehicles with similar characteristics. Finally, *microscopic* models aim for a much greater level of detail. Thus, they imitate the behavior of single agents and their interactions to reproduce more accurate traffic dynamics (Kouvelas, 2019). With the advancing digitization of infrastructure and the rising number of traffic sensors, a new type of model emerged in the form of digital twins. Like microscopic models, digital twins strive to replicate the real-world system as realistically as possible. In addition, they integrate current detector data to model the network in real-time. Therefore, digital twins make it possible to forecast traffic development over the next few hours and help initiate immediate measures to stabilize the traffic system in the event of a disruption (Schmidt, 2021). In this thesis, the potential of the open-source traffic simulation software SUMO to create the basis of a digital twin for Seychelles' road transport system will be assessed.

1.1 Seychelles in context

Seychelles is a rapidly emerging small island developing state (SIDS). The archipelago in the Indian Ocean consists of 115 islands. Almost 90% of the roughly 97'000 inhabitants live on Mahé, Seychelles' main island (Central Intelligence Agency, 2022). Population, wealth, and mobility grew constantly over the last years (Seychelles National Bureau of Statistics, 2020). This development has led to continuous growth in traffic volume, steadily increasing the pressure on the road network. However, most road infrastructure was built between 1950 – 1970 and never adapted to today's requirements (D. Simara, personal communication, February 2022). The unique, hilly topography of Mahé and strict land-use rules[1] make adequate infrastructure

[1] Anti-expropriation policies make it difficult to expropriate someone (D. Bistolet, personal communication, January 2022)

enlargements challenging to implement. The problem culminates in Victoria, the capital of Seychelles and the heart of the 27 km long and up to 11 km wide main island. With more than 25'000 inhabitants, the city and its suburbs - called the Greater Victoria Area (GVA) - are home to around 27% of the country's population. As the island's economic, cultural, and political center, Victoria attracts many commuters, day-trippers, and tourists. In addition to that, Victoria is also an important transport hub since it is home to the international seaport, the inter-island ferry terminal, and the central bus hub of Mahé. Moreover, the most important North-South and East-West corridors join up in the city center, leading to substantial transit traffic and congestion in the morning and evening peak hours. Unfortunately, the location between steep hills and the coastline and the dense structure of the city further complicates alleviating the heavy congestion with infrastructure upgrades. A shift towards a higher motorization rate is observable, thus further aggravating the congestion problem. Although Seychelles has a well-developed bus system and around 33% of the population rides the bus regularly (Aeschlimann *et al.*, 2022), the public transport system has not had enough capacity to alleviate the traffic problem. The car is globally regarded as a powerful status symbol (Fitt, 2021), limiting the shifting effect of advantages of public transport over individual motorized traffic. A strong preference for cars over other modes of transport is also evident in Seychelles (Willimann *et al.*, 2022).

The authorities recognized the difficulties of rapid growth and had extensive strategic plans drawn up by the international consulting company ARUP in 2015. Among other topics, these Seychelles Strategic Land Use and Development Plan (SSLUDP) also address congestion in detail. As part of the Transport Assessment (Arup and Government of Seychelles, 2015b), a macroscopic traffic model was built. For this reason, extensive traffic surveys and traffic counts were performed. The existing origin-destination matrix is a good starting point for further planning. In a later stage, the *Victoria Masterplan* (Arup and Government of Seychelles, 2015c) increased the level of detail for the GVA, where planning is particularly demanding. Therefore, a microscopic model of the traffic system of Victoria was built by ARUP and used for the assessment of possible infrastructure projects. However, the model was developed for the Victoria Masterplan and could solely be used for this report. Neither the simulation nor detailed raw data inputs are available.

The Department of Land Transport (DoLT) is responsible for developing the road infrastructure in the whole country and supervises projects from strategic planning until realization. The affiliated Seychelles Land Transport Agency (SLTA) is then in charge of maintenance and optimization of the built road network. Both bodies operate with limited human and financial resources. Consequently, targeted use of the available resources is all the more essential. However, an informed decision is often not possible due to data scarcity.

1.2 Objective

From an outsider's perspective, the effects of Seychelles' infrastructure improvements were only assessed for individual network elements in the past, without considering the systemic nature of a road network. A reason for that is the lack of appropriate tools to evaluate systemic impacts. A traffic model can serve as a valuable basis for decision-making by forecasting the overall benefit of an intervention on the entire road network. It is helpful to simulate future demand scenarios, predict the impact of policies, and provide a holistic assessment of the road system. In particular, it can also assist in evaluating proposals from political actors, a task that the DoLT regularly faces.

During this master's thesis, I developed the foundation for a digital twin of the transport system of Mahé. This foundation is created by building a microscopic model. The model strives to replicate Mahé's road transport system as accurately as possible during the busiest hour of the day. Furthermore, the thesis aims to assess the applicability of open-source software for a real-life model. Moreover, it examines ways to deal with limited data availability and explores innovative methods to gather traffic data. Further, the thesis addresses how traffic models can be used as tools for decision-making. In addition, the advantages of a transdisciplinary approach involving stakeholders throughout the whole process are explored.

Consequently, the model, developed during this thesis, should become a valuable tool for transport planning, available to the authorities in Seychelles, namely the DoLT and the SLTA. To ensure this, calibrating the model and training local professionals were further key pillars of the project. Following the successful implementation of the model, I showed possibilities of application in a case study. The case study has multiple objectives, listed below:

- Further validation of the model
- Demonstration of the possibilities of the model
- Evaluation of a pressing topic in traffic engineering in Seychelles

1.3 SUMO

For modeling Mahé's road transport system, I used Simulation of Urban MObility (SUMO). SUMO is a microscopic traffic flow simulation platform developed at the German Aerospace Center (DLR). It works inter- and multi-modal, space-continuous, and time-discrete (Alvarez Lopez *et al.*, 2018). As an open-source project based on C++ (Stroustrup, 2000) and Python (Van Rossum and Drake, 2009), SUMO is published under an Eclipse Public License v2.0 (Eclipse Foundation, 2017) and can be used and modified freely. In contrast to popular commercial microscopic traffic simulators, such as PTV Vissim (PTV Vison, 2022) or Aimsun Next (Aimsun, 2021), SUMO does not provide a unified Graphical User Interface (GUI). Rather, it consists of command-line applications and scripts, forming a wide-ranging toolbox for building, executing, and assessing traffic models. These tools can run independently of other parts, allowing for slim data structures and fast execution. The downside of this approach is lower user-friendliness compared to monolithic simulators (Alvarez Lopez *et al.*, 2021). However, there are GUIs for essential tasks, notably a network editor and a visual representation of the simulation. These and further essential applications of the SUMO suite are listed in Table 1.1.

All simulation inputs and outputs are given in the Extensible Markup Language (XML) format. This interface enables easy preparation and processing of the data with external tools like Python or R Programming. Furthermore, the SUMO suite already includes additional scripts for many common uses as Python extensions. Finally, the open-source design of SUMO also offers the possibility to review and modify all underlying model mechanics, such as the car-following models or routing algorithms. This feature is a crucial advantage compared to commercial software, where the user usually only sees inputs and outputs while all calculations are hidden in a black box. The open format also provides an ideal foundation for later upgrading the microscopic model to a digital twin because it enables integrating any additional information in the XML format. Moreover, SUMO allows retrieving the current traffic state and initiating interventions instantly (online) over the Traffic Control Interface (TraCI) (Alvarez Lopez *et al.*, 2021).

Table 1.1: *Overview of most used SUMO applications, based on the SUMO User Documentation (Alvarez Lopez et al., 2021).*

Application	Description
sumo	The microscopic simulation with no visualization; command line application
sumo-gui	The microscopic simulation with a graphical user interface
netconvert	Network importer and generator; reads road networks from different formats and converts them into the SUMO-format
netedit	A graphical network editor
od2trips	Decomposes origin/destination-matrices into single vehicle trips
polyconvert	Imports points of interest and polygons from different formats and translates them into a description that may be visualized by sumo-gui

2 Methods and Procedure

This chapter introduces the approach of transdisciplinarity that overarches the whole thesis in Section 2.1. Further, Section 2.2 embeds the thesis in a broader context and provides an overview of the work structure. The technical methodology regarding model building follows in Chapter 3.

2.1 Transdisciplinarity

ETH Zürich's USYS TdLab (2022) defines transdisciplinary research on their webpage as follows: "Transdisciplinary research is an interdisciplinary approach to scientific inquiry that deals with complex, real-world problems and which places an emphasis on joint problem framing between people inside and outside of academia with the aim of developing possible solutions." They further state that transdisciplinarity is reached by a reflexive collaboration process, where researchers can react adaptively to changes in the real world while working with project partners.

A road system has to meet many requirements. Consequently, the interests of car owners, public transport users, and pedestrians might be contrary. Also, commuters, residents, shop owners, urban planners, politicians, and others want to shape the size and function of the road network. Typically, these conflicts of interest are bigger the denser an area is built over. Because of the diverse interests and the high complexity of traffic systems, the topic is well suited for a transdisciplinary approach. Thereby, different non-academic actors participate in all project phases, ensuring that the research meets the stakeholders' needs.

Bridging the gap between research and practice was a vital pillar of this thesis. I involved Seychellois stakeholders in all project steps, from developing the thesis topic to validating the model and defining the case study. Nowadays, SUMO is mainly used in research (Alvarez Lopez *et al.*, 2021). However, due to its specifics, outlined in Section 1.3, SUMO is well suited for use in a non-academic environment. The simulation suite is used for a real-life setting in this transdisciplinary thesis. Close collaboration with non-academic partners, especially DoLT and SLTA, allows tailoring academic tools and methods to Seychelles' needs. Furthermore, possible long-term use of the simulation is enabled by including local stakeholders and supported by additionally training them in using the software and the model.

The work with SUMO revealed some constraints in terms of applicability in real-life networks. In the course of the project, I reported numerous bugs and user feedback to the developers. Especially the left-hand driving caused many errors since sumo is mostly used in countries with right-hand driving. This work is very time-consuming but essential for an immaculate simulation. The collaboration with the SUMO developers and the user community worked over different channels like GitHub, Mattermost, and e-mail.

Throughout the work, I emphasized regular feedback from local authorities. Thus, I collected the opinions of stakeholders of DoLT and SLTA at different stages of the project. The cooperation further intensified during the 45-day field phase. By that, a constant exchange on a daily basis was established. In addition to regular meetings on the work status, we discussed the virtual network and demand patterns and refined all model parts in small groups. The exchange further helped me understand the authority's daily routine, current pressing issues, and possible application cases of the traffic model.

Training sessions Another essential element of the transdisciplinary approach are the training sessions on traffic simulation, which I conducted with staff from DoLT and SLTA. The training program took place during the last part of the field phase. Up to twelve persons participated in the training, eight of them followed all or most of the sessions. The goal of the training was to introduce the staff to traffic simulation and familiarize them with the software. The training was split into five sessions. Table 2.1 summarizes the structure of the program. All staff members work in the field of transport and understand the importance of the subject. However, most participants had never worked with traffic simulation software before. Therefore, I used the first short session to introduce the topic holistically. Then, basic tutorials from the SUMO user documentation (Alvarez Lopez *et al.*, 2021) helped to familiarize everybody with the software suite. In the third session, I deployed an excerpt of the real Mahé model. I guided the participants through all model-building steps to ensure that the underlying logic of the model was clear for everybody. Besides SUMO, I also introduced participants to working with the command prompt, processing XML files, and handing over configuration parameters to Python. These tools are also necessary to efficiently work with the simulation. In a concluding session, I also introduced a smaller group of people to visualization options to display simulation results properly.

In addition to the training sessions, I supported the participants with installing the software. Further, I coached them individually in case of questions and problems, but also with challenges beyond the scope of the training sessions. I also offered my support beyond the field phase and the end of this thesis.

After the workshop, all participants should be able to work with SUMO. They know how the model is working, its limitations, and how to execute everyday operations. Furthermore, they know where to seek further assistance if needed.

Along with the training sessions, I prepared a user guide (Appendix F). The guide provides help to get started with SUMO and can be used in combination with the SUMO User Documentation (Alvarez Lopez *et al.*, 2021).

Table 2.1: *Structure of the training program.*

Training session	Duration	Guiding questions
1 Introduction	1 h	How does a traffic model work? What is it good for? Where are the limitations?
2 SUMO tutorial	3 h	How does SUMO work? How do I create a basic scenario?
3 Working with SUMO	3 h	What is the command prompt? How do I use it to work with SUMO? What model components are needed to build-up the Mahé simulation?
4 Scenario creation	3 h	How can I create new scenarios on top of my base model? How can I compare these scenarios? When do we need to work with Python?
5 Visualization	1h	How can I visualize my simulation results?

2.2 Outline

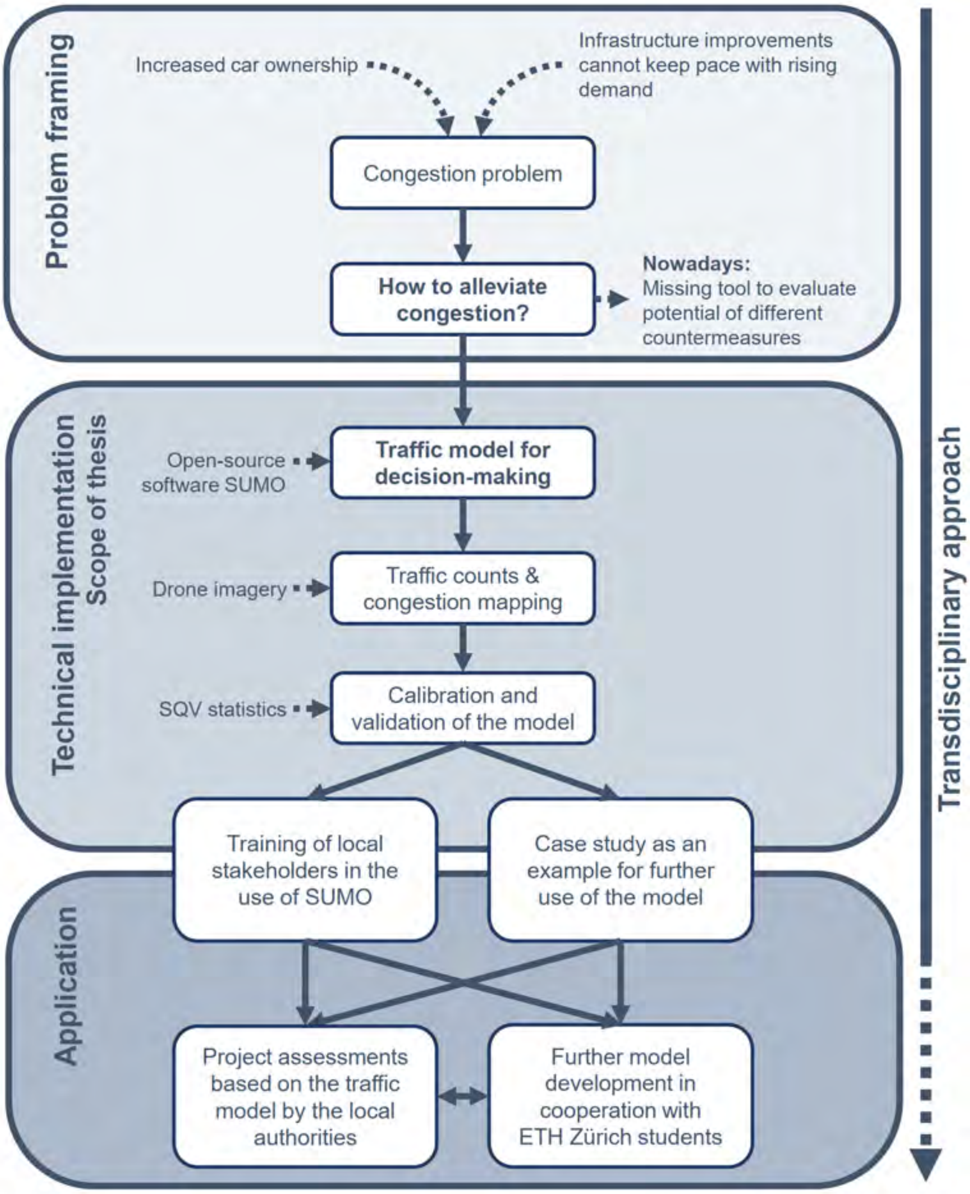
As a consequence of the applicative orientation of this thesis, it is of higher importance to embed it in an overall context. Fig. 2.1 conceptualizes what gave impulse to the project, what I implemented during it, and what possibilities arise for the future. The congestion problem was already discussed in Section 1.1. The digital twin is a promising tool to solve the problem. Its technical implementation is the scope of this thesis.

Chapter 3 shows the development of the digital twin. It addresses in detail the construction of a traffic model. Besides the composition of the model, I present concepts for collecting traffic data, calibrating, and validating a simulation. In addition, I tackle the impact of different traffic behavior in Seychelles and Western Europe on the traffic model qualitatively. In Chapter 4, I analyse the resulting model in detail.

Chapter 5 acts as a case study. It intends to demonstrate the capabilities of a traffic model based on a current transportation issue in the GVA. Specifically, it examines the impact of introducing a pedestrian zone in downtown Victoria on road traffic. Political actors currently demand such a pedestrian zone. In addition to the actual assessment, the case study will also serve as an example for the future use of the traffic model by DoLT and SLTA to analyze new traffic policies.

In an overarching conclusion, I reflect insights from the model development and the transdisciplinary approach, and present an outlook to future applications of the model. Furthermore, I provide some practical insights about the model building process as guidance for similar projects.

Figure 2.1: *Conceptual placement of thesis in context. The scope of the thesis is thereby focusing on the technical implementation of the model.*



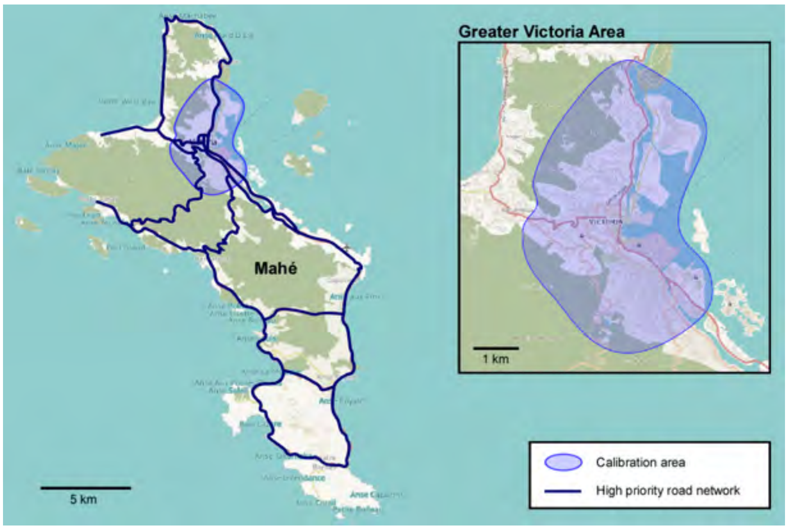
3 Building the Traffic Model

Creating the traffic model was the key task of this thesis. After specifying the model's field of application, the section Section 3.1 outlines the whole model building process of building, calibrating and validating.

3.1 Traffic model specifications

Fig. 3.1 shows the extent of the modeled area. The entire island of Mahé and all smaller surrounding islands with a road connection to the main island are replicated on a microscopic level. Since the simulated area has a heterogeneous settlement structure and topography, different network parts might also require a differing parameter set. However, data for calibration is only available for the GVA. Therefore, the microscopic model can only be adequately calibrated for the highlighted region of Fig. 3.1. Subsequently, a higher model quality for the Capital Region is expected. Regardless of that, the model of the rest of the island is still valuable and allows to investigate impacts of network interventions on a higher level.

Figure 3.1: *The microscopic model covers the whole island of Mahé and all surrounding small islands with a road connection, such as Ile Perseverance or Eden Island. Due to the limited data available, the model calibration focused on the GVA. The map's background shows land use types, helping with orientation but not relevant for the model. Source base map: Open Street Maps Contributers (2021).*



The availability of traffic demand data limits the temporal coverage of the model. Origin-destination relations are only available for the morning rush hour. Therefore, a detailed scenario was created for the busiest hour in the morning. This morning peak hour (MPH) was identified by Arup and Government of Seychelles (2015b) between 07:15 and 08:15 AM. Representatives of DoLT and SLTA confirmed these findings.

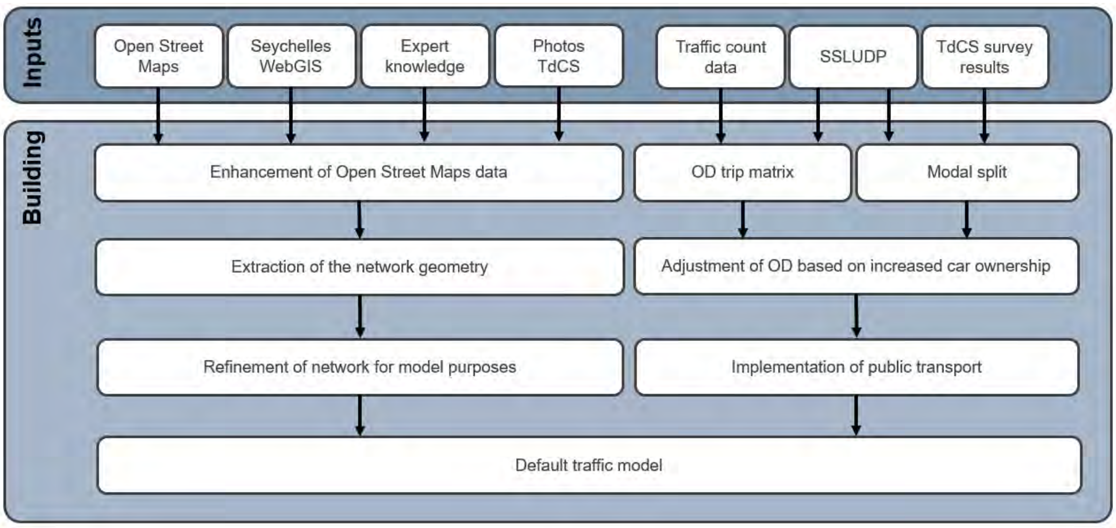
The model focuses on individual road traffic. Other transport modes such as public transport or slow mobility are only represented to the extent that their influence on the road system can be reproduced. For example, buses operate only in the GVA, and the lines are aggregated according to their route. Pedestrians are not modeled, but traffic signal-controlled pedestrian crossings are implemented.

The SARS-CoV-2 pandemic affected the mobility behavior of society (Abdullah *et al.*, 2020). It coincided with the field phase, where I gathered data for calibration. Consequently, less traffic than usual was registered (P.Andre, personal communication, January 2022). Hence, the model draws a state impacted by the pandemic.

3.2 Traffic model development

Fig. 3.2 provides an overview of the input data of various model elements and how they assemble into an entire model. The following subsections take up these work steps and discuss the procedures.

Figure 3.2: *Summary of working steps to build the model. All working shown in the figure are described in the following paragraphs.*
TdCS: Transdisciplinary Case Study (TdCS) (Krütli et al., 2022)
SSLUDP: Seychelles Strategic Land Use and Development Plan (SSLUDP) (Arup and Government of Seychelles, 2015a)
OD: origin-destination matrix



3.2.1 Network geometry

Accurately replicating the road network is the first part of building a traffic model. The road network of the Mahé traffic simulation is based on map data from Open Street Maps (OSM) (Open Street Maps Contributers, 2021). The OSM project is a community-driven map provider that offers openly available geographic data. Developing the Mahé traffic simulation network requires several steps listed below.

Enhancement of Open Street Maps data In a first visual inspection of the map on OSM, I compared the data with the aerial imagery from MHILT WebGIS (2021) and photos that were taken during the Transdisciplinary Case Study (Krütli *et al.*, 2022). I corrected errors and added more precise information directly in the OSM database. Thereby, the necessary working step of network cleaning also contributed to the data quality of the open data platform. Besides, I consulted local experts (S. Monnaie and S. Belle, personal communication, November 2021) to resolve ambiguous cases. The edited maps are available to the public on the OSM platform (Open Street Maps Contributers, 2021), containing over 1000 improvements.

Extraction of network geometry I extracted the improved network with the online tool BB-Bike.org (Schneider and Rezic, 2013) on 22.11.21. It facilitates downloading big OSM files, including the road network, as well as additional elements such as buildings, land-use types, or bus stops. However, even though the tool offers the extraction as XML files, these files are not directly usable for simulation.

Refinement of network for modeling purposes The conversion of the extracted data into a suitable format is possible with *Netconvert*, a tool of the Sumo toolbox (Section 1.3), which relies on a myriad of parameters. These parameters are given in a configuration file. Additionally, default parameters of different road types, such as default lane widths or default speeds, are defined in a typemap. The configuration file, as well as the typemap, are part of the delivery folder (see Appendix A for an overview).

The network must be refined for model purposes in a second cleaning step. In this process, I simplified the network by deleting irrelevant elements such as parking aisles, hiking paths, or short cul-de-sacs. Furthermore, I manually processed artifacts from the network conversion and anomalous situations (e.g., different speed limits or irregular intersection designs). I recorded the signal plans of all traffic lights in Victoria during the MPH on January 12th, 2022, and implemented them accordingly. In addition to the existing traffic lights, I also added artificial traffic lights in intersections where police officers manage traffic during the MPH. These traffic lights imitate the traffic control by the traffic police officers with short phases without yellow phases.

Due to the challenging topography of Seychelles, the steepness of a road is a key element to reproduce realistic traffic behavior. OSM has a relief embedded, but it allows only to download contour lines with 40 m elevation difference, which is too imprecise for the purpose of this model. Therefore, I added from SRTM elevation data, provided by the EarthExplorer of the U.S. Geological Survey (USGS, 2021), to the model. This service offers height information with a spatial resolution of one arc-second (corresponding to roughly 30 m). The relative accuracy of the elevation model is +/- 6 m (DLR, 2011). I added the height information to the base map with a second Netconvert configuration (see Appendix A). Netconvert ensures a realistic height profile of all road segments by interpolation. The application suggests flattening slopes greater than 10% incline to avoid unrealistic behavior. However, maximum gradients of 10% would not reflect local circumstances where very steep road sections are common. Hence, only road segments with an incline exceeding 30% were corrected automatically. This high threshold created unavoidable problems in network parts with short network sections where minor height differences of start- and endpoint result in steep slopes. Sudden changes in the slope could be observed, affecting the traffic flow negatively. Consequently, I had to level out some network sections in the GVA manually in Netedit to ensure stable flow conditions.

Network refinement is a tedious, iterative process. The first iterations focus on fixing apparent mistakes. In this process, experts from DoLT and SLTA assisted me in analyzing the network in detail. In subsequent iterations, I examined the simulation for inexplicable behavior. Here, a trade-off between authentic geometric representation and an accurate description of traffic behavior is necessary. Changes were made in Netedit and checked visually by running the simulation with SUMO-gui. For some changes, it is necessary to apply Netconvert with another configuration file (see Appendix A).

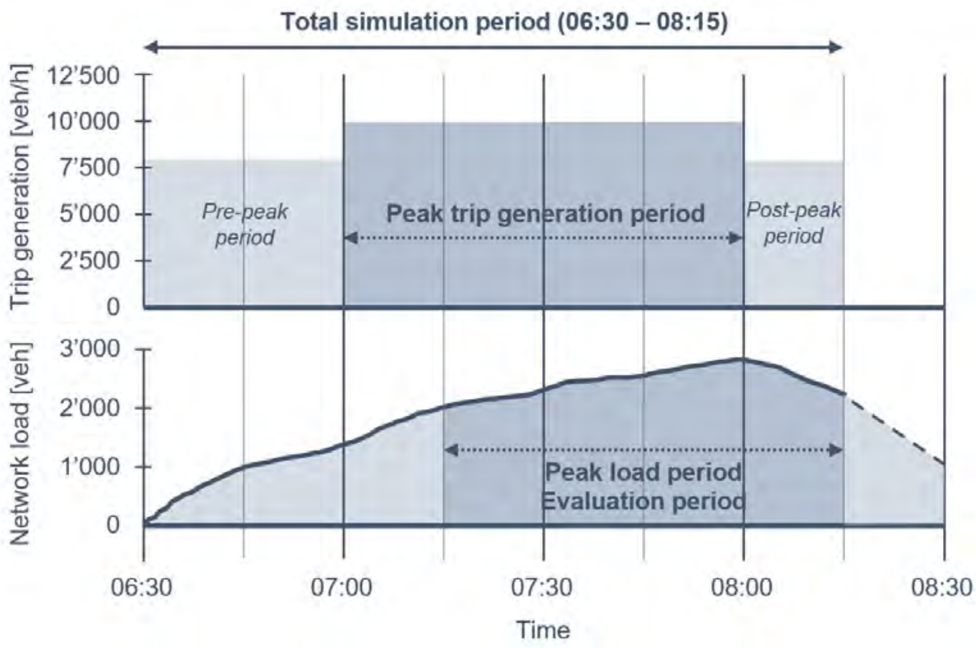
3.2.2 Traffic demand

As mentioned in Section 3.1, the model focuses on the hour between 07.15 and 08.15 AM, which is the busiest hour of the day in the GVA (Arup and Government of Seychelles, 2015b).

I split the demand into three time periods to model the peak realistically. A pre-peak period of 30 min aims to fill the system with vehicles between 06.30 - 07.00 AM. Compared to the peak trip generation period, the simulation generates only at an 80% rate during this stage.[1] The second period represents peak hour demand. Because most traffic in the city center has its origin outside the city, I applied the full load between 7:00 and 8:00 AM. Thereby, traffic has time to reach the city resulting in peak hour traffic in the GVA between 7:15 - 8:15 AM. A third post-peak period of 15 min (80% load) ensures that the simulation still generates some additional traffic between 8:00 AM and the end of the simulation at 8:15 AM. Hence the network is only slowly reducing its load. Fig. 3.3 provides a schematic representation of the applied demand distribution.

[1]Own demand assumption during the pre-peak period to saturate the network without overloading it.

Figure 3.3: *Trip generation over time in vehicles per hour and the according network load (in vehicles), measured in the completed simulation.*

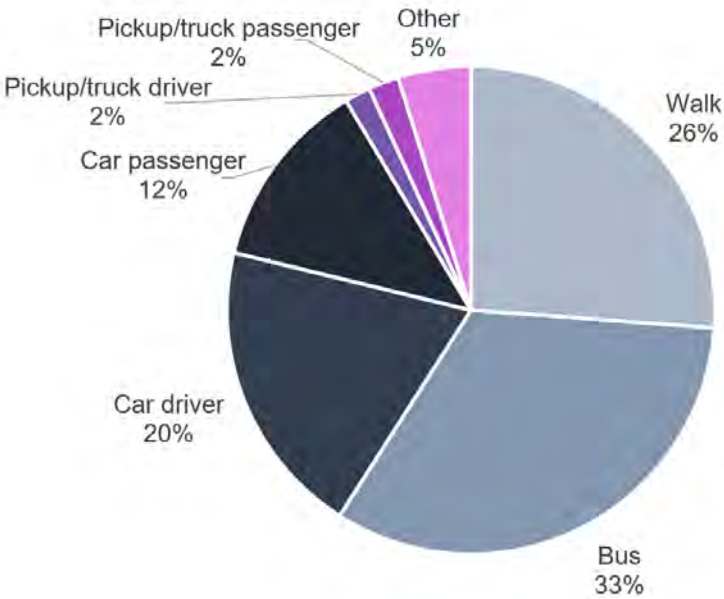


Origin-destination matrix The basis for the used origin-destination matrix (OD matrix) is given by Arup and Government of Seychelles (2015b). It is well-founded on extensive roadside interviews and traffic counts. The matrix allocates demand to 35 traffic assignment zones (TAZ), 31 on Mahé. The remaining four zones are located on other islands. Therefore, I allocated traffic from these zones to the inter-island ferry terminal since all traffic from Mahé to other islands or vice versa passes through this terminal. Appendix Fig. B.1 shows a map of all TAZs.

Arup and Government of Seychelles (2015b) only provide a preliminary OD matrix on a trip basis. The matrix does not distinguish between different transport modes. It includes trips with all modes of transport. This non-processed matrix included unrealistic demand figures for certain relations. Further, significant developments, such as major housing projects, were realized after 2014 and influenced the traffic demand in these areas. I smoothed these errors by manually adding demand for certain relations based on assessments of local traffic experts. However, only punctual yet important improvements were possible due to the manual adaptation. The improved OD matrix is shown in Table B.1 and Table B.2 in the appendix.

Modal split Based on the Transport Assessment (Arup and Government of Seychelles, 2015b), nearly 150'000 trips/day were made in 2012 on Mahé. Thereof, around 30'000 trips were made by car, resulting in a mode share of 20%. The full modal split, as found by Arup and Government of Seychelles (2015b) is shown in Fig. 3.4.

Figure 3.4: *Modal split in trips per day for Mahé in 2012 (Arup and Government of Seychelles, 2015b).*



Adjustment of OD based on increased car ownership The most recent publicly available data on population and car ownership is from 2019. Accordingly, 2019 serves as a reference year. This choice also has the advantage that the data is not tackled by uncertainty caused by the SARS-CoV-2 pandemic on mobility. Between 2014 (when the OD matrix was developed) and 2019, the population of Seychelles grew by 6.8%. Moreover, car ownership increased in this time period by almost 50% (Seychelles National Bureau of Statistics, 2020). Hence, further matrix operations were needed to incorporate these developments.

As a first simplification, I assumed that the average number of trips per person did not change significantly between 2014 and 2019. Thus, I concluded that the total number of trips per day had increased proportionally to the population growth. Consequently, the total number of trips per day rose from 154'100 in 2014 to 164'600 in 2019 on Mahé.

To include the impact of increased vehicle ownership, I calculated the number of car trips per vehicle in 2012 based on information from the Seychelles National Bureau of Statistics (2017).[2] Then, it was stated that new vehicles are used the same number of times per day as the existing fleet. Therefore, it is possible to calculate the number of car trips per day for the whole island (Eq. (3.1)). Based on this calculation, the number (n) of daily passenger car trips increased from 29'400 in 2012 to 43'600 in 2019.

$$\frac{n_{\text{daily car trips, 2012}}}{n_{\text{registered cars, 2012}}} \cdot n_{\text{registered cars, 2019}} = n_{\text{daily car trips, 2019}} \tag{3.1}$$

[2]Note that modal split data (including the number of car trips per day) is only available for 2012, while the OD matrix is only available for 2014. However, this did not reduce accuracy because population data is available for all years.

Using Eq. (3.2), it is possible to estimate the modal share of cars for the year 2019. Compared to the modal split from 2012 shown above, a major shift towards the car occurred. I used the adjusted modal share to extract a mode-specific OD matrix from the overall OD trip matrix.

$$\frac{n_{\text{daily car trips, 2019}}}{n_{\text{daily trips, 2019}}} = \frac{43'600}{164'600} = \text{modal share}_{\text{car, 2019}} \approx 0.265 \tag{3.2}$$

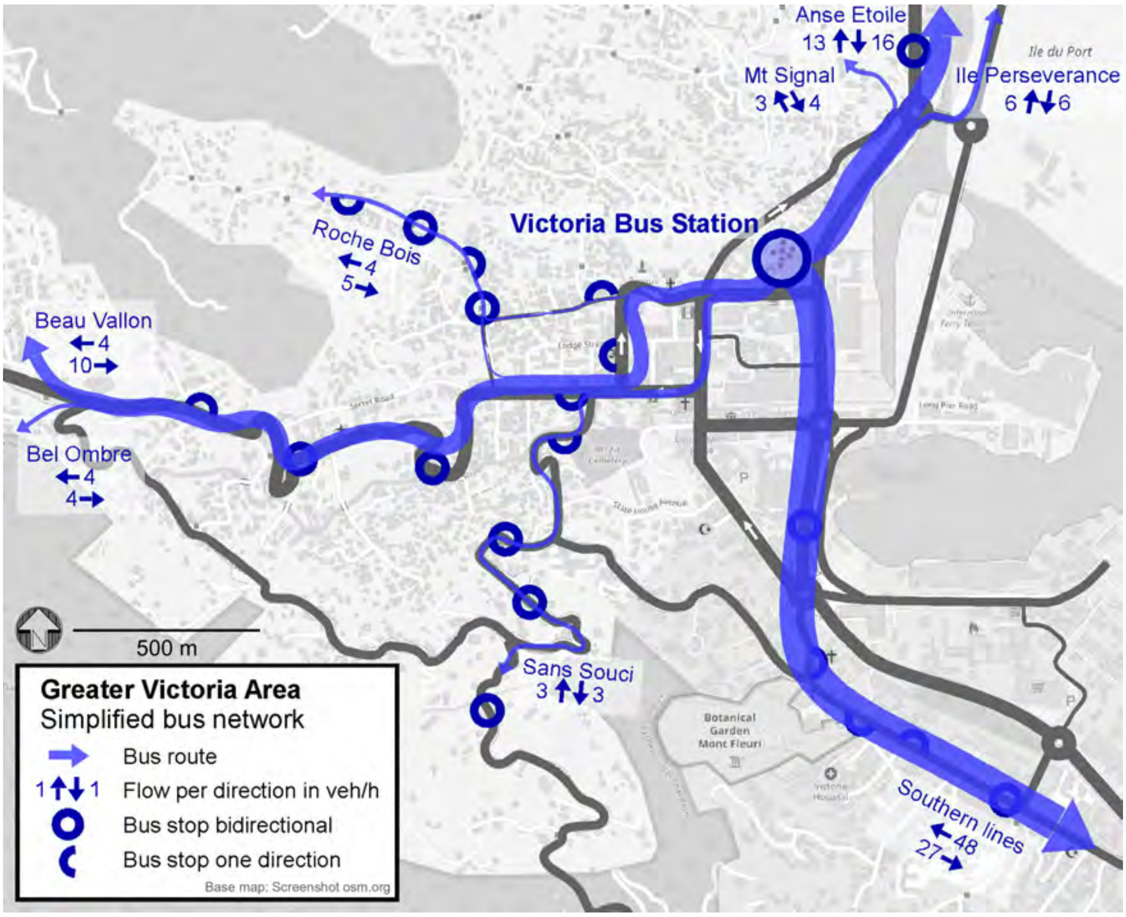
Dealing with trucks is more sophisticated. For one thing, trucks and pickup trucks are listed in the same category, making it impossible to determine the actual number of trucks. Further, the government has recently introduced a ban on trucks driving in the GVA during the MPH. Nevertheless, smaller trucks were regularly counted during the traffic counts (see following Section 3.3.2). Therefore, I did not remove trucks from the simulation. However, I did not adjust them to population growth and left them at 2012 levels. I modified the type-specific vehicle parameters for trucks to match pickup and smaller trucks' driving behavior (see Section 3.3.1).

Implementation of public transport As seen above, buses are a popular mode of transport in Seychelles. The network of the national bus operator SPTC consists of over 100 lines, most of which are located on Mahé. Victoria is home to the busiest bus hub in Seychelles. Almost all bus lines on Mahé start or end their route at the Victoria bus terminal. During peak hours, the station counts over 150 bus movements (Seychelles Public Transport Corporation, 2022). All bus stops on Mahé were imported from OSM. The data set was cleaned and improved in the GVA. In coordination with a public transport planner from SPTC (G. Zialor, personal communication, February 2022), I simplified the complex structure of the bus network to eight bus corridors for the simulation. These corridors combine all bus lines that follow the same route within the GVA. A map with the corridors and served bus stops within the modeled area is provided in Fig. 3.5. Bus routes are only modeled within the GVA. I assume that buses would not have a systemic impact on traffic in other parts of the island. For all bus stops in the GVA, I set a default stopping time of 15 seconds and defined whether they have a bus bay.

3.3 Calibration

"All models are wrong, but some are useful" is a well-known aphorism by George Box (1979, p. 202). Calibration is a crucial part of developing a digital twin and ensuring that the model is indeed useful. The goal of calibration is to adjust the model parameters to reflect the real-world conditions as accurately as possible. In the case of this thesis, I distinguished two different kinds of calibration. On the one hand, the calibration of the OD matrix assures that the simulated traffic flows match the real demand. On the other hand, the calibration of behavioral parameters, such as typical vehicle specifics or driver's aggressiveness, ensures that modeled agents behave similarly to real road users. The two kinds of calibration differentiate in the type of used reference

Figure 3.5: *Modeled bus corridors in the Greater Victoria Area. Corridors combine multiple bus lines with similar routes in the GVA.*



data. The calibration of model parameters is based on literature values and engineering judgment Section 3.3.1. The calibration of the OD matrix relies on the data gathered in traffic counts at strategic network locations (Section 3.3.2). Specifics about the calibration of the OD matrix are provided in Section 3.3.3. However, an iterative procedure was necessary to achieve the best results. Although I defined most of the model parameters initially, there were still some erroneous behaviors after the OD calibration, which I corrected in a further run.

3.3.1 Model parameter calibration

SUMO offers a vast amount of configuration parameters. Most of them are left on the default value. The SUMO configuration file provides a full overview of all used parameters (see Appendix A). In this subsection, I present the chosen global model configuration and the proceeding with the most important model parameters.

Table 3.1: *Global model configurations.*

Parameter	Value	Reasoning
Time step length	0.5 s	Compromise between simulation speed and accuracy
Car-following model	KraussPS	Krauss is the default SUMO model. KraussPS is an extension to incorporate the road slope. Due to the steep roads, the inclination has a big impact on traffic behavior. Recommended by Alvarez Lopez *et al.* (2021)
Speed deviation	0.15	Speed deviation is set on the same value for all categories, recommended by L. Ambühl (personal communication, February 2022)
Lane-changing model	LC2013	Default lane-changing model based on Erdmann (2015)
Routing algorithm	A*	Improvement of the default "dijkstra" algorithm (Hart *et al.*, 1968), recommended by L. Ambühl (personal communication, February 2022)
Share of regularly rerouted vehicles	0.9	Drivers know the small network very well and adapt quickly to traffic conditions (own observations).

Global model configuration SUMO yields a considerable number of parameters to configure the traffic model. Exact calibration of each parameter would only be possible with intensive research, exceeding this thesis's scope. Therefore, it is necessary to rely on default values, or values recommended in literature, personal on-site observations, and expert knowledge. In Table 3.1, I provide an overview of the most important algorithms and settings of the simulation as well as a brief reasoning that led to the choice. A complete list of all parameters is given in the main configuration file ("Mahe_Simulation.sumocfg"; see Appendix A).

Vehicle type parameters Besides the global model configuration, some parameters may differ between different vehicle types. Such parameters with relevance to the simulation result are listed in Table 3.2.

Table 3.2: *Vehicle type-specific parameters for all vehicle types. If nothing else is specified, the parameters correspond with the SUMO default parameters.*

Vehicle type parameters	Unit	Passenger	Truck	Bus
Vehicle length[a]	[m]	4.4	7	9
Max. speed	[m/s]	55.6	36.1	23.6
Max. acceleration[b]	[m/s^2]	4	3	2
Normal deceleration[c]	[m/s^2]	-5.5	-5	-3
Emergency deceleration	[m/s^2]	-9	-7	-7
Time to total impatience[d]	[s]	120	120	120

[a] I reduced the vehicle size for all categories because Seychelles' vehicle fleet consists of smaller vehicles than Europe's (own observation, January 2022). Further, in contrast to the Swiss distinction, pick up trucks are categorized in the Truck category. Therefore, the average length of both, the Passenger and the Truck category, decreases.

[b] It was necessary to increase the maximum acceleration for passenger cars and trucks to cope with the steep inclinations, the traffic behavior is unrealistic without this change.

[c] I increased the normal deceleration for the Passenger and Truck category to model a more aggressive driving behavior compared to the German default values.

[d] The reduced time to impatience (default: 300 s) models the aggressive, yet cooperative driving behavior in Seychelles (own observations, January 2022).

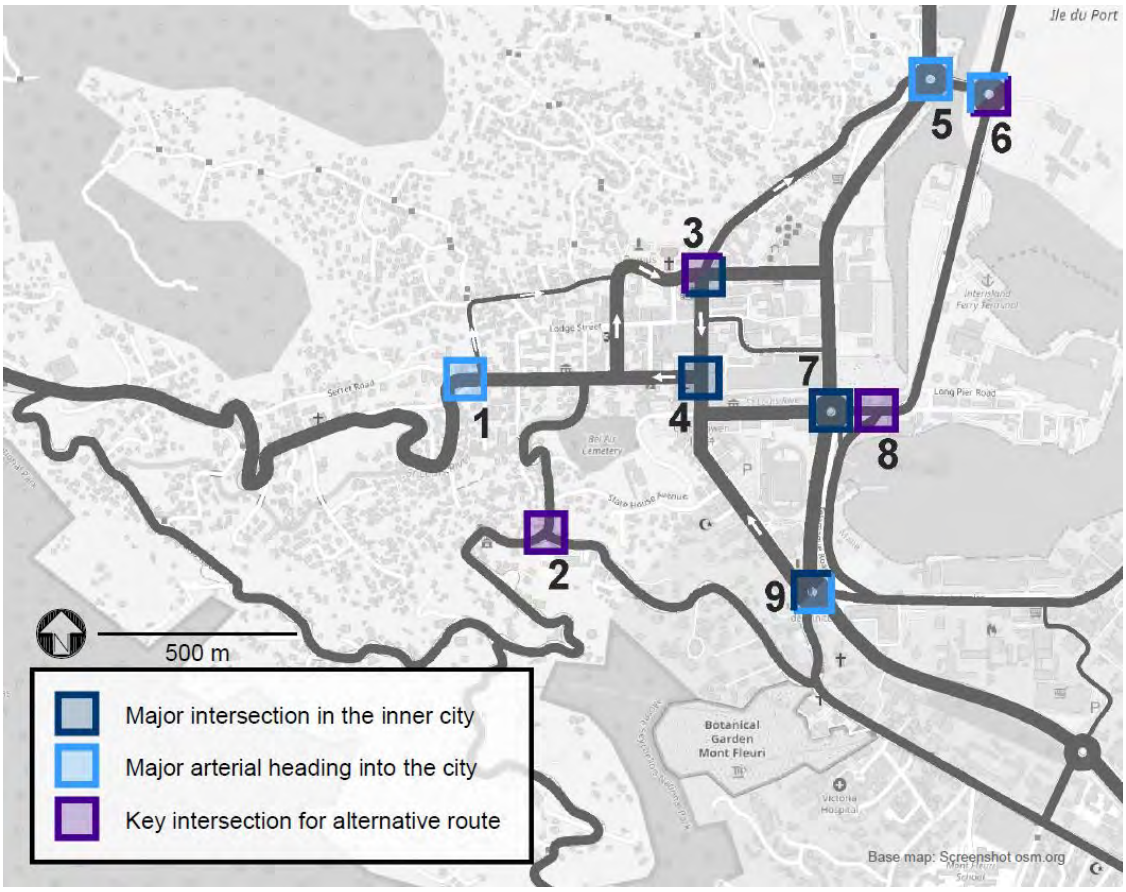
3.3.2 Traffic counts

Traffic counts are an important tool to get an overview of the traffic flows within a network. In particular, the OD matrix provides detailed information about origins and destinations of traffic, but it does not show which route the road users take. Traffic counts at strategic points in the network can fill this gap. The location choice followed the three guiding questions below:

- How much traffic flows through the city center?
  → Counts at major intersections in the inner city
- How much traffic enters the city in the MPH and from which direction?
  → Counts at all major arterials heading into the city
- How much traffic takes an alternative route to avoid congestion?
  → Counts at known alternative routes

To answer all questions confidently, I chose nine locations in the GVA together with local traffic experts. A map of all locations is given in Fig. 3.6. Snapshots of all location are provided in Fig. C.1. With help of SLTA staff, I conducted most traffic counts at intersections. Thereby, we were able to gather more information simultaneously as we could count the traffic on all adjacent roads. Thus, we counted 39 road sections in total. All measured links are mapped in Appendix C. Some of the locations were also useful to answer more than one of the questions above.

Figure 3.6: *Traffic count locations. Some intersections serve two purposes.*



Survey design Each of the nine intersections was observed twice during a MPH between 24. January and 03. February 2022. We conducted the counts with two drones (DJI Mavic Mini 2 and DJI Mavic Pro 3). During the survey, the drones hovered at 15 - 45 m above the intersection. An example excerpt from the drone footage is provided in Fig. 3.7. Thanks to this technique, we could cover all traffic streams in the intersection on our own, and there was no need to deploy additional counting personnel. On the downside, the duration of the counts was capped at 15 minutes. This limitation arises due to the limited flight time of the drones. Even though the drones covered entire intersections, we only counted flows on incoming and outgoing edges. We did not count turning movements because of the considerable additional effort needed for that. Attention was paid to ensure that all counts took place outside of school vacations. Therefore, we conducted the counts during the MPH between Monday and Thursday and counted all intersections on two different days of the week. A list of all traffic counts and the respective results are shown in Table C.1.

Figure 3.7: *Example image from the drone footage at the Independence roundabout (intersection 5th June Ave / Independence Ave) in the center of Victoria, captured during the morning peak hour on 27.01.22.*

Automated vehicle detection For evaluating the drone images, I employed the same approach as He *et al.* (2022). They used an open-source vehicle detection program based on the deep learning model YOLO.v3 to count passing vehicles (Redmon and Farhadi (2018); Bewley *et al.* (2016)). The tool also offers classifications into different vehicle types (passenger, truck, bus, motorcycle). I validated the reliability of the summed vehicle counts in test runs, but the classification was not accurate enough. Therefore, I refrained from distinguishing different vehicle classes in the countings. However, strong winds during filming constrained the applicability of the automated approach. The drones were not able to stay steady in place during the filming period, causing problems in automated vehicle detection. Hence, I could only use the technique for counting a few traffic streams (see Table C.1). An example screenshot from the vehicle detection tool is shown in Fig. 3.8. A further constraint of the automated vehicle detection approach was the evaluation speed. During the field phase in Seychelles, computational power was limited to two laptops (both Intel i5 processors, roughly 2.2 GHz, without a dedicated graphics card). Despite lowering the quality of the footage to 360 p and reducing the frame rate to 8 fps, the evaluation of a 15-minute video still took about 2.5 hours.

Manual traffic counts Due to the difficulties with automated vehicle counting, I evaluated many drone videos manually. Nevertheless, the drone imagery was still beneficial because it allowed me to re-run the video and count different intersection arms using the same footage. Furthermore, it had the beneficial side effect that I could analyze the imagery much faster by running the video at quadruple speed.

Figure 3.8: *Example screenshot from the automated vehicle detection tool. The red perimeter is set manually. Vehicles are detected within this area. However, the perimeter has a fixed position in the frame. If the drone moves due to wind, the road may no longer be covered by the detection area.*

3.3.3 OD matrix calibration

I inserted loop detectors into the simulation at those points where we performed the traffic counts. Thus, the detectors recorded the flow at each simulation run. I could then compare these values with the counted values. This comparison was the foundation for the OD matrix calibration. For the data analysis, I wrote a simple R script ("OD_Calibration.R"; see Appendix A).

For the calibration, I proceeded in the following steps:

1. Selective correction of obvious matrix errors as described in Section 3.2.2.
2. Scaling of the total OD matrix using the average number of vehicles in all measurement points. For doing this, I multiplied the whole matrix with a single factor to roughly reach the same traffic volume as what we found in the traffic counts.
3. Analysis of single measurement points to find systemic errors in the simulation configuration (e.g., are all alternative routes overestimated or underestimated to a similar extent?)
4. Fine-tuning simulation parameters based on the analysis
5. Insertion of specific traffic flows to optimize some specific traffic flows. The introduction of these flows is legitimate since the OD matrix systematically underestimated the traffic flows on these axes. I inserted additional flows with much care to avoid overfitting and only in line with engineers' judgment. The seven added flows are shown in the delivery folder ("CalibrationFlows.rou.xml"; see Appendix A).

3.3.4 Calibration results

Fig. 3.9 shows the calibration results. The graph compares the counted traffic flow and the simulated traffic flow for each measurement point. Appendix C maps the measurement points geographically. On average, the simulated flow is 665 veh/h. The counted flow for the same points consisted of 655 veh/h on average. Overall, the simulated traffic volume, thereby, slightly overestimates the traffic volume by 1.5%.

Figure 3.9: *Simulated flows compared to the counted flows at each measurement point. Detector positions are visible in Appendix C.*

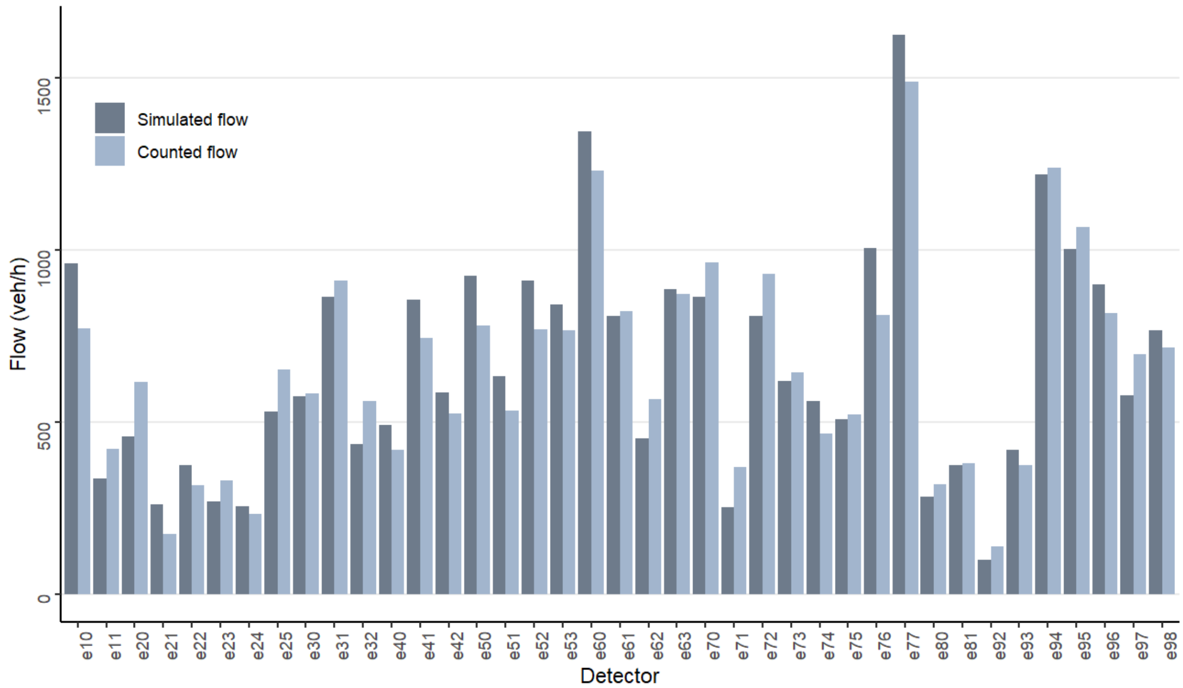
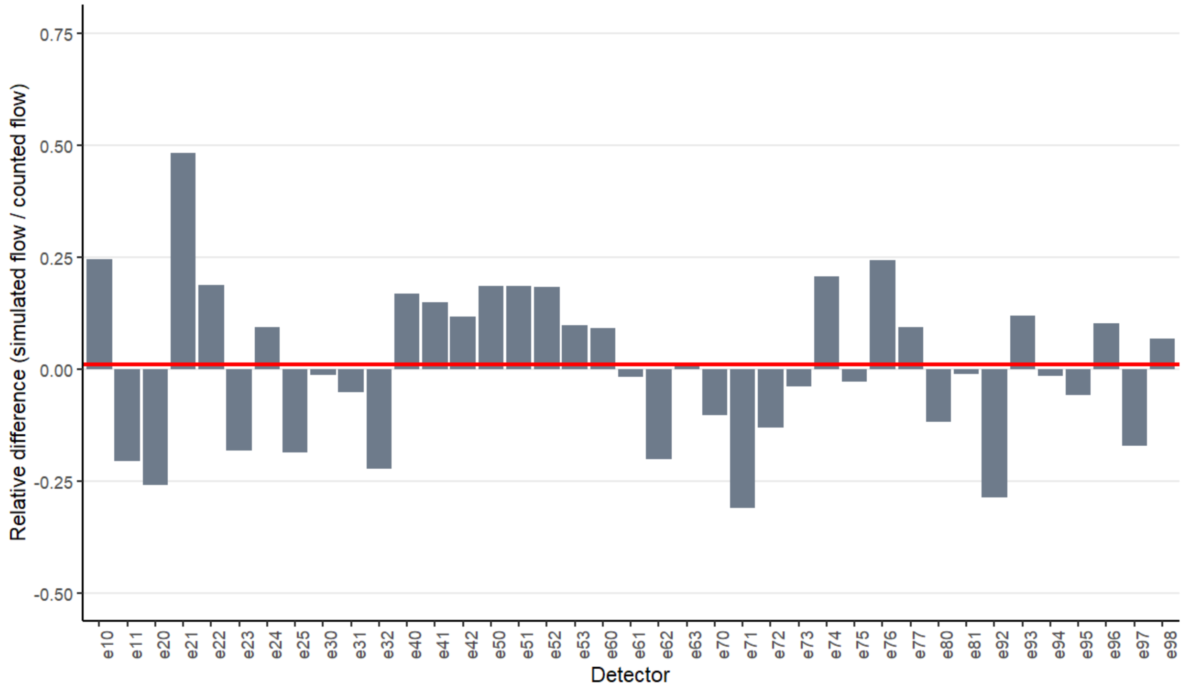


Fig. 3.10 depicts the relative difference of the simulated flows compared to the counting data for each measurement point. The pattern shows that some measured links have considerable differences between simulated and counted flows. However, measured links with large relative deviations tend not to be heavily used, so few vehicles can considerably impact the result.

Figure 3.10: *Relative difference between simulated and counted flow at each detector. The red line shows the averaged difference of +1.5% between simulated and counted flows.*



3.4 Validation

3.4.1 Statistical validation

The Scalable Quality Value (SQV) (Friedrich *et al.*, 2019) served as the primary performance benchmark. The formula is a further development of the widely used GEH Statistics invented by Geoffrey E. Havers. It is based on an empirical formula and calculated from the absolute and relative error. SQV offers significant advantages over GEH Statistics due to its scalability, symmetry, and applicability. The measure is also recommended by SVI, the Swiss association of traffic engineers and traffic experts (Rieser *et al.*, 2019). The formula is presented in Eq. (3.3). Friedrich *et al.* (2015) suggest to rate traffic flows according to Table 3.3.

$$SQV = \frac{1}{1 + \sqrt{\frac{(M-C)^2}{f*C}}} \tag{3.3}$$

M: Modeled flow in [veh/h]
C: Flow from traffic counts in [veh/h]
f: Scaling factor (for traffic flows in [veh/h]: f=1000)

Table 3.3: *SQV rating according to Friedrich et al. (2015), translated from German.*

SQV	Rating
> 0.90	Very good
0.85 - 0.89	Good
0.80 - 0.84	Fair
0.75 - 0.79	Acceptable
< 0.75	Insufficient

For the validation of the model, I inspected the SQV values. In particular, I considered the 85th percentile of all SQV values: SQV_{85}. Thus, SQV_{85} is the value for which 85% of all measurements perform equally or better. The 85th percentile is a typical indicator in the field of traffic. Besides SQV_{85}, I also took the SQV of the worst measurement point and the median SQV into account. Fig. 3.11 shows the performance of all measurement points. The worst value (e76), which corresponds to the Northbound flow on 5th June Avenue entering the Independence roundabout, reaches a SQV of 0.82. Therefore, even the worst traffic flow rates in the "Fair" category (see Table 3.3). The SQV_{85} reaches the "Good" category with a score of 0.86. The median SQV of 0.91 even ranks in the best category of "Very good". Fig. 3.12 depicts the validation results on a abstracted map of the main road network of Victoria.

Figure 3.11: *Resulting SQV of all measurement point. The rating coincides with Table 3.3.*

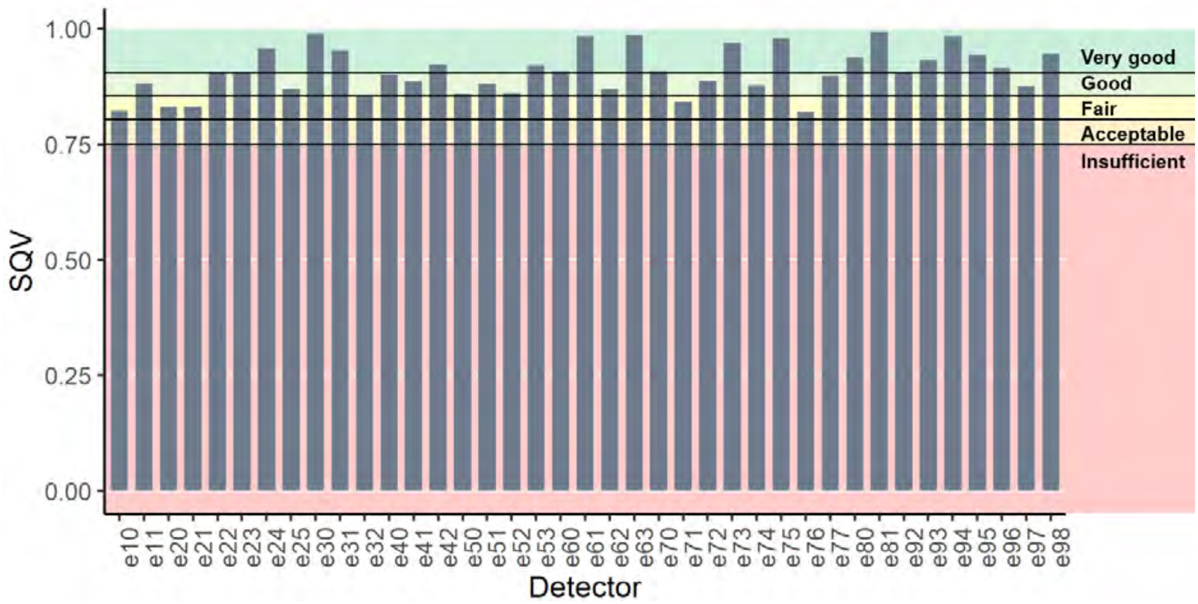
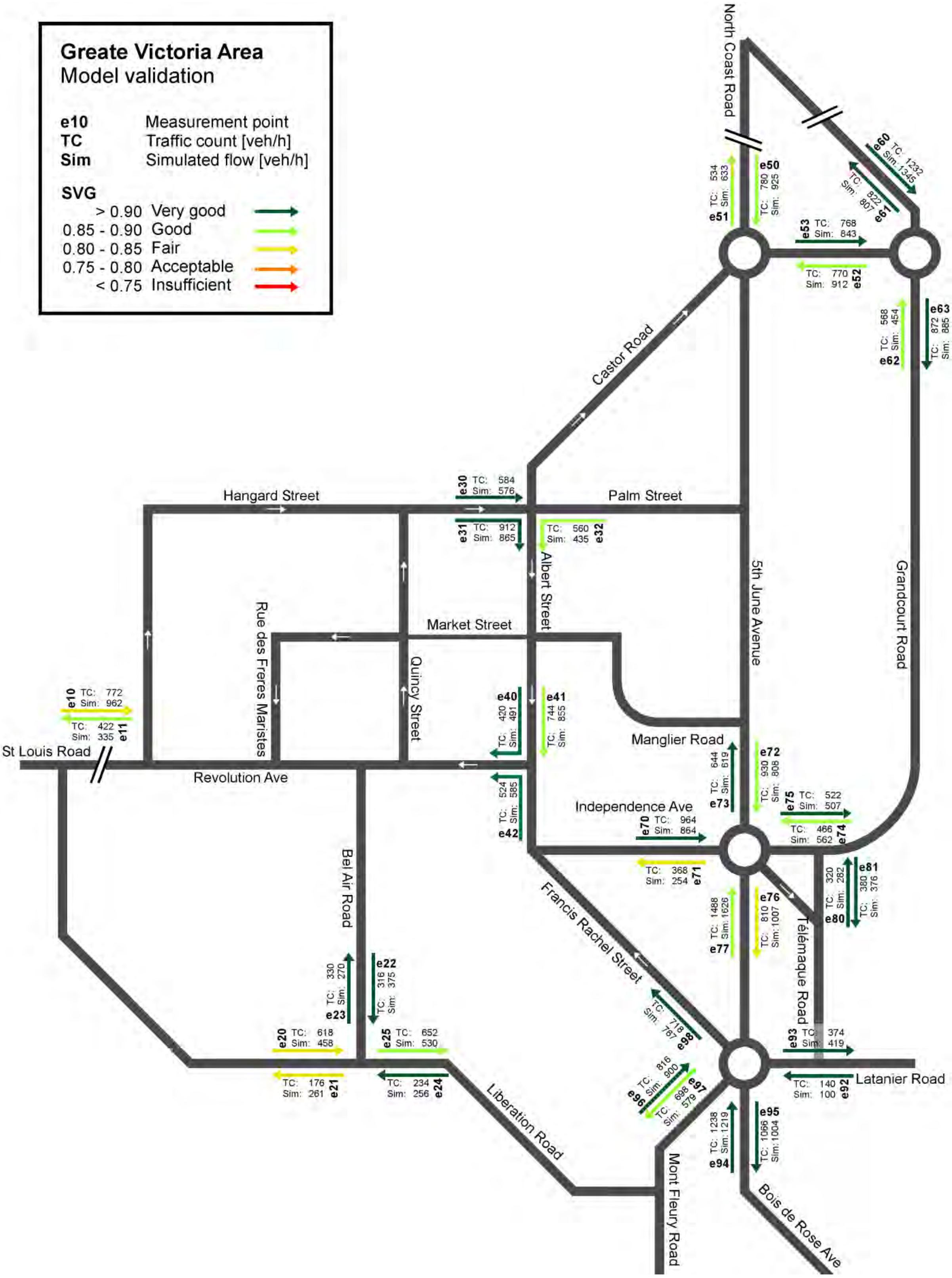


Figure 3.12: *Comparison of counted and simulated vehicles for every measurement point, as well as their resulting SQV category.*



3.4.2 Visual validation

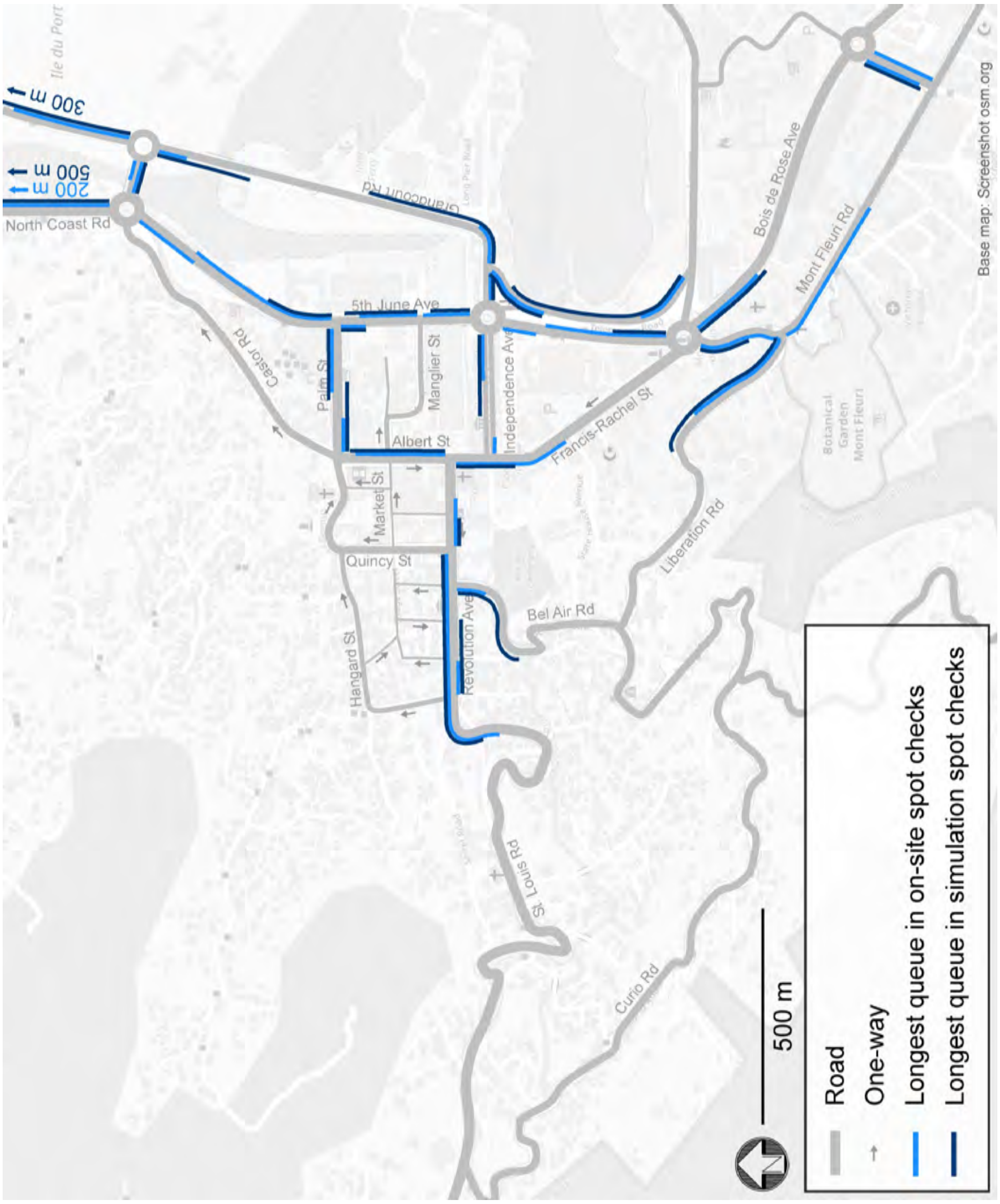
The fundamental diagram is one of the base principles of traffic engineering. It states that the traffic changes from stable to unstable conditions after reaching a critical density. In unstable conditions, the throughput of a road lowers. Accordingly, the same flow on a road section can be measured in two network states, once in free-flow (stable) conditions and once in congested conditions (Kouvelas, 2019).

While the Section 3.4.1 is a great tool to validate the traffic flows, it cannot determine if a particular flow is in a congested or uncongested state. Typically, this could be determined by looking at a second traffic variable, such as speed or density. However, all other variables are more complicated to measure than flow. Therefore, I used a congestion map as a second validation input. By checking whether links were congested or not in the real network as well as in the simulation, I controlled if they were in the same state as the simulated one.

The results, depicted in Fig. 3.14, show that the network state in the simulation met the real network state in nearly all cases. The measurements are based on two to three on-site checks each. I used the drones to overview the situation in case of long queues (Fig. 3.13). I retrieved congestion information from the simulation manually as well. I sampled the congestion state in the simulation by mapping congestion every 15 minutes of simulated time.

Figure 3.13: *Example from congestion checks with drone imagery at Mont Flery Road (February 2022).*

Figure 3.14: *Measured and simulated congestion in the GVA. Congestion data was sampled from drone imagery in February 2022.*



4 Results and Discussion

The main result of this thesis is the Mahé traffic model as presented in Chapter 3. It can be started by calling the file "Mahe_Simulation.bat" in the delivery folder (Windows OS is required). When opening it, some warnings about missing phases of traffic lights are reported on the bottom console. These warnings are generated due to the artificial traffic lights that I added to the simulation to model traffic police officers (see Section 3.2.1). They are not critical and can be neglected. The same traffic lights cause also most of the warnings during the simulation. Due to their implementation without a yellow phase, they often provoke emergency stops. However, I chose this compromise to avoid unrealistic capacity losses.[1] The network consists of roughly 1400 nodes and 3100 edges, building a network with a length of almost 900 km. The following example plots show some of the key characteristics of a transport network. Fig. 4.1 depicts the modeled vehicle flows in the city center of Victoria during the MPH. Fig. 4.1(b) illustrates the relative speeds on all road sections, as an indicator of congestion. However, the relative speed can also be impacted by other environmental impacts such as the road's slope. Therefore, a density plot for the same area is provided in Appendix D.1. In the same section, some screenshots from the simulation are shown.

[1] It was observed, that police officers regulated traffic in an efficient way by non-verbal communication with drivers.

Figure 4.1: *Simulation results visualised.*

(a) *Vehicle flows in the GVA during the MPH, modelled in the Mahé Simulation. The colour scale spans from grey (low traffic volume) to red (high traffic volume).*

(b) *Relative Speed in the GVA during the MPH, relative speed is defined as the driven speed on a single edge in relation to the allowed speed on this edge; modelled in the Mahé Simulation. The colour scale spans from red (low relative speed) to green (high relative speed). No values are available for the grey road sections because of restricted accessibility.*

4.1 Model analysis

Network The road network is mapped in great detail. With input from local experts, it is more up-to-date than any available map material. The base data from OSM (Open Street Maps Contributers, 2021) have also proven to be useful. It was more accurate than Google Maps (Google, 2022) and the MHILT WebGIS (2021). However, I focussed on the GVA for the improvements. At a later stage, I sacrificed a small part of accuracy again in order to enhance the traffic behavior.

Traffic demand Assessing the quality of the OD matrix is challenging because of a thin data foundation. However, the underlying OD matrix already showed wrongful patterns. My modifications could only cover apparent mistakes. On top of that, Seychelles developed remarkably during the last decades. The substantial increase in car ownership, a grown economy, and new developments increased uncertainty further (Seychelles National Bureau of Statistics, 2020).

On the other hand, traffic counts are also subject to uncertainty. The chosen time duration of 15 min per measurement short. In addition, we surveyed each location only twice. To make up for that, we surveyed 39 links, which, considering the small calibration area, corresponds to a remarkable number. While the manual counts reached a high accuracy, the automated vehicle detection came with uncertainty that varied depending on the video footage. Hence, I only used the automated vehicle detection conservatively to ensure good data quality.

Furthermore, the traffic counts were affected by the SARS-CoV-2 pandemic. At the time of the counts, some restrictions were in place that impacted traffic counts. First, some companies and government agencies had work-from-home policies in place. Second, the tourism industry was under capacity, supposedly leading to reduced overall business activity. Based on the experiences of local stakeholders, congestion has massively dropped compared to the pre-pandemic situation (P. Andre, personal exchange, January 2022). It is impossible to determine the pandemic's exact impacts on traffic or estimate the long-term effects on mobility behavior with the gathered data. However, it is assumed that the proportional share of each OD relation stays the same, meaning that a single pandemic impact factor can scale down the entire matrix. To highlight that the demand reflects a pandemic state, I calibrated the entire traffic demand to a scaling factor[2] of 0.88 (-12%). Therefore, I artificially increased the traffic demand in the OD matrix over the level of the traffic counts and then calibrated the simulation to a scaling factor of 0.88. I chose a reduction factor of 12% based on assumptions from traffic experts at the DoLT, who estimated that the traffic load during the field phase of the thesis was 10 to 15% under pre-pandemic conditions. Therefore, the simulation should show a pre-pandemic state when the scaling factor is increased to 1. However, I could not verify this because there is no comparative data.

[2]The scaling factor is a parameter of the SUMO configuration file (see Appendix A). It is always visible when running a Simulation in sumo-gui.

After all, the calibration showed that the measured values can be reproduced well despite the large uncertainty. This suggests that the data quality is not too bad or that the sensitivity of the simulation to traffic demand errors is low. In both cases, the reproduction of the traffic demand can thus be considered accurate.

Calibration The calibration of the OD matrix is solely based on traffic count data. This fact is critical due to the characteristics of road traffic. For instance, the fundamental diagram states that the flow on a road segment drops after reaching a critical density (Kouvelas, 2019). Accordingly, a specific traffic count can be measured in two network states: once under free-flow conditions and once in a congested network. This distinction is usually performed by looking at a second variable; such as traffic density, detector occupancy, or speed. In the case of Mahé, no such data is available. The congestion map (Section 3.4.2) is a good solution for overcoming the lack of data, validating the demand scenario qualitatively, and ensuring that I modeled the right traffic conditions in the simulation. Arup and Government of Seychelles (2015b) also used a similar approach.

Resulting model While the last paragraphs addressed some challenges, the resulting model represents reality adequately. Moreover, it reflects the traffic behavior in the GVA properly and can be used to assess scenarios with confidence.

4.2 Limitations

As discussed in Section 4.1, the Mahé traffic simulation replicates road traffic very well in general. Like every model, it simplifies reality. It was built to mirror the road traffic in the GVA. For the correct usage of the simulation, it is crucial to raise awareness of its limitations. Although I already discussed the model constraints in various parts of this report, the following list provides a clarifying overview of all significant limitations in one place.

- Spatial limitation: although the simulation incorporates the whole of Mahé, I only calibrated the model for the GVA. The model showed a reasonable behavior outside the core area in a brief visual inspection. Still, I did not adjust the network and the traffic demand in detail. Also, the traffic system might behave differently in rural areas than in the urban GVA.
- Modal limitation: The simulation only reflects the road transport system. I did not model other modes of transport, such as public transport or slow mobility, correctly and set a fixed demand. Therefore, the model is not capable of including multimodal routes or mode shifts. For example, it does not allow for traffic induction due to road system improvements or reduction of road traffic because of an improved bus system.

- Temporal limitation: Traffic data is only available for the MPH. Additional matrix operations and approximations would be necessary to extend the temporal extent of the simulation.
- Situational limitation: The SARS-CoV-2 pandemic had an unquantifiable impact on the traffic counts. New traffic counts might be necessary when the situation has normalized, and the long-term effects of the pandemic on mobility behavior have settled.

When considering the mentioned limitations, the model can be used with confidence. To better determine if the model is applicable in a particular use case, a table with examples is provided in Appendix D.2.

4.3 Digital twin

The Mahé traffic simulation is a microscopic traffic model. Further developing it into a digital twin would create additional benefits in understanding and optimizing the traffic system. With its open format, SUMO offers an optimal foundation to build upon. To expand the built model to a real digital twin, it must be combined with additional data sources. The TraCI interface can be used to add the most recent traffic data to the simulation and find the optimal traffic management strategy. Before implementing that, digitization of the traffic infrastructure must be promoted in Seychelles. Traffic cameras and loop detectors at strategic locations in and around Victoria could generate benefits for understanding and steering traffic in the GVA.

Another option to develop the model into a digital twin is by including further information about the road infrastructure. For example, by combing information about the current road conditions and used materials with the daily traffic volumes, the deterioration of infrastructure parts can be modeled. Road operators can therefore schedule maintenance well in advance and secure funding early enough. Integrating information from different sources and disciplines is a challenging task optimally suited for transdisciplinary processes.

Although digital twins are booming and much money is being invested in their development worldwide, the question is whether further development of the Mahé traffic simulation into a digital twin makes sense. Digital twins are powerful tools that have great potential for the future. But their development is very costly and demanding. However, they are most useful for large, highly complex traffic systems. Moreover, Seychelles' traffic volume and road network are limited and cannot be compared to extensive metropolitan areas. The value of expanding the model to a digital twin would therefore have to be determined in advance.

5 Case Study: Impacts of Pedestrianization on the Road Transport System

Following the successful implementation of the Mahé traffic simulation, this part of the thesis uses the simulation to model the impacts of road closures in a case study. The case study explores an actual proposal from political actors demanding the pedestrianization of two road sections in the inner city of Victoria. The section introduces the current situation, builds four different scenarios, and evaluates the scenarios based on model results.

5.1 Situation analysis

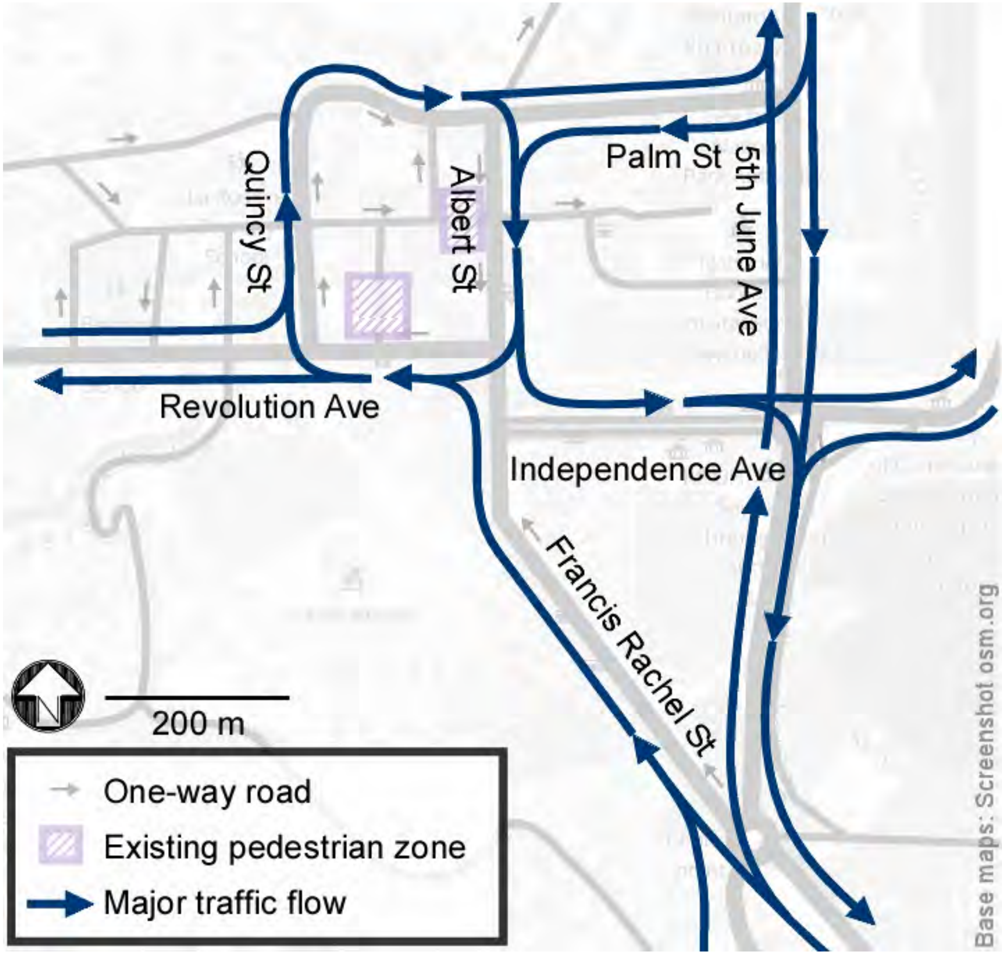
Victoria is the economic, political, and cultural center of the country. Many services and specialized stores concentrate in the GVA. Therefore, many Seychellois come to the capital for work or shopping. However, Victoria is not a place to linger for most people, neither for Seychellois nor for tourists. The car-oriented city structure has negative impacts on the quality of stay. Traffic noise is omnipresent, and pedestrians often feel unsafe. Victoria offers many open spaces, but many of them lie fallow. Hence, they are not attractive to spend leisure time. The fact that Victoria has only a few cafés and restaurants reflects this. While the city is busy during the daytime, it empties of people and activities in the evening (Arup and Government of Seychelles, 2015c). The Victoria Masterplan (Arup and Government of Seychelles, 2015c), analyzed the situation around the city center in detail. Based on this analysis, the plan derived six core strategies for further development of the GVA. Three of them are relevant in this context:

- Creating a livable place
- Revitalizing the public realm
- Developing a coherent movement network

All strategies work towards balancing coping with growth and increasing quality of living. One of the suggested projects to support the strategies is creating pedestrian zones in the city center of Victoria. While working towards the strategies, the idea of incorporating Albert Street and Independence Avenue in the planned pedestrian zones arose. A map of the situation is provided on the following page. Appendix Fig. E.4 offers a more detailed map for orientation.

Traffic routing Albert Street and Independence Avenue are critical elements in today's city road network. Therefore, it is essential to inspect the current traffic routing on a map to understand the situation. A schematic overview is shown in Fig. 5.1. The current system is referred to as the reference network from here on. 5th June Avenue is the main North-South corridor, while most traffic from the West of the island enters the city on St. Louis Road, which turns into Revolution Avenue at the inner city borders. Important to note is that Albert Street, Revolution Avenue, and Quincy Street form a one-way ring around the market district. Further, Francis Rachel Street is also a one-way street, diverting southbound traffic on Independence and 5th June Avenue.

Figure 5.1: *Major traffic flows through the city center of Victoria.*



Albert Street Albert Street is an important component of the traffic system. As part of a one-way ring around the market district, it is a heavily used network element. In the traffic counts (Section 3.3.2), up to 1'500 veh/h were counted during the MPH entering the road. In the section between Palm Street and Market Street, the road has three lanes, whereof one is normally used for short-time parking (Fig. 5.2). At the intersection with the existing pedestrian zone in Market Street, a traffic light is installed to secure the pedestrian crossing over Albert Street. In the Southern section between Market Street and Revolution Avenue (Fig. 5.3), Albert Street has two lanes. There is a traffic light at the end of the section, where Albert Street intersects with Revolution Avenue. However, it only controls flows on the right lane, turning into Revolution Avenue. Accordingly, vehicles on the left lane can pass the intersection without interference. The entire section has a length of around 230 m. Many shops developed along the road, connected by sidewalks on both sides.

Figure 5.2: *Impressions from the Northern part of Albert Street. Pictures taken by A. Amberi Premanand in March 2022.*

(a) *Albert St / Palm St, southbound* (b) *Albert St / Market St, northbound*

Figure 5.3: *Impressions from the Southern part of Albert Street.*

(a) *Albert St / Market St, southbound* (b) *Albert St / Revolution Ave, northbound*

Independence Avenue Independence Avenue is a major road with two lanes in each direction Fig. 5.4(a). On a length of roughly 280 m, it connects two key intersections. In the West, it intersects at the Clocktower junction with Francis Rachel Street, forming a two-lane mini-roundabout Fig. 5.4(b). In the East, the avenue joins up with the most important North-South axis, 5th June Avenue. During the traffic counts (Section 3.3.2), a traffic volume of almost 1'000 veh/h in the eastbound direction and around 370 veh/h in the opposite direction was registered during the MPH. Compared to a theoretical road capacity of around 3'600 veh/h per direction[1], the road has some free capacities. Independence Avenue is broader than most other roads in Victoria. The distance from storefront to storefront measures over 20 m. Besides the four lanes, the road cross-section also offers sidewalks on both sides of the street.

Figure 5.4: *Impressions from Independence Avenue.*

(a) *Independece Avenue from a bird's perspective, viewing direction: West.*

(b) *Clocktower intersection, viewing direction: North, Independece Ave enters on the right side of the picture.*

[1]Each lane has a capacity of 1'800 veh/h when considering a headway of two seconds between two vehicles

5.2 Methodology

The impacts of closing key elements of the road system are hard to foresee. The presented Mahé simulation offers a possibility to assess the impacts of the planned pedestrianization on the road transport system. In cooperation with traffic experts from DoLT and SLTA, I defined the four different implementations. I compared the scenarios then to the reference state.

5.2.1 Scenarios

All scenarios are shortly described below. Fig. 5.5 illustrates all network modifications for better understanding.

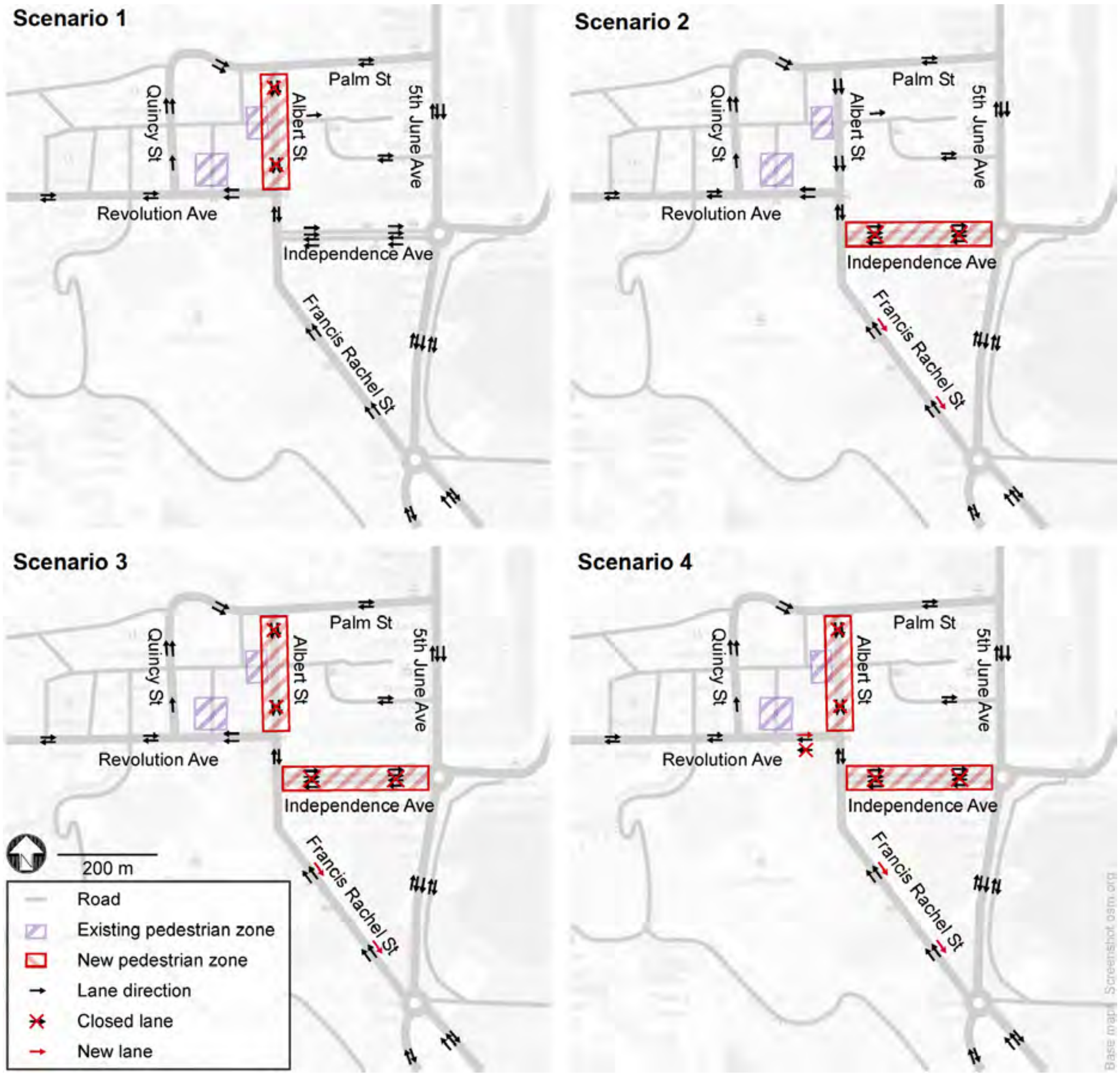
Scenario 1 In scenario 1, Albert Street is pedestrianized between Palm Street and Revolution Avenue. This measure impacts especially traffic from and to the West coast. Due to the one-way ring, all traffic that travels in the reference scenario through Albert Street has to take the parallel 5th June Avenue instead. Thereby, all traffic to the South is channeled on this axis. This also affects bus lines from the Victoria Bus Station to the West. Buses are diverted to 5th June Avenue and Independence Avenue. The opposite direction is not affected from the road closure.

Scenario 2 Scenario 2 describes a case where only Independence Avenue is pedestrianized between Francis Rachel Street and 5th June Avenue. Contrary to the first scenario, Albert Street is open for road transport. The second measure in this scenario is to add a third lane to Francis Rachel Road to allow traffic in both directions. Therefore, car drivers transiting Victoria from the West to the South might profit from shorter routes. Bus lines are not affected by this pedestrianization.

Scenario 3 In scenario 3, both investigated road sections are converted to pedestrian zones. Therefore, as described above, the one-way ring is implicitly enlarged over the whole city center. 5th June Avenue is the only axis that allows through traffic in both directions in this scenario. Other roads, such as Palm Street and Francis Rachel Street, allow two-way traffic but only serve as connector roads. As a result, buses have to take a significant detour when heading from Victoria to the West.

Scenario 4 The last scenario build upon scenario 3. Again, Albert Street and Independence Avenue are turned into pedestrian zones. However, in addition to scenario 3, scenario 4 also opens Revolution Avenue between Albert Street and Quincy Street to two-way traffic. This intervention will create a new, more direct connection from West to South. Consequently, the number of lanes in the westbound direction has to be reduced from two to one to make room for the new connection. As in Scenario 3, the bus system is heavily affected by this scenario, causing detours of around 800 m.

Figure 5.5: *Road network configuration in each scenario.*



5.2.2 Procedure

For each scenario, I created a copy of all model elements. The necessary working steps are summarized in the following list.

1. Network modifications as mentioned in Section 5.2.1 with Netedit
2. Update OD matrix to adjust trips to the new network (no changes in demand)

3. Manual adjustments of affected bus corridors
4. Adjustments of intersection design to meet the new expected demands, optimization of signalling plans of traffic lights according to the new situation
5. Simulation and visual inspection of the network

To compare the scenarios, I collected edge data and overall statistics for each scenario. Edge data is a standard XML output offered by SUMO that collects statistical information about every road section individually and aggregates it over a chosen time interval. The overall statistics aggregate the data from the whole simulation over all edges and the entire simulation time. For this case study, I aggregated the edge data over the whole MPH. In addition, I extracted data for the average trip distance and the average travel time per trip from the overall statistics.

For the edge data analysis, I transformed the data with the xml2csv.py Python script, offered by SUMO toolbox, to the Comma-Separated Values (CSV) format, which allows data processing in Microsoft Excel. There, I combined the edge data outputs from different scenarios to compare them. I created the bar plots directly in Microsoft Excel. To create comparison plots, I transformed the CSV data back to XML with SUMO's csv2xml.py tool. I generated the plots of the network then with SUMO's plot_net_dump.py script. Primarily, I evaluated the average speed and travel time on each section. Further, I collected the number of vehicles that entered each road section to determine the traffic volume.

Example routes Besides the standard data analysis, I introduced three commuters as an example to show direct impacts on possible highly affected commuters.

- Person A: lives in Anse Etoile, North of Victoria, and takes the car every morning to the city and parks it at the car park at Quincy Street.
- Person B: comes from Beau Vallon, West of Victoria, and reaches work at the commercial port in the South-East of Victoria by car.
- Person C: lives around Plaisance, South of Victoria, and travels by bus to its workplace in Bel Ombre (West of Victoria). There is no direct bus connection, so the person must change busses at the Victoria Bus Station.

Figure 5.6: *Routes of the three examples in the reference network.*

The routes in the reference network are depicted in Fig. 5.6. Then, Fig. 5.7 shows the routes of all examples for each scenario. All routes draw the shortest path in free-flow conditions, not considering alternative routes due to congestion. I only considered the part of the route within the city center of Victoria because I expected no differences on the rest of the route. For easier data analysis, I defined a separate edge data set for each example route.

Figure 5.7: *Routes of the three examples in each scenario. In scenarios 3 and 4, Person C profits from the rerouting of the bus lines and can change busses earlier. Source background map: Open Street Maps Contributers (2021).*

5.3 Results and discussion

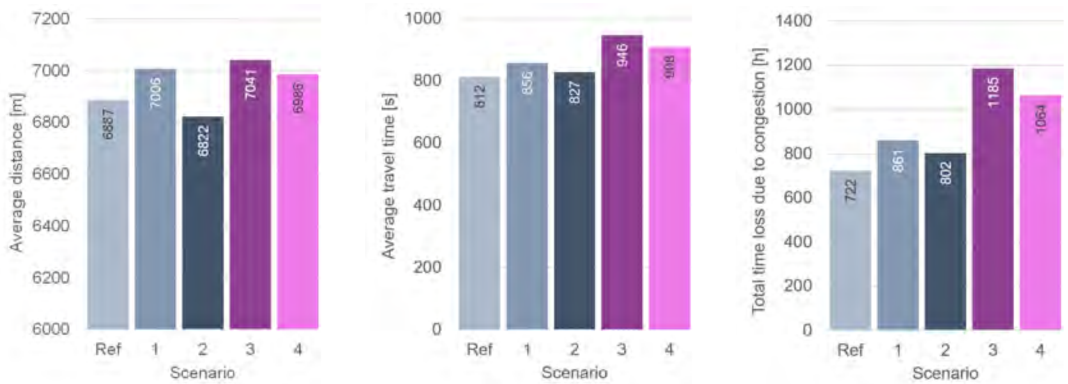
The created scenarios can all be inspected in the scenario folder of the delivery.

5.3.1 Overall network impact

The results of the overall statistics are shown in Fig. 5.8. These statistics summarize all trips in the simulation, including trips that never crossed the limits of the GVA. Therefore, it sets the results in a greater context, looking at the entire system as one. On the left side (Fig. 5.8(a)), the average trip distance in each scenario is shown. The difference between the reference case and the worst scenario is only 2.3%. Hence the y axis does not start at 0 to emphasize the differences. Although the differences are minor on a relative basis, the resulting impacts of the added network load and additional emissions can be significant. Scenario 2 performs even better than the reference scenario. This means that the additional lane for two-way traffic on Francis Rachel Street can compensate for the detours due to the closure of Independence Avenue. The impact of the added network load, in combination with the channeling of traffic due to road closures, manifests in the comparison of the average travel time for each scenario (Fig. 5.8(b)). In the current network, the simulated trips take 812 s, corresponding to 13.5 min, on average. The difference between the average trip in the reference state and the worst scenario is already over 16% (or more than two minutes).

Marcoeconomically, it is interesting to look at the overall costs of congestion. Fig. 5.8(c) shows the time loss during MPH due to heavy traffic summed up over all modeled agents.

Figure 5.8: *Comparison of average trip distance, average travel time, and total time loss due to congestion between all scenarios and the reference case.*



(a) *Average distance per trip, y-axis not normalized.* (b) *Average travel time per trip.* (c) *Time loss summed up over all vehicles.*

5.3.2 Greater Victoria Area

Apart from the overall network comparison, a view of the developments in the directly affected network parts is reveals further insights. In the following paragraphs, every scenario is analyzed and compared to the reference state.

Scenario 1 The impact of closing Albert Street on the traffic flow within the city is presented in Fig. 5.9. Traffic from West to South uses the parallel 5th June Avenue as an alternative route. Road users from North to West also switch their route to 5th June Avenue. The pedestrianization of Albert Street also leads to slightly more vehicles using the alternative routes Castor Road and Liberation Road. Based on the relative speeds (Fig. E.2(a)), congestion is especially increased on Palm and Quincy Street.

Figure 5.9: *Traffic volume on each edge in Scenario 1 compared to the reference state. The excerpt shows the city center of Victoria. The scale ranges from red and yellow (reduced flow) over grey (no change) to green and blue (increased flow). The biggest change is traffic volume occurs on the pedestrianized road, where flow drops to 0.*

Scenario 2 The effect of the road closure of Independence Avenue on the traffic flow within the city is shown in Fig. 5.10. The most impact is clearly observable in the Southern city center, where traffic southwards gets shifted from Independence Avenue and 5th June Avenue to Francis Rachel street. This is also supported by the relative speeds, shown in Fig. E.2(b).

Figure 5.10: *Traffic volume on each edge in Scenario 2 compared to the reference state. The excerpt shows the city center of Victoria. The scale ranges from red and yellow (reduced flow) over grey (no change) to green and blue (increased flow). The biggest change is traffic volume occurs on the pedestrianized road, where flow drops to 0.*

Scenario 3 In scenario 3, both investigated roads, Albert Street and Independence Avenue, are closed for road traffic. The shifts in traffic flow are visible in Fig. 5.11. An interesting picture is drawn on 5th June Avenue. In the Northern part, between Palm Street and Independence Avenue, traffic flow increases due to the closing of the parallel axis. However, in the Southern part of the avenue, the flow decreased. This decrease is not due to less demand but due to the lower capacity of the road system in unstable (congested) conditions. This is also represented in the fact that in scenario 3, over 3'200 vehicles remained in the network at the end of the simulation. In contrast, in the reference simulation, only 2'100 vehicles have not reached their destination at 08.15 AM. As mentioned in the scenario description, scenario 3 widens the one-way ring implicitly over the whole city center. This is also clearly visible when comparing the relative speeds in scenario 3 (Fig. E.3(a)) with the relative speeds of the reference scenario (Fig. E.1). The relative speeds drop on the road segments part of the extended ring.

Figure 5.11: *Traffic volume on each edge in Scenario 3 compared to the reference state. The excerpt shows the city center of Victoria. The scale ranges from red and yellow (reduced flow) over grey (no change) to green and blue (increased flow). The biggest change is traffic volume occurs on the pedestrianized roads, where flow drops to 0.*

Scenario 4 The last scenario creates a direct connection from the West to the South of Victoria. The resulting traffic flow are shown in Fig. 5.12. The results over the entire simulation showed that the average traveled distance and traveled time was reduced compared to the third scenario. This reduction is likely due to the more direct connection offered. On the other hand, the relative speeds reveal that the network is more congested than in the third scenario (Fig. E.3(b)). The roundabout at the Southern entry of the city (Unity-roundabout; intersection of 5th June Avenue and Francis Rachel Street) is overloaded. As a result, traffic queues in all directions from there.

Figure 5.12: *Traffic volume on each edge in Scenario 4 compared the reference state. The excerpt shows the city center of Victoria. The scale ranges from red and yellow (reduced flow) over grey (no change) to green and blue (increased flow). The biggest change is traffic volume occurs on the pedestrianized roads, where flow drops to 0.*

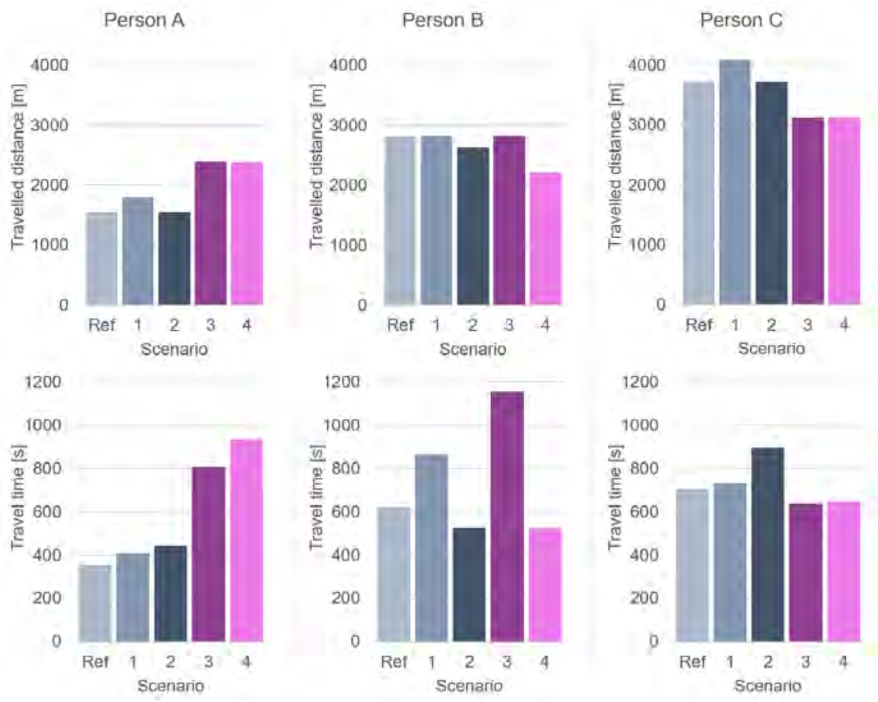
Example routes The results shown above are also reflected in the assessments for the three example routes. However, the variants affect the persons to different extents. An overview is provided in Fig. 5.13.

Person A, traveling from the North to the city center of Victoria, is not heavily impacted by scenario 1 or 2. The person experiences only slightly higher travel times. For scenario 3 or 4, the travel time more than doubles compared to the reference state. This increase is due to the detour on Person A's trip and the much more congested condition of the main roads within Victoria's city center.

Entering from the Western part of the island, Person B benefits from the additional lane in the opposite direction on Francis Rachel Road in scenario 2 and 4. In the other scenarios, the travel time rises drastically.

In the case of Person C, who is traveling West through Victoria by bus from the South, the results must be treated with caution. The bus route is affected in scenario 1, resulting in slightly higher travel times. In scenario 2, the travel time increases further, even though the route is not affected by the pedestrian zone on Independence Avenue. The reason for that is the increased travel time into the city and on 5th June Avenue. For scenario 3 and 4, traveled distance and travel time decrease under the level of the reference scenario. That is only the case if buses are also affected by road closures. Person C would profit from the detour that buses would need to take in the direction of Beau Vallon (West). Person C could change buses earlier in this case. However, how big the time saving would depend on the bus schedule, which is not modeled accurately.

Figure 5.13: *Comparison of all scenarios with the reference scenario for all three example routes. The upper row of bar charts shows traveled distance, the lower row the according travel time.*



5.3.3 Holistic view

All results of the different scenarios show clear disadvantages for road traffic if Albert Street and/or Independence Avenue are pedestrianized. However, the simulation neglects some essential factors that also need to be considered at this point.

Fixed demand If the congestion situation worsens, agents will very likely start to look for other destinations or consider other means of transportation. Nevertheless, the demand and the modal split are fixed in the OD matrix of the Mahé traffic simulation. This simplification has the consequence that I might overestimate congestion.

Bus routes The bus routes from Victoria towards Beau Vallon (in the Western direction) will suffer from increased travel times if they have to go around Albert Street. This rerouting lowers the level of service of SPTC, which is not desirable. Therefore, an alternative solution must be found for buses. One possibility would be to still allow buses to drive through Albert Street. On the downside, this would significantly lower the pedestrian zone's quality.

Quality of stay Positive arguments for implementing a pedestrian zone are not considered in the simulation. One of the most critical effects of pedestrianization is the increase in quality of staying. Besides, the pedestrianized areas benefit from less noise and air pollution. Further, the road surface can be repurposed for other uses, such as outdoor seating for cafés. The introduction of pedestrian zones generally increases pedestrian frequencies along pedestrianized roads and boosts thereby adjacent businesses (Hass-Klau, 1993).

Promotion of slow mobility Walking and cycling have considerable potential to alleviate the pressure on the road network. The reallocation of road space from cars to pedestrians and cyclists supports the mode shift two-fold. Firstly, road safety improves, making the streets more attractive for slow modes of transport. Secondly, the more congested network lowers the attractiveness for using the car, also promoting a mode shift towards walking and cycling (Wildhaber *et al.*, 2022).

Victoria Masterplan The pedestrianization of the city center of Victoria supports multiple core strategies, defined by the Arup and Government of Seychelles (2015c). It supports the revitalization of the public realm and creates a lively, high-quality area. It further helps to develop a coherent slow mobility network.

Weighing competing interests Balancing the interests of different stakeholder groups is a key challenge for urban and transport planning. While the simulation of the different scenarios quantified the negative impacts of pedestrianization on the road transport system, many other interest groups can benefit from the road closure. Weighing these competing interests is a political and societal task. The traffic simulation can contribute inputs to a fact-based debate. It can also show where problems are likely to occur, helping to ensure that they are addressed and mitigated during the planning process.

6 Conclusion and Prospect

6.1 Conclusion

This work shows how the foundation for developing a digital twin in the form of a microscopic traffic model was developed. The thesis has addressed the use of open-source data and software and has shown that SUMO is suitable for use under real-world conditions.

As shown during the thesis, the simulation is well calibrated and fully functional. Therefore, it is possible to use the simulation to assess the impacts of future infrastructure improvements or transport policies. However, the use cases are constrained by limitations (Section 4.2). I had to calibrate the model on a demand state that was presumably affected by the SARS-CoV-2 pandemic.

The microscopic model offers a good base for a digital twin. The open data format of SUMO is well-suited to develop the model into a digital twin. However, I also discussed whether this is desirable in the near future (Section 4.3). Further, considering the scarcity of sensor data in Seychelles today, the goal of a fully functional digital twin is still a long way.

The applicability of the Mahé traffic simulation was demonstrated in a case study. The results indicate that the pedestrianization of major connections in Victoria's road network harms the network stability and increases congestion. However, the severity of congestion varies significantly between the scenarios. The impacts should also be compared to the positive aspects of pedestrian zones, as discussed in Section 5.3.3. The weighing of positive and negative effects of pedestrianization is up to the governmental decision-makers.

The transdisciplinary approach spanned all phases of the project. The close cooperation with the Seychelles authorities played a decisive role in shaping and advancing the project. The integration of the staff members of DoLT and SLTA facilitated the model development. Furthermore, the training sessions helped to reduce fears about the software. The employees have shown great commitment and interest, making further use of the traffic model likely.

6.2 Prospect

The successful implementation of the traffic model opens up possibilities for the application of the simulation. The model can be used in the future by DoLT and SLTA staff to evaluate new infrastructure projects or transportation policies. Further, they can also adapt the simulation to the latest changes to keep it up to date. The employees know the basics for building the model and can also deepen their knowledge if necessary. Thus, the Mahé traffic model can contribute to further developing the traffic infrastructure in Seychelles.

If the behavior depicted in the simulation no longer matches reality after the last pandemic measures have been lifted, the traffic counts and calibration can be repeated. Due to the rapid development of Seychelles, traffic demands have to be reviewed after a few years anyway. A further enhancement of the model would also be conceivable. For example, other transport modes such as the bus system or pedestrians could be included in the model. For such tasks, further transdisciplinary projects with ETH Zürich students would be a possibility.

At a later stage, including real-time data and enhancing the microscopic model to a digital twin would also offer exciting additional prospects.

6.3 Lessons learned

Lastly, I would like to list some personal experiences that could help others in similar projects. All comments in this section are based on my personal experience and are not necessarily supported by scientific literature.

SUMO

- Due to the compared toolbox, it is hard to get started SUMO. The extensive XML files can be overwhelming in the beginning. However, after getting used to it, SUMO allows for efficient working.
- The simulation runs fluently and fast on standard laptops. The simulation speed can be increased by many configuration parameters, including the routing algorithm (A* faster than Dijkstra), rerouting and its adjacent parameters (probability and interval), the simulation step length, or the generated outputs.
- The software is still under constant development. It is advisable to regularly update to the latest development version.
- A big plus of SUMO is cooperation with developers. The developers can be reached directly through various channels such as the SUMO user mailing list and Github and usually

respond to questions or suggestions within a few days.
- SUMO is still struggling with many bugs. Even though reporting the bugs and fixing them is prioritized by the developers, limitations due to bugs must be expected. This is especially the case with special functions that are used less often and are accordingly tested less. Examples that caused frequent problems during the project were left-hand driving and the car-following model KraussPS.

Model building

- OSM is surprisingly well suited as a data base. In general, the OSM data was more reliable and up-to-date than data from Google Maps or the governmental MHILT WebGIS (2021).
- When editing the network in Netedit, all additional files should be loaded, regardless of whether they should be changed. This is necessary to avoid inconsistencies in the network.
- It is crucial to understand all simulation parameters and their impact on the simulation. Working though all configuration parameters takes a lot of time but pays off in the long run.

Traffic counts

- The use of drones for traffic counts has advantages and disadvantages. On the one hand, they enable the fast and complete collection of primary data; on the other hand, they are very susceptible to environmental influences such as rain, wind, or even birds. The limited flight duration of about 25 min resulted in short counting intervals. On the other hand, the bird's eye view also allows getting a detailed overview of the situation.
- I was sceptical about the short counting duration of only 15 min, that could affect data quality. However, the differences between the two countings per intersection were quite small, therefore I conclude that the 15 min countings are already representative.
- The automated vehicle detection software is not mature enough to handle drone imagery. The small correcting movements of the drone while hovering are already enough to reduce the quality of the evaluation. This is especially true under windy conditions.

Transdisciplinarity

- Transdisciplinarity has added many facets to the thesis and has enriched it remarkably. However, it also requires time to build up a basis of trust and bring openness to things that initially do not contribute to the project's progress.
- Informal conversations are just as insightful as formal meetings. A combination of both accelerates the progress.

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A File Index

Table A.1: *Description of all important files in the Mahé traffic simulation delivery folder.*

File name	Folder	Description
Mahe_Simulation.bat	Main	Start-up file, opens simulation with all dependencies
UpdateOD.bat	Simulation	Mini program to update the OD tables after small network changes (no change in TAZ file)
Mahe_Simulation.sumocfg	Simulation	Main configuration file with all parameters for running the simulation
Mahe.poly.xml	Landscape	Contains all additional shapes such as buildings, points of interest or land use types
Mahe.polycfg	Landscape	Configuration file for Polyconvert to convert shapes from OSM format to SUMO format
typemap_polyconvert.typ.xml	Landscape	Defines aesthetics of all additional shapes
ViewSettings.xml	Landscape	Configurates the GUI default aesthetics
Mahe_osm2net.netccfg.xml	Network	Netconvert configuration file to create a network from OSM data
Mahe_AddElevation.netccfg.xml	Network	Netconvert configuration file to add elevation data to the network
Mahe_AfterCleaning.netccfg.xml	Network	Netconvert configuration file used after network cleaning
typemap_network.typ.xml	Network	Defines defaults for different road types
Mahe_BaseNet.net.xml	Network	Network created by Mahe_osm2net.netccfg.xml
Mahe_CompleteNet.net.xml	Network	Network created by Mahe_AddElevation.netccfg.xml
Mahe_CleanedNet.net.xml	Network	Final network
BusStops.xml	Network	Contains all bus stops
LoopDetectors.xml	Network	Contains all detectors used for calibration
Mahe_TAZasPolygons.xml	OD\TAZ	Shapes of all TAZ
Mahe_Districts_cleaned_filtered.taz.xml	OD\TAZ	Stores which edge belong to which TAZ
CMD_LinesForAdjustingTAZ.txt	OD\TAZ	Text file with Python commands for updating TAZ files after significant network changes (updates weights of edges and allocates edges to a TAZ)
BusFlows.rou.xml	OD	Simplified Bus flows
CalibrationFlows.rou.xml	OD	Flows that were entered in optimization step to reach a well calibrated network
Mahe_Cars.od2tcfg.xml *Mahe_Trucks.od2tcfg.xml* *Mahe_Pre-AMPeak.od2tcfg.xml* *Mahe_Post-AMPeak.od2tcfg.xml*	OD	Od2trips configuration files for conversion from the OD-matrix to single vehicle trips (conversion automated by UpdateOD.bat)
OD-Trips_AMPeak_Cars.xml *OD-Trips_AMPeak_Trucks.xml* *OD-Trips_Pre-AMPeak.xml* *OD-Trips_Post-AMPeak.xml*	OD	The finalized files created by od2trips (all updated with UpdateOD.bat)
VehicleTypes.xml	OD	Stores vehicle type specific parameters
OD_AM_Matrix_AdjustedByARUP.csv	OD	Base OD from the Transport Assessment (ARUP, 2015)
OD_Calibration.R	OD	R Script for data analysis, used for calibration
ODTable2OFormat.R	OD	R Script to convert data from OD table into O-Format, which is readable for od2trips; also contains some improvements to cope with matrix errors
Mahe_map_211122.osm.xml	OSMData	Data dump from OSM, extracted with bbbike.org
sumo-win64extra-git_220311	SUMO	Development extra version from 11.03.22 of SUMO; this can be exchanged with newer versions (ajdust Mahe_Simulation.bat and UpdateOD.bat after exchange)

B Origin-Destination Matrix

Figure B.1: *Traffic assignment zones, zones 31 - 35 are located at inter-island ferry terminal. Source: Arup and Government of Seychelles (2015b), Transport Assessment.*

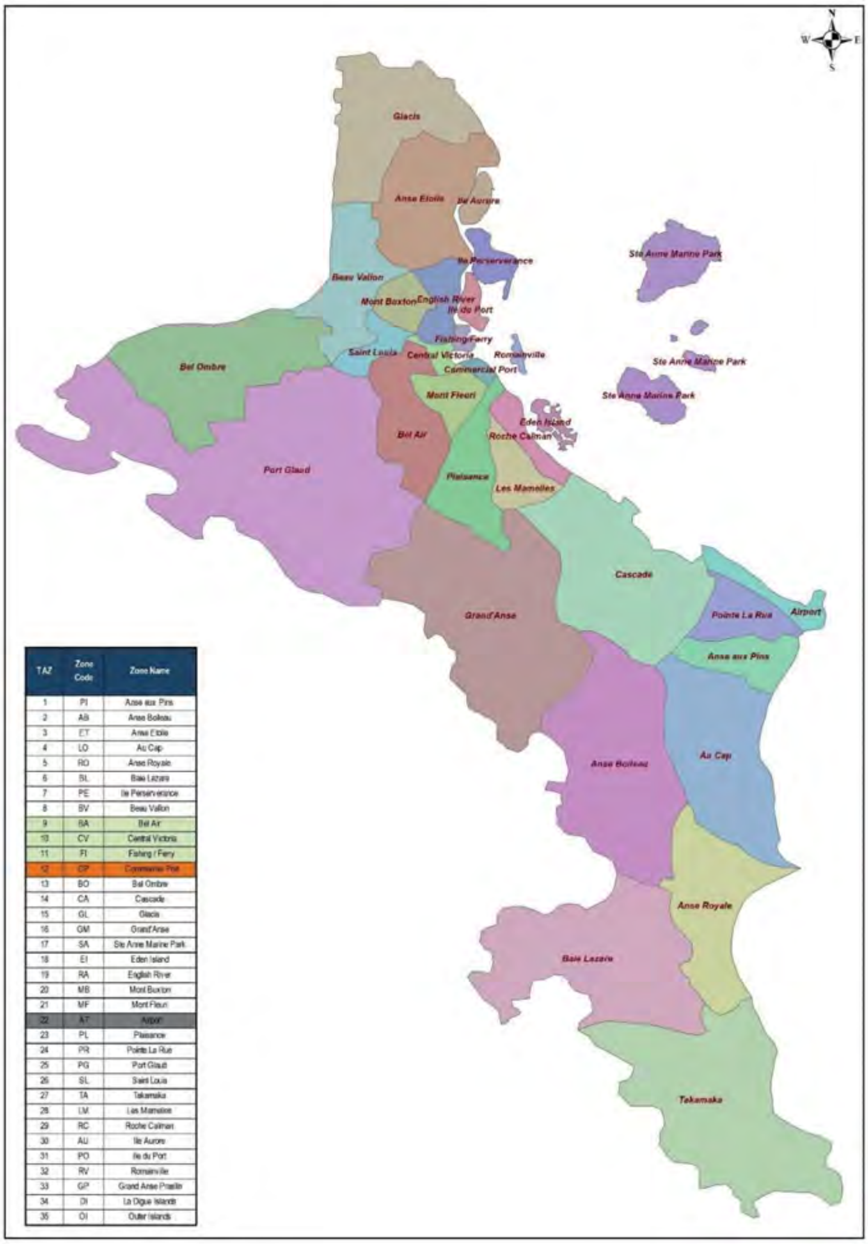


Table B.1: *OD matrix during morning peak hours, only cars. Numbering follows the TAZ numbering on Fig. B.1; all values in veh/h.*

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35
1	0	0	0	0	0	11	0	0	2	58	40	0	0	0	0	0	0	0	11	0	47	0	0	0	0	0	0	0	6	0	0	0	0	0	0
2	0	0	0	0	0	0	0	6	0	18	2	0	0	11	0	0	0	0	0	0	47	0	0	0	0	0	0	0	0	0	0	0	0	0	0
3	13	0	0	8	0	6	0	11	12	139	10	87	6	38	0	0	0	0	20	0	148	8	16	8	0	0	0	10	19	0	68	0	0	0	11
4	0	0	4	0	0	0	0	0	0	38	0	0	0	0	0	0	0	0	11	0	0	11	0	11	0	0	0	0	11	0	0	0	0	0	0
5	0	0	0	0	0	0	0	0	0	116	20	0	0	0	0	0	0	0	66	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
6	0	0	12	0	0	0	0	0	6	58	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
7	0	0	0	0	0	0	18	0	0	66	0	66	16	70	0	0	0	34	48	0	142	25	25	0	0	33	0	0	0	0	114	0	0	0	0
8	0	0	0	0	0	0	0	17	0	70	40	26	0	40	11	0	0	22	77	10	95	11	15	10	0	0	0	0	50	0	0	0	0	0	0
9	0	0	42	0	0	0	34	18	70	112	22	40	14	0	0	18	0	0	14	7	239	0	0	2	0	19	0	0	14	0	11	0	0	0	0
10	18	0	23	0	0	0	52	27	22	101	44	26	46	36	0	0	0	34	18	13	118	11	23	6	2	62	0	0	55	0	23	0	0	0	0
11	4	6	19	4	7	4	11	11	11	61	0	15	0	18	0	7	0	4	15	11	106	0	4	18	0	4	4	4	17	0	0	0	0	0	0
12	0	0	0	0	12	0	0	0	0	66	20	50	0	22	0	0	0	0	12	4	49	0	0	0	0	0	0	0	0	0	0	0	0	0	12
13	0	0	20	0	0	0	34	0	10	62	40	33	10	10	0	22	0	0	23	0	54	0	0	0	7	11	0	0	17	0	0	0	0	0	0
14	0	0	0	0	0	0	34	0	0	46	0	0	0	2	0	0	0	0	6	0	47	0	0	0	0	0	0	0	0	0	23	0	0	0	33
15	0	0	0	0	8	0	25	8	30	80	42	28	0	33	6	0	0	10	60	8	208	0	10	0	11	0	10	10	26	0	0	0	8	0	6
16	11	0	0	0	0	0	0	2	9	103	0	0	0	11	0	0	0	0	11	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
17	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
18	0	0	0	0	0	0	0	0	0	12	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
19	33	0	18	8	18	0	69	26	12	186	46	27	14	62	7	8	0	11	170	0	315	15	22	11	0	27	0	18	14	0	114	0	0	0	0
20	0	0	0	0	0	0	0	22	0	15	0	75	6	18	4	11	0	6	30	0	42	0	0	0	0	0	0	0	0	0	0	0	0	0	0
21	0	34	34	0	0	0	0	0	20	119	61	90	23	94	16	0	0	88	170	0	42	0	6	0	0	16	0	6	66	0	0	0	0	0	0
22	0	0	4	0	0	0	0	6	0	0	10	0	6	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
23	0	0	0	0	0	0	34	6	14	22	30	35	0	29	0	0	0	0	23	0	34	0	2	6	0	2	0	0	0	0	0	0	0	0	0
24	0	0	0	0	0	0	34	0	0	110	10	0	0	0	0	0	0	0	11	0	0	2	0	7	0	6	0	0	0	0	0	0	0	0	0
25	0	0	12	0	10	0	18	0	0	18	10	0	0	0	0	0	0	0	29	0	0	0	0	0	0	0	0	10	0	0	0	0	0	0	0
26	0	0	0	10	0	0	0	6	29	66	10	0	0	22	0	0	0	0	51	10	48	0	0	6	0	2	0	0	10	0	0	0	0	0	0
27	0	0	0	0	0	0	0	0	0	12	20	0	0	0	0	0	0	0	0	0	0	10	11	0	0	0	0	0	0	0	0	0	0	0	0
28	0	0	0	0	0	0	0	0	22	18	10	0	11	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
29	0	0	11	0	0	0	0	46	2	59	10	66	0	0	0	0	0	0	11	0	0	0	0	12	0	0	0	0	0	0	0	0	0	0	0
30	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
31	0	0	22	0	0	0	90	0	0	0	0	21	0	0	0	0	0	0	40	0	42	0	0	0	0	0	0	0	10	0	0	0	0	0	0
32	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
33	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
34	0	0	0	0	0	0	0	6	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
35	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	33	0	0	0	0	0	0	0	0	0	0	0	0

Table B.2: *OD matrix during morning peak hours, only trucks. Numbering follows the TAZ numbering on Fig. B.1; all values in veh/h.*

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35
1	0	0	0	0	0	1	0	0	0	3	2	0	0	0	0	0	0	0	1	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2	0	0	0	0	0	0	0	0	0	1	0	0	0	1	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0
3	1	0	0	0	0	0	0	1	1	7	0	4	0	2	0	0	0	0	1	0	7	0	1	0	0	0	0	0	1	0	3	0	0	0	1
4	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	1	0	0	1	0	1	0	0	0	0	1	0	0	0	0	0	0
5	0	0	0	0	0	0	0	0	0	5	1	0	0	0	0	0	0	0	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
6	0	0	1	0	0	0	0	0	0	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
7	0	0	0	0	0	0	1	0	0	3	0	3	1	3	0	0	0	2	2	0	7	1	1	0	0	2	0	0	0	0	5	0	0	0	0
8	0	0	0	0	0	0	0	1	0	3	2	1	0	2	1	0	0	1	4	0	4	1	1	0	0	0	0	0	2	0	0	0	0	0	0
9	0	0	2	0	0	0	2	1	3	5	1	2	1	0	0	1	0	0	1	0	11	0	0	0	0	1	0	0	1	0	1	0	0	0	0
10	1	0	1	0	0	0	2	1	1	5	2	1	2	2	0	0	0	2	1	1	6	1	1	0	0	3	0	0	3	0	1	0	0	0	0
11	0	0	1	0	0	0	1	1	1	3	0	1	0	1	0	0	0	0	1	1	5	0	0	1	0	0	0	0	1	0	0	0	0	0	0
12	0	0	0	0	1	0	0	0	0	3	1	2	0	1	0	0	0	0	1	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	1
13	0	0	1	0	0	0	2	0	0	3	2	2	0	0	0	1	0	0	1	0	3	0	0	0	0	1	0	0	1	0	0	0	0	0	0
14	0	0	0	0	0	0	2	0	0	2	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	1	0	0	0	2
15	0	0	0	0	0	0	1	0	1	4	2	1	0	2	0	0	0	0	3	0	10	0	0	0	1	0	0	0	1	0	0	0	0	0	0
16	1	0	0	0	0	0	0	0	0	5	0	0	0	1	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
17	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
18	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
19	2	0	1	0	1	0	3	1	1	9	2	1	1	3	0	0	0	1	8	0	15	1	1	1	0	1	0	1	1	0	5	0	0	0	0
20	0	0	0	0	0	0	0	1	0	1	0	4	0	1	0	1	0	0	1	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0
21	0	2	2	0	0	0	0	0	1	6	3	4	1	4	1	0	0	4	8	0	2	0	0	0	0	1	0	0	3	0	0	0	0	0	0
22	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
23	0	0	0	0	0	0	2	0	1	1	1	2	0	1	0	0	0	0	1	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0
24	0	0	0	0	0	0	2	0	0	5	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
25	0	0	1	0	0	0	1	0	0	1	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
26	0	0	0	0	0	0	0	0	1	3	0	0	0	1	0	0	0	0	2	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0
27	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0
28	0	0	0	0	0	0	0	0	1	1	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
29	0	0	1	0	0	0	0	2	0	3	0	3	0	0	0	0	0	0	1	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0
30	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
31	0	0	1	0	0	0	4	0	0	0	0	1	0	0	0	0	0	0	2	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0
32	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
33	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
34	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
35	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0

C Traffic Counts

Figure C.1: *Snapshots of all traffic count locations. Subfigure 1 is a screenshot from the MHILT WebGIS (2021), all other subfigures are from own drone imagery.*

1 *St. Louis Rd*

2 *Bel Air Rd / Liberation Rd*

3 *Albert St / Palm St*

4 *Albert St / Revolution Ave*

5 *Northern roundabout*

6 *Ile du Port roundabout*

7 *Independence roundabout*

8 *Grandcourt / Telemaque Rd*

9 *Unity roundabout*

Figure C.2: *Overview of all measured links with corresponding measurement point ID*

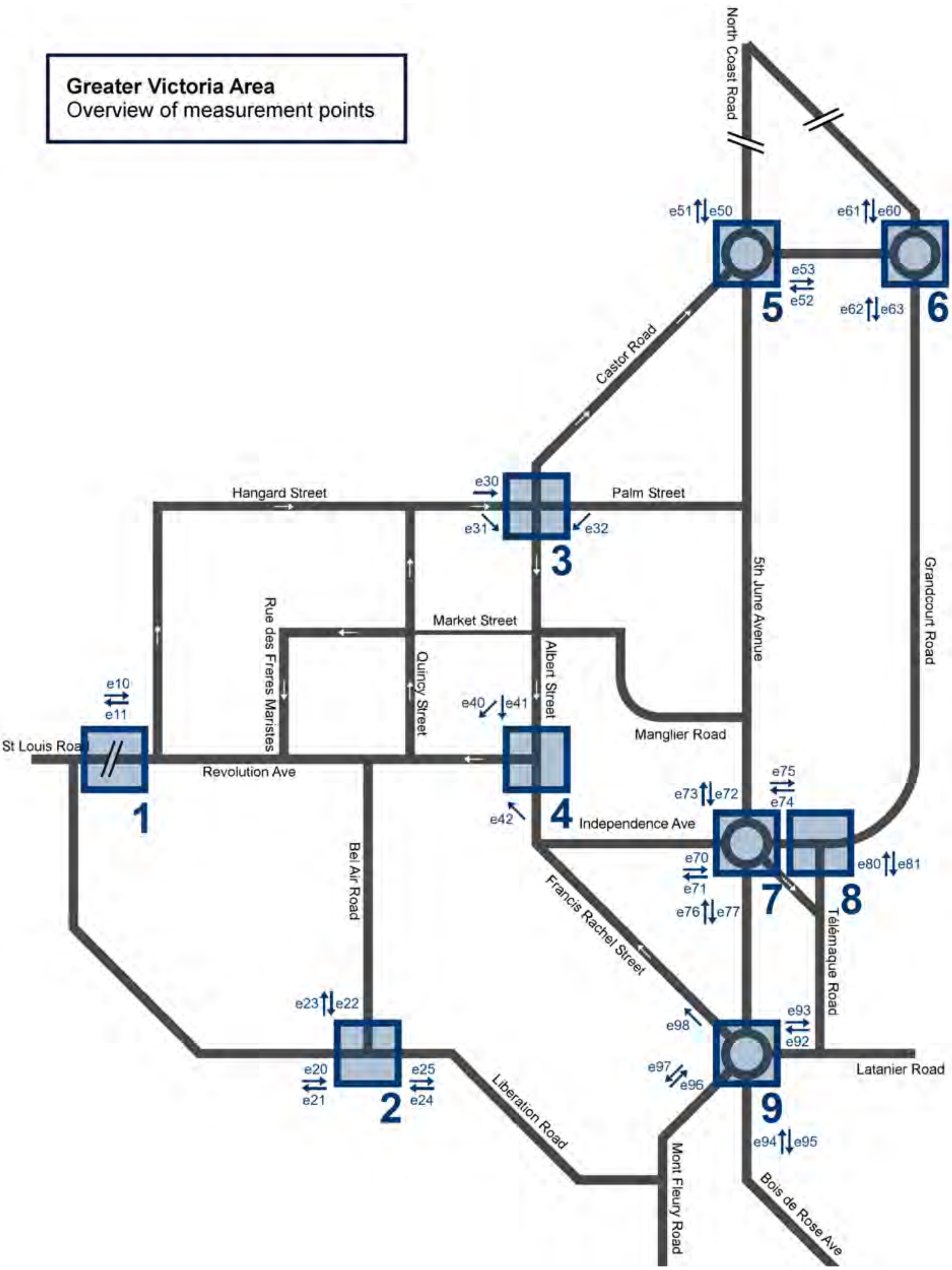


Table C.1: *Traffic count data (continues on next page).*

Traffic counts

A = Automated counting
M = Manual counting

1		Detector	A/M	Thu, 27.01.22 (07.20 - 07.35am) Cars 15min	Cars 60min	Trucks 15min	Trucks 60min	Total 15min	Total 60min	A/M	Wed, 02.02.22 (07.30 - 07.45am) Cars 15min	Cars 60min	Trucks 15min	Trucks 60min	Total 15min	Total 60min	Average Cars 60min	Average Trucks 60min	Average Total 60min	St.Dev
St Louis Road	EB	e10	M	200	800	8	32	208	832	M	173	692	5	20	178	712	746	26	772	60
St Louis Road	WB	e11	M	106	424	4	16	110	440	M	96	384	5	20	101	404	404	18	422	18

2		Detector	A/M	Thu, 27.01.22 (07.40 - 07.55am) Cars 15min	Cars 60min	Trucks 15min	Trucks 60min	Total 15min	Total 60min	A/M	Wed, 02.02.22 (07.30 - 07.45am) Cars 15min	Cars 60min	Trucks 15min	Trucks 60min	Total 15min	Total 60min	Average Cars 60min	Average Trucks 60min	Average Total 60min	St.Dev
Bel Air Rd West	EB	e20	M	162	648	2	8	164	656	M	142	568	3	12	145	580	608	10	618	38
Bel Air Rd West	WB	e21	M	44	176	2	8	46	184	M	39	156	3	12	42	168	166	10	176	8
Bel Air Rd North	NB	e23	M	81	324	3	12	84	336	M	80	320	1	4	81	324	322	8	330	6
Bel Air Rd North	SB	e22	M	85	340	1	4	86	344	M	69	276	3	12	72	288	308	8	316	28
Liberation Road	EB	e25	M	174	696	0	0	174	696	M	148	592	4	16	152	608	644	8	652	44
Liberation Road	WB	e24	M	58	232	2	8	60	240	M	53	212	4	16	57	228	222	12	234	6

3		Detector	A/M	Tue, 25.01.22 (07.50 - 08.05am) Cars 15min	Cars 60min	Trucks 15min	Trucks 60min	Total 15min	Total 60min	A/M	Tue, 01.02.22 (07.50 - 08.05am) Cars 15min	Cars 60min	Trucks 15min	Trucks 60min	Total 15min	Total 60min	Average Cars 60min	Average Trucks 60min	Average Total 60min	St.Dev
Olivier Maradan Street	EB	e30	M	125	500	4	16	129	516	A	157	628	6	24	163	652	564	20	584	68
Olivier Maradan Street	SB	e31	M	230	920	4	16	234	936	M	219	876	3	12	222	888	898	14	912	24
Palm Street	SB	e32	M	128	512	7	28	135	540	M	140	560	5	20	145	580	536	24	560	20

4		Detector	A/M	Tue, 25.01.22 (07.20 - 07.35am) Cars 15min	Cars 60min	Trucks 15min	Trucks 60min	Total 15min	Total 60min	A/M	Mon, 31.01.22 (07.50 - 08.05am) Cars 15min	Cars 60min	Trucks 15min	Trucks 60min	Total 15min	Total 60min	Average Cars 60min	Average Trucks 60min	Average Total 60min	St.Dev
Albert Street North	SB	e41	A	180	720	0	0	180	720	A	191	764	1	4	192	768	742	2	**744**	24
Albert Street North	WB	e40	M	89	356	7	28	96	384	M	109	436	5	20	114	456	396	24	**420**	36
Albert Street South	WB	e42	M	121	484	5	20	126	504	M	133	532	3	12	136	544	508	16	**524**	20

5		Detector	A/M	Wed, 26.01.22 (07.30 - 07.45am) Cars 15min	Cars 60min	Trucks 15min	Trucks 60min	Total 15min	Total 60min	A/M	Tue, 01.02.22 (07.25 - 07.40am) Cars 15min	Cars 60min	Trucks 15min	Trucks 60min	Total 15min	Total 60min	Average Cars 60min	Average Trucks 60min	Average Total 60min	St.Dev
North Coast Road	NB	e51	A	108	432	7	28	115	460	M	148	592	4	16	152	608	512	22	534	74
North Coast Road	SB	e50	A	205	820	2	8	207	828	M	182	728	1	4	183	732	774	6	780	48
Dam	EB	e53	M	172	688	13	52	185	740	M	185	740	14	56	199	796	714	54	768	28
Dam	WB	e52	M	177	708	7	28	184	736	M	194	776	7	28	201	804	742	28	770	34

6			A/M	Wed, 26.01.22 (07.30 - 07.45am) Cars		Trucks		Total		A/M	Tue, 01.02.22 (07.25 - 07.40am) Cars		Trucks		Total		Average Cars	Trucks	Total	St.Dev
				15min	60min	15min	60min	15min	60min		15min	60min	15min	60min	15min	60min	60min	60min	60min	
Ile Perseverace	NB	e61	A	195	780	12	48	207	828	M	189	756	15	60	204	816	768	54	822	6
Ile Perseverace	SB	e60	A	306	1224	8	32	314	1256	M	293	1172	9	36	302	1208	1198	34	1232	24
Grandcourt Road	NB	e62	M	146	584	2	8	148	592	M	133	532	3	12	136	544	558	10	568	24
Grandcourt Road	SB	e63	M	212	848	6	24	218	872	M	209	836	9	36	218	872	842	30	872	0

7			A/M	Mon, 24.01.22 (07.20 - 08.10am) Cars		Trucks		Total		A/M	Thu, 27.01.22 (08.00 - 08.15am) Cars		Trucks		Total		Average Cars	Trucks	Total	St.Dev
				15min	60min	15min	60min	15min	60min		15min	60min	15min	60min	15min	60min	60min	60min	60min	
5th June Ave North	NB	e73	M	145	580	9	36	154	616	M	157	628	11	44	168	672	604	40	644	28
5th June Ave North	SB	e72	A	214	856	20	80	234	936	M	218	872	13	52	231	924	864	66	930	6
5th June Ave South	NB	e76	M	187	748	13	52	200	800	M	192	768	13	52	205	820	758	52	810	10
5th June Ave South	SB	e77	M	362	1448	17	68	379	1516	M	352	1408	13	52	365	1460	1428	60	1488	28
Independence Ave	EB	e70	M	221	884	9	36	230	920	M	245	980	7	28	252	1008	932	32	964	44
Independence Ave	WB	e71	M	91	364	3	12	94	376	M	89	356	1	4	90	360	360	8	368	8
Grandcourt Road	EB	e75	A	125	500	1	4	126	504	M	133	532	2	8	135	540	516	6	522	18
Grandcourt Road	WB	e74	A	111	444	7	28	118	472	M	111	444	4	16	115	460	444	22	466	6

8			A/M	Mon, 24.01.22 (07.20 - 08.10am) Cars		Trucks		Total		A/M	Thu, 27.01.22 (08.00 - 08.15am) Cars		Trucks		Total		Average Cars	Trucks	Total	St.Dev
				15min	60min	15min	60min	15min	60min		15min	60min	15min	60min	15min	60min	60min	60min	60min	
Télémaque Road	NB	e80	M	75	300	2	8	77	308	M	79	316	4	16	83	332	308	12	320	12
Télémaque Road	SB	e81	M	99	396	5	20	104	416	M	85	340	1	4	86	344	368	12	380	36

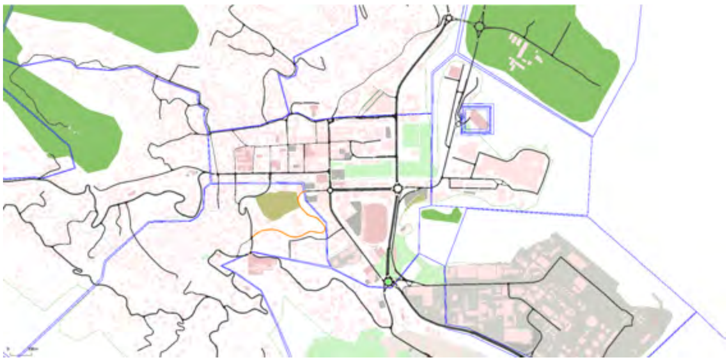
9			A/M	Tue, 25.01.22 (07.20 - 07:35am) Cars		Trucks		Total		A/M	Thu, 03.02.22 (7.30 - 7.45am) Cars		Trucks		Total		Average Cars	Trucks	Total	St.Dev
				15min	60min	15min	60min	15min	60min		15min	60min	15min	60min	15min	60min	60min	60min	60min	
Francis Raquel Street	NB	e98	M	167	668	3	12	170	680	M	183	732	6	24	189	756	700	18	718	38
Latanier Road	EB	e93	M	88	352	1	4	89	356	M	97	388	1	4	98	392	370	4	374	18
Latanier Road	WB	e92	M	37	148	0	0	37	148	M	32	128	1	4	33	132	138	2	140	8
Bois du Rose Highway	NB	e94	M	266	1064	8	32	274	1096	M	333	1332	12	48	345	1380	1198	40	1238	142
Bois du Rose Highway	SB	e95	M	275	1100	5	20	280	1120	M	247	988	6	24	253	1012	1044	22	1066	54
Mt Fleury Road	NB	e96	M	200	800	11	44	211	844	M	180	720	17	68	197	788	760	56	816	28
Mt Fleury Road	SB	e97	M	151	604	12	48	163	652	M	171	684	15	60	186	744	644	54	698	46

D Additional Model Use

D.1 Model plots

Figure D.1: *Vehicle density in the GVA during the MPH, modelled in the Mahe Simulation.*

Figure D.2: *Screenshots form the Mahé Simulation.*



1 *Overview of the Greater Victoria Area in the Mahé Simulation*

2 *Traffic light at intersection Palm St / 5th June Ave*

3 *Independence roundabout*

4 *Exit bus terminal at 5th June Ave*

D.2 Use cases

Table D.1: *Examples of suitable and unsuitable case of application.*

Suitable case	Unsuitable case
Checking efficiency of a new intersection design	Evaluating the impact of a road pricing policy
Changing the speed limits	Doubling all bus frequencies
Assessing the impact of building a new shopping mall[a]	Building cycling paths along every major road
Building a new bypass road [a]	Quantifying the additionally generated traffic due to an new bypass road

[a] Additional (induced) demand must be added manually

E Case Study

Figure E.1: *Relative Speed during the MPH on each edge within the city center of Victoria in the reference scenario. Relative speed is defined as the average driven speed divided by the speed limit on this edge. The color bar spans from red (presumably congested) to green (presumably uncongested).*

Figure E.2: *Relative Speed during the MPH on each edge within the city center of Victoria. Relative speed is defined as the average driven speed divided by the speed limit on this edge. The color bar spans from red (presumably congested) to green (presumably uncongested).*

1 *Scenario 1*

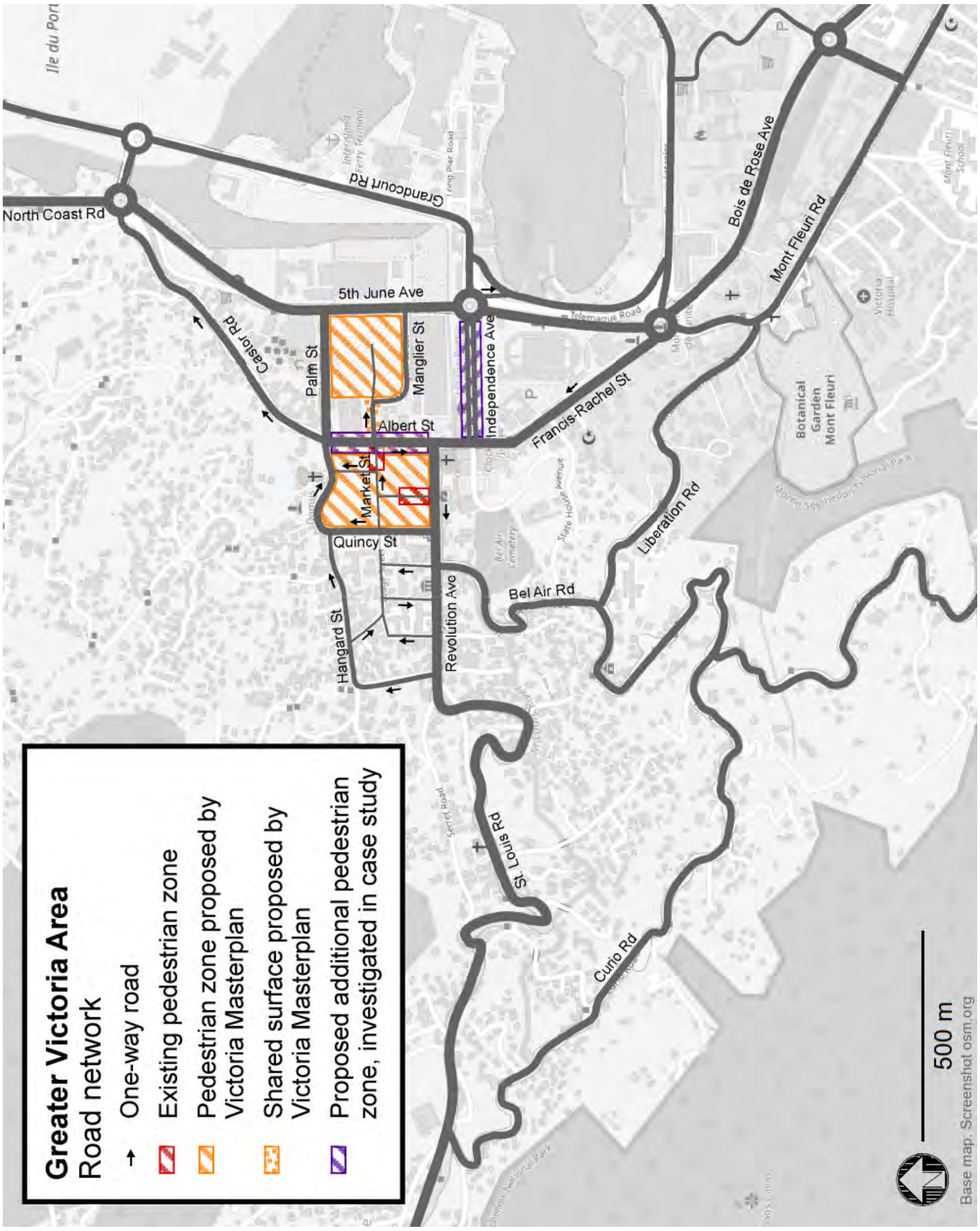
2 *Scenario 2*

Figure E.3: *Relative Speed during the MPH on each edge within the city center of Victoria. Relative speed is defined as the average driven speed divided by the speed limit on this edge. The color bar spans from red (presumably congested) to green (presumably uncongested).*

1 *Scenario 3*

2 *Scenario 4*

Figure E.4: *Map of the inner city of Victoria, with all relevant streets and different pedestrian zone extents.*



F SUMO Guide

This guide is aimed to walk new users of SUMO through the first steps to successfully working with Mahé's traffic model. It bases on the SUMO 1.12.0, released in January 2022. If the guide is not clear enough or unexpected difficulties arise, the following bodies can be consulted:

- SUMO User Documentation (Alvarez Lopez *et al.*, 2021) under:
  `https://sumo.dlr.de/docs/`
- Search for your issue in the SUMO GitHub repository under:
  `https://github.com/eclipse/sumo/issues`
- Subscribe to the SUMO user mailing list where you can ask questions:
  `https://www.eclipse.org/sumo/contact/`

F.1 Download and installation

To work efficiently with SUMO, three tools must be installed on the computer.

SUMO In the following, only the installation on Windows OS is described. Installations for Linux and macOS are also available, but are not recommended as not all parts of the simulation may run correctly on these systems. The SUMO suite can be downloaded from `https://sumo.dlr.de/docs/Downloads.php`. Please download the latest 64-bit release with all extras. Only the "extra" version contains additional licenses which are necessary to work with elevation information and allow for other important tools used in the Mahé traffic model. The development of SUMO is very dynamic and new functions or fixes are implemented daily. Therefore, it can also make sense to download the latest development "extra" version instead of the last release. (`https://sumo.dlr.de/docs/Downloads.php#nightly_snapshots`). By downloading the zip-package, no installation is needed. The package can simply be extracted to the desired file location.

For convenience, environmental variables should be defined. Please follow the instructions of the SUMO Documentation here: `https://sumo.dlr.de/docs/Basics/Basic_Computer_Skills.html#configuring_path_settings`

Text editor All simulation files are written in XML format. In some cases, it is necessary to edit these files manually. XML files can be written and revised in every text editor tool. Even most browsers and the preinstalled text editor (Notepad on Windows) can be used for that. Still, it is worth the effort to install a more powerful text editor. A widely used freeware is Notepad++ (Download: `https://notepad-plus-plus.org/downloads/`). After opening an XML file, XML can be selected under the "Language" tab, making the file much easier to read.

Python Many tools of the SUMO suite are written in Python (Van Rossum and Drake, 2009). Hence, installing Python is a must. It is suggested to download the Anaconda distribution platform (`https://www.anaconda.com/products/individual`). This facilitates working with Python. However, a stand-alone Python 3 release is sufficient for working with SUMO.

F.2 Working with the Command Prompt

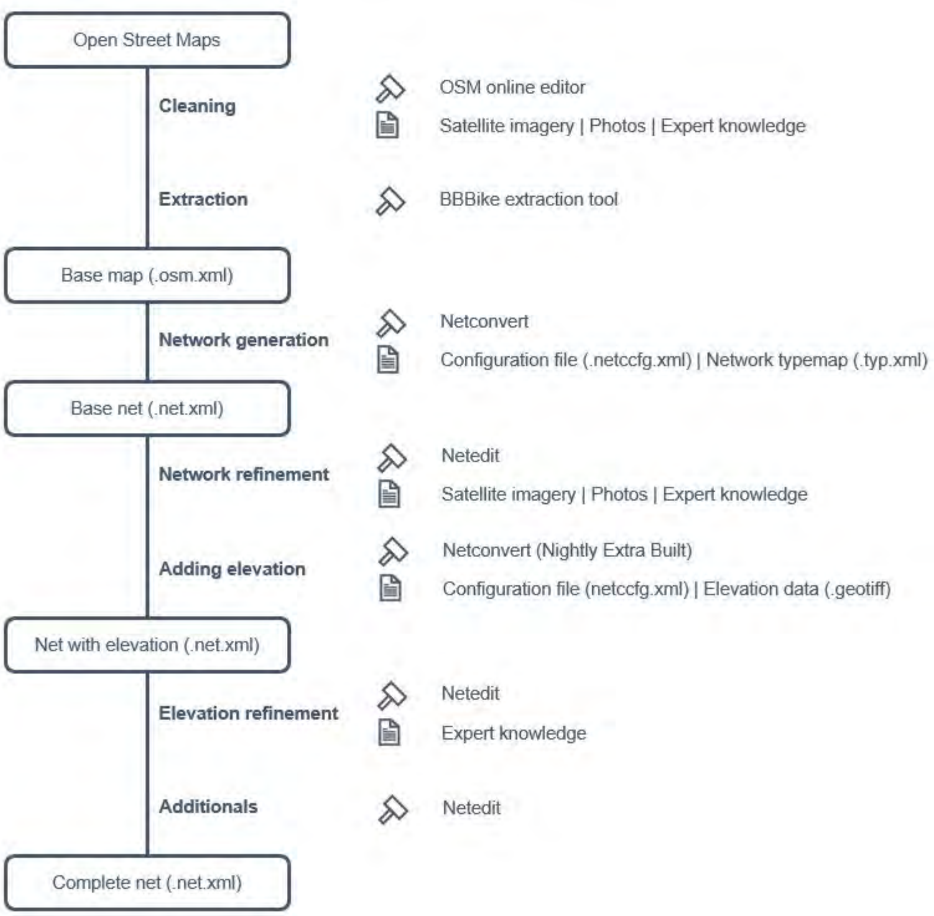
Section 1.3 shows a short overview of the structure of SUMO. Many of its tools are command-line applications. Meaning they don't have a Graphical User Interface (GUI) and have to be controlled over the Command Prompt. The Command Prompt is also known under various other names, such as terminal, cmd, shell, or command-line interpreter. Under Windows, the Command Prompt can be accessed by searching for "cmd" or running it directly ($Windows + R \rightarrow cmd$). Familiarize yourself with navigation through the directory and the notation of the Command Prompt before starting to work with SUMO. The easiest way to do so might be to watch a short YouTube tutorial.

F.3 Network editing

Fig. F.1 shows all steps from the raw data to the finished network. All steps are explained in greater detail below. These steps are already completed for the Mahé traffic simulation. They only have to be repeated to create a new model from scratch. For minor changes, only the last refinement step can be repeated.

Cleaning Open Street Maps (OSM) is a powerful open data platform for maps. Information is gathered by volunteers. The data quality of the map of Seychelles is very good. Often it was found to be better up to date than MHILT WebGIS (2021) or Google Maps (Google, 2022). The preliminary cleaning of the network on OSM has the advantage that edits are instantly available to the public. However, it also has to be checked carefully because quality checks of

Figure F.1: *Working steps to build a network based on Open Street Maps*



edited network parts are not ensured. OSM provides an intuitive and straightforward interface for map editing. Make sure only to map the existing network state.

Extraction Extraction of OSM data can be done by several tools. For extensive networks, such as Mahé, BBBike (Schneider and Rezic, 2013) is an optimal tool. It can be accessed under `https://extract.bbbike.org/`.

- Select the desired map excerpt
- Download the data in the "OSM XML" format
- Unzip the file
- Add the file extension ".xml" to the OSM file to make sure that the file is handled correctly in later stages
- Important: It can take up to a week until edits on OSM are included in the BBBike database!

Another possibility is to use the OSM Web Wizard. This python tool comes along with the

SUMO suite. It is easy to use and optimal to extract small size networks. Network changes on the map are instantly included in the generated network. However, the OSM Web Wizard is not well suited for extracting networks of the size of Mahé.

Network generation The XML file has to be reshaped to a format that is compatible with SUMO. This conversion is done with Netconvert, a tool of the SUMO suite. It offers a vast amount of parameters to configure the conversion. But they only have to be changed if a systemic problem in the created network occurs. All parameters can be stored in a XML configuration file. The used configuration can be found in Appendix A. Such configuration files exist all major tools of the SUMO suite and use all the same syntax. Use Notepad++ for editing the XML configuration files. The resulting network file is called BASENET.net.xml.

Netedit To learn how to work with Netedit, work through the official SUMO Quickstart tutorial, which you can find here: `https://sumo.dlr.de/docs/Tutorials/quick_start.html`.

More in-depth information about the possibilities of Netedit are provided here: `https://sumo.dlr.de/docs/Netedit/index.html`.

Network refinement The network has to be adjusted according to your needs in an iterative process. Read Section 3.2.1 to understand how elevation data can be added, and the network files are refined. Depending on the project and the aim of the simulation, more or less time should be invested in refining the network.

Additionals As the name suggests, additionals are not mandatory elements of the simulation. However, they can provide valuable additional information and increase the comprehensibility of the model. On the one hand, particular elements in the network, such as bus stops or traffic detectors, are added as additionals. On the other hand, additional map elements such as houses or land-use types can be stored to facilitate orientation in the simulation. While objects like bus stop or detector positions can easily be created in Netedit or imported from OSM, the landscape and buildings must be extracted from the OSM file by polyconvert. Polyconvert is command-line application of the SUMO package. You can find an example configuration for polyconvert in Appendix A. The typemap (typemap_polyconvert.typ.xml) defines the appearance of various elements. You can change the colors of different element types by changing the typemap and re-running the application.

The Mahé traffic simulation also includes a file representing the TAZ boundaries as polygons. These polygons are only for better orientation but don't have an actual impact on the simulation.

F.4 Modeling traffic demand

Modeling the traffic demand the second major part of building a traffic model. In the Mahé traffic simulation, the demand is composed of three time periods (see Section 3.2.2). The data were prepared in the following steps.

Definition of Traffic Assignment Zones The existing OD matrix lists relations between TAZs. These TAZs are defined as polygons. Before applying the demand, we have to make sure that all network elements are added to the corresponding TAZ, the Python script edgesInDistricts.py from the SUMO toolbox should be used after editing the network. The syntax for running the Python script looks similar to the following:

```
python edgesInDistricts.py -n Network.net.xml -t TAZ.xml -w -s
-o TAZ_Allocation.taz.xml
```

The file names and paths must be adjusted.

The just generated file must be filtered to avoid problems with invalid routes. Hence, we use the Python script filterDistricts.py to filter out links that restrict access for motorized traffic (e.g., pedestrian zones). The syntax follows the example below:

```
python filterdistricts.py -n Network.net.xml -t TAZ_Allocation.taz.xml
-o TAZ_Allocation_filtered.taz.xml -vclass="passenger"
```

Again, file names and paths must be adjusted accordingly.

Generating demand For updating the OD matrix after edits of the network, the batch-file "UpdateOD.bat" can be used. It automatically updates all trips following the network changes.

Creating demand from the raw data is possible with the R script ODTable2OFormat.R. However, this is only necessary for significant changes in the OD matrix. After running the script, "UpdateOD.bat" has to be executed as well.

F.5 Running the simulation

SUMO allows to adjust many parameters. All parameters were already adjusted for the Mahe traffic simulation. However, they can be changed by editing the Mahe_Simulation.sumocfg file. A list with descriptions to every parameter is provided in the Alvarez Lopez *et al.* (2021): `https://sumo.dlr.de/docs/sumo.html`

The easiest way to start the simulation is by using the "Start_Mahe_Simualtion.bat" file.