CHALMERS
UNIVERSITY OF TECHNOLOGY

A performance analysis of a congested multimodal intersection using VISSIM

A case study of Åkareplatsen, Göteborg

Master's thesis in Infrastructure and Environmental Engineering

EVELINA SKANTZ, EMMA TURESSON

Department of Architecture and Civil Engineering
CHALMERS UNIVERSITY OF TECHNOLOGY
Gothenburg, Sweden 2024
www.chalmers.se

Master's thesis 2024

A performance analysis of a congested multimodal intersection using VISSIM

A case study of Åkareplatsen, Göteborg

EVELINA SKANTZ, EMMA TURESSON

Department of Architecture and Civil Engineering
Division of Geology and Geotechnics
Chalmers University of Technology
Gothenburg, Sweden 2024

A performance analysis of a congested multimodal intersection using VISSIM
A case study of Åkareplatsen, Göteborg
EVELINA SKANTZ, EMMA TURESSON

Supervisor: Alexander Hörnquist, Trivector Traffic
Supervisor: Omkar Parishwad, Division of Geology and Geotechnics
Examiner: Kun Gao, Division of Geology and Geotechnics

Master's Thesis 2024
Department of Architecture and Civil Engineering
Division of Geology and Geotechnics
Chalmers University of Technology
SE-412 96 Gothenburg
Telephone +46 31 772 1000

Cover: A design proposal of Åkareplatsen constructed in the traffic microsimulation software VISSIM.

Typeset in LaTeX
Printed by Chalmers Reproservice
Gothenburg, Sweden 2024

A performance analysis of a congested multimodal intersection using VISSIM
A case study of Åkareplatsen, Göteborg
EVELINA SKANTZ, EMMA TURESSON
Department of Architecture and Civil Engineering
Chalmers University of Technology

Abstract

Åkareplatsen is a complex intersection in the city centre of Gothenburg, Sweden's second-largest city, that is utilised by buses, trams, cars, trucks, bicyclists and pedestrians. Since the rebuilding in 2018, Åkareplatsen has been struck by recurring congestion, gridlocks and accidents. To study this roundabout with tram-crossing traffic, a model created in VISSIM was analysed, calibrated and validated using 2024 traffic data. This study is limited to what is possible wihtin the bounds of VISSIM. The method primarily consisted of collecting traffic data in the field and official data, model calibration and validation, interviews, suggestions for improvements, and a stress test. To capture the stochastic variability of the model simulations, the simulation time was set to 3 hours in 15-minute intervals and was repeated in 10 runs. Queue length and travel time were the measures of effectiveness (MOEs) used to compare the model versions and reality during maximum traffic flow. The deviation between the simulation results and the field measurements was evaluated visually from video recordings and statistically using Root Mean Square Error (RMSE). The final model calibration was able to capture realistic diving behaviour and deviated by 33 minutes and 49 seconds in travel time and 104 m in queue length, an improvement compared to the original model. During validation, it was found that the calibrated model is about equal at estimating travel time and queue length during calmer and more dense traffic states. From the simulation results of suggestions for improvements, removing signal heads for tram-crossing traffic and re-routing some of the bus lines greatly reduced queues and the number of gridlocks. The stress test with a higher public density load shows that the suggested design can manage a 50 % increase in public transportation density without extensive gridlocks forming. Realistic traffic models are time-consuming to build, require a lot of data, and do not directly reflect reality. Nonetheless, they can be beneficially used to anticipate traffic-related problems, avoid potential damages they cause, and provide citizens with their need for mobility.

Keywords: Åkareplatsen, multimodal intersection, microsimulation, VISSIM, calibration, validation, RMSE, design improvements

Acknowledgements

We would like to express our gratitude to all those who participated in the making of this thesis. First, we would like to thank all employees at Trivector Traffic in Gothenburg for their cooperation and kind reception. A special thanks to Alexander Hörnquist at Trivector for providing us with invaluable supervision and guidance, and for teaching us all he knows about VISSIM. We would also like to recognise our co-supervisor at Chalmers University of Technology, Omkar Parishwad, for valuable input and feedback on our thesis. Additionally, we would like to acknowledge all those who made this thesis possible regarding data collection: Tina Erenstedt at the architecture firm Semrén och Månsson for assisting us in accessing their balcony with a view of Åkareplatsen, in which the observations took place: to all interviewees (Claes Johansson, Magnus Lorentzon, Mimmi Mickelsen, and Christoffer Liljebjer) for providing us with useful knowledge and their point of views on the study area. Finally, we would like to emphasise our gratitude towards Lovisa Borgström at Västtrafik for supplying us with all kinds of inaccessible data we requested and to Kun Gao at Chalmers University of Technology for being our examiner.

Evelina Skantz & Emma Turesson, Gothenburg, June 2024

List of Acronyms

Below is the list of acronyms that have been used throughout this thesis listed in alphabetical order:

am	morning
avg	average
bic	bicycle
CS	Central Station
LF	line frequency
max	maximum
MOEs	Measure of Effectiveness
N	north
OD	origin-destination
P	Polhemsplatsen
Post	Hotel Post
pm	afternoon
QL	Queue Length
RMSE	Root Mean Square Error
RSA	Reduced Speed Areas
S	south
TT	Travel Time
VIS	VISSIM
W	west
ÅTC	Åkareplatsen Travel Center

Contents

List of Figures

List of Tables

1

Introduction

The human need to achieve certain actions and perform chores at various physical locations at different times requires the possibility of movement. Mobility affects these essential and non-essential actions and chores (Barceló, 2010). Commoners depend on transportation to find themselves at work, school, stores, and activities in mundane life (Berg and Ihlström, 2019). In the age of urbanisation, where more residents choose to settle in urban areas, the stress increases on metropolitan transportation systems and might result in traffic congestion. With increasing urbanisation, the demand on metropolitan transportation systems grows, often resulting in significant traffic congestion. The side effects of congestion are a decline in vehicle velocity, longer travel time, and higher fuel consumption, leading to more emission of health-deteriorating pollutants and higher operational costs (United Nations, 2004).

Besides these consequences, congestion is quadratically correlated with deaths related to traffic accidents (Albalate and Fageda, 2021). While the congestion problem steadily increases in urban areas, political actions towards achieving safety on the roads are simultaneously gaining more attention. One such action is the so-called Vision Zero, first introduced in Sweden in the 1990s (Belin et al., 1997). Vision Zero is a strategy that aims to eliminate all traffic fatalities and severe injuries and ensure safe mobility for all.

A congested area in Gothenburg, Sweden's second-largest city, is Åkareplatsen, located between Gothenburg Central Station and Gamla Ullevi Stadium. It is an important public transit hub that consists of a travel centre and an intersection utilised by buses, trams, and private transportation, including pedestrians and bicyclists. The intersection is complex and has been considered problematic because of reoccurring congestion and accidents. The complexity has required the traffic signals for public transportation to occasionally be replaced with traffic directors. The intersection was rebuilt in 2018, and parallel to this, a model in the microscopic traffic simulation software PTV VISSIM was created. However, Åkareplatsen is still poorly functioning and about to be rebuilt once more.

1.1 Aim

This study aims to analyse, calibrate, and validate the existing VISSIM model of Åkareplatsen, Gothenburg. Model calibration involves adjusting the model parameters to better match observed data, while validation ensures that the model accurately represents real-world conditions. Site improvements will be suggested based on a performance analysis of the current design.

1.2 Research questions

The following questions will be answered consecutively to meet the aim of the study:

- What traffic-related problems arise with the current design, and why do they result in congestion?
- To what extent does the original model represent reality?
- How are the simulation results affected by changes in model parameters?
- What changes can potentially improve the traffic situation at Åkareplatsen?

1.3 Limitations

The study's primary constraint is the reliance on the VISSIM software for model simulations. The limitations of this software, which dictate the scope of the simulations, are detailed in Section 2.2.4.

The traffic situations during congested states are particularly relevant in this study. The time period of interest to simulate was weekday peak hours when congestion is most striking and significantly impacts public and private transportation. The data collection was limited to the morning peak hour (07:00-09:00) and afternoon peak hour (15:00-18:00), which are periods of significant congestion impacting public and private transportation.

The study exclusively considers the area of Åkareplatsen and nearby streets in terms of spatial limitations. Based on the maximum measured queue lengths with a margin, the spatial extent of the model, i.e., the street lengths, was set to include all queues in the model area. However, the streets of Åkerigatan (north) and Odinsgatan (east) were more or less out of the camera's view when recording traffic. Therefore, their queue formations were not accounted for when comparing model results to field data in the calibration and validation.

The consulting firm Ramboll created the existing VISSIM model on which this study is based. Henceforth, it is mainly referred to as the original model. Ramboll's input data has been preserved as far as possible. However, some modifications have been made to simplify the comparison with the adjusted and calibrated model of a smaller spatial extent. Details about this can be found in section 3.5. As all necessary files to change the signal coding, such as signal timing and phases, could not be accessed, analysis of and changes to these were limited.

This study did not consider all vehicle types and clustered some as one. For instance, private cars, taxis, and vans were all classified as cars. Larger vehicles, such as cars with trailers, garbage trucks, and buses not part of the Västtrafik fleet, were classified as trucks. E-scooters, mopeds, and electric wheelchairs were considered bicycles. Pedestrians walking with children or suitcases, using walkers or wheelchairs, were clustered. This study did not consider motorbikes and bicycles travelling on roads designated for cars or jaywalking pedestrians.

When modelling alternative designs to improve the traffic state at Åkareplatsen, the main focus is on environmental and safety factors. Most changes are relatively small and thereby require little effort to realise them. The economic factor is thereby indirectly accounted for, but no economic cost or benefit is calculated or further considered.

2

Background

2.1 Åkareplatsen

Åkareplatsen Travel Centre (ÅTC) for long-distance commuter buses opened in 2018 to temporarily relieve the traffic density at Nils Ericsson Terminal at the Central Station (Karlsson, 2023). This arrangement would last ten years during the construction of significant infrastructure projects near the terminal, including the West Link (Västlänken) and the Hisingen Bridge (Hisingsbron). See the location of Åkareplatsen in Figure 2.1, marked in red.

Figure 2.1: The location of Åkareplatsen in the city of Gothenburg. Modified in Google Maps.

The construction of the travel centre led to the reconstruction of nearby roads and the addition of a roundabout to the transportation infrastructure at Åkareplatsen. In this study, the case study area of Åkareplatsen includes the travel centre and its vicinity. Burggrevegatan, Åkerigatan, Odinsgatan, and Polhemsplatsen form the four legs of the roundabout, each playing a crucial role in the area's traffic dynamics. Stampgatan, located south of the roundabout, is also partially included in the study area. Figure 2.2 shows the connected streets around Åkareplatsen, highlighting the complexity of the intersection. The streets and the tram tracks, represented by the red lines, can be seen here.

Figure 2.2: Åkareplatsen and its vicinity. Retrieved from the municipal map service (karta.goteborg.se)

The roundabout and its entrances consist of only one vehicle lane, except for a dedicated right turn lane from Polhemsplatsen, for vehicles turning right onto Odinsgatan. The five relevant pedestrian crossings, two of which are signalized, are marked in yellow in Figure 2.3. Here, each origin or destination is named Central Station, KvarterETT, Scandic, ÅTC, and Hotel Post. The bike paths stretch from the north-east corner of the Hotel Post building, around ÅTC, across Polhemsplatsen and further to Odinsgatan or alongside Polhemsplatsen. In Figure 2.3, the bike paths are shown in red, and dedicated bus lanes in white.

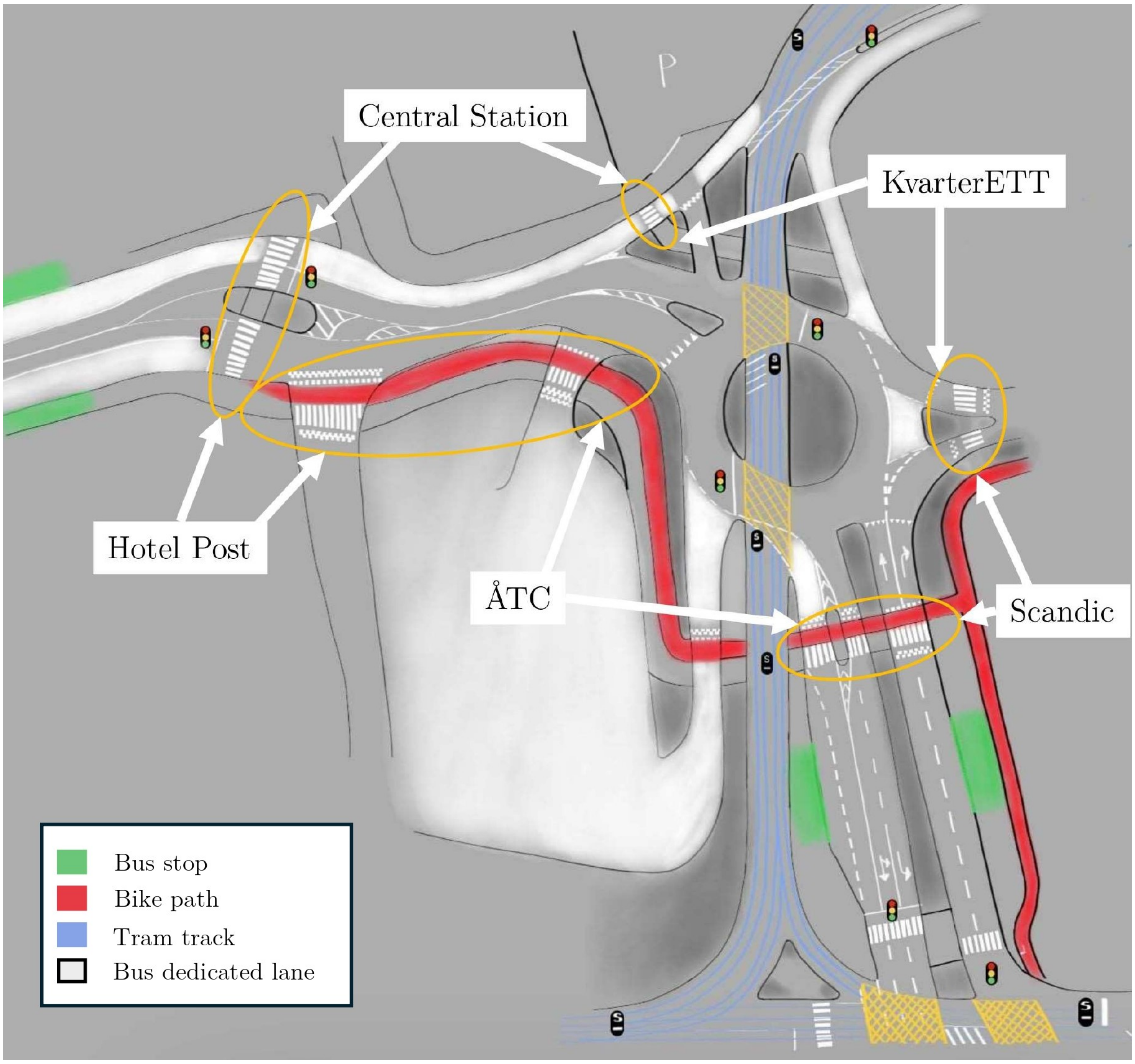

Figure 2.3: Pedestrian crossings, dedicated lanes and tracks, and bus stops. Created in Freeform

21 public transportation lines, including trams and buses for local and regional traffic, operate through Åkareplatsen. While most lines pass through, some dock for boarding and exiting passengers at the bus stops of Polhemsplatsen to the south, and the Central Station to the west. These bus stops are marked in green in Figure 2.3 above. Five more lines operate on Stampgatan without docking in the study area. 26 lines and 49 routes interact with the case study area on a weekday during peak hours.

Parallel to the redesign of Åkareplatsen, the consultancy firm Ramboll created a VISSIM model of the area to simulate traffic flows and queues (Sjöholm and Kryh, 2017). In this model, public- and private transportation, as well as pedestrians and bicyclists, were included. Their simulation results identified several possible problem areas with the design. For public transportation, expected areas of congestion were mainly centred around the roundabout and its connection to Burggrevegatan to the west (Sjöholm and Kryh, 2017). At capacity, there was a risk of queue formation at several locations. A queue forming around the roundabout could block traffic in several directions, including crossing tram traffic, causing a gridlock.

Additionally, if a queue formed at the bus terminal exit, it would block the bicycle and pedestrian paths. The tram priority along Stampgatan could lead to a queue forming at the roundabout to Burggrevegatan. The detected congestion area for private transportation was at the eastern leg at Odinsgatan rather than the expected, centred in and close to the roundabout.

Some evidence suggests that the traffic simulation results embodied the original model predictions about congestion. The new design of Åkareplatsen does not only imply accidents but also the risk of queueing and congestion. On the 4th of October 2018, the queue formations were so significant that several public transit users dismounted the vehicles and decided to walk instead (T. Andersson, 2018). Västtrafik, the public transportation agency in the Gothenburg region, had to redirect the traffic in and around Åkareplatsen and found no obvious explanation for the occurrence. This incident identifies the severe congestion issues and the necessity to improve the traffic situation.

In 2020, Åkareplatsen was the sixth most accident-prone area in Gothenburg (City of Gothenburg, 2021). Accidents, primarily involving buses and trams, significantly impact public transportation accessibility. On the 14th of April 2023, Göteborgs-Posten recorded a collision between a tram and a bus, resulting in a complete hold of the traffic flow in one direction (Ekström, 2023). On the 14th of September the same year, yet another accident occurred at Åkareplatsen, involving a tram and a taxi, hospitalising one victim and affecting the traffic for over half an hour during the morning rush hour (Ekström et al., 2023). On the 7th of November 2023, a tram collided with a taxi at Åkareplatsen, resulting in the brief redirection of several tram lines (Jonsson, 2023). A similar incident occurred not less than 20 days later (Sävenlund, 2023). In the most recent collisions on the 16th of April and the 7th of May 2024, both a bus and a tram collided, causing several lines to be redirected and greatly impacting the afternoon rush hour traffic (Fernholm and Söderqvist, 2024; J. Andersson, 2024). These frequent accidents underscore the need for a more efficient traffic management system.

2.2 Traffic simulation models

Traffic simulation tools can facilitate the study and allow us to predict the behaviour of the traffic system within a limited area (Wahlstedt et al., 2014). Their purpose is to depict reality to the best of their abilities and future situations that may arise. Traffic simulation software allows for assessing the behaviour of the traffic system in different scenarios and over time. These tools help in assessing the impact of different traffic loads and road designs on congestion and queue lengths.

Traffic systems can be modelled at micro-, meso-, or macroscopic scales. (Wahlstedt et al., 2014). Macroscopic traffic models are used to analyse overall traffic flows and relationships between speed, density, and volume. These models display the traffic network in relatively low resolution. Microscopic models, on the other hand, focus on individual vehicle movement. Mesoscopic models combine elements of both by considering groups of vehicles based on macroscopic principles.

Different parameters can control how traffic simulation models conduct the simulation (Wahlstedt et al., 2014). The time the simulation is updated depends on whether it is event-driven or time-driven. Event-driven models update the simulation when changes occur in the system, while time-driven models update it at predetermined time steps. An event-driven model is unsuited for a complex model design consisting of several transportation modes and entities due to the extensive required computing power. In these situations, time-driven models are the better option.

The simulation results differ depending on whether the model is deterministic or stochastic (Wahlstedt et al., 2014). Deterministic models produce the same results for the same input, making them suitable for scenarios with minimal variation. Stochastic models, which incorporate randomness, are better for capturing the variability of real-world traffic conditions as they generate slightly varying results. However, the user should consider the associated uncertainties in the result analysis. Microscopic simulation models are almost exclusively time-driven and stochastic.

2.2.1 VISSIM

Simulation software is recommended when modelling and analysing complex intersections consisting of traffic roundabouts, signals for pedestrian crossings, or other nearby junctions (Wahlstedt et al., 2014). Utilising microscopic simulation software is advisable when the simulation outcome requires a certain level of detail, which the macro- and meso simulations cannot fulfil. VISSIM is a commercial microscopic traffic flow simulation software developed by Planung Transport Verkher (PTV), widely used in Sweden for detailed traffic analysis (PTV, 2023; Wahlstedt et al., 2014).

VISSIM is built upon stochastic principles, updating at pre-determined time steps. It provides a high level of detail and allows for simultaneous analysis of public and private transportation (Fellendorf and Vortisch, 2010). The software can be used in a wide range of studies and settings. It is helpful in multimodal traffic simulations where cars, buses, trams, trucks, pedestrians and bicycles are included in the traffic system. The software allows for different road network designs and signal priorities for public transportation to be analysed and specialises in small geographical study areas, making it suitable for modelling and simulating the traffic at Åkareplatsen.

The software consists of three interdependent blocks that make up the modelled transportation system; see Figure 2.4 (Fellendorf and Vortisch, 2010). The first block includes physical infrastructure objects: roads, railways, parking lots, signs, and stops for public transportation. The second comprises private and public traffic, including volumes and routes. The third, traffic control, includes the technical systems and rules that affect traffic behaviour, such as traffic lights and rules for prioritisation. These blocks work together to create a comprehensive simulation of the transportation system.

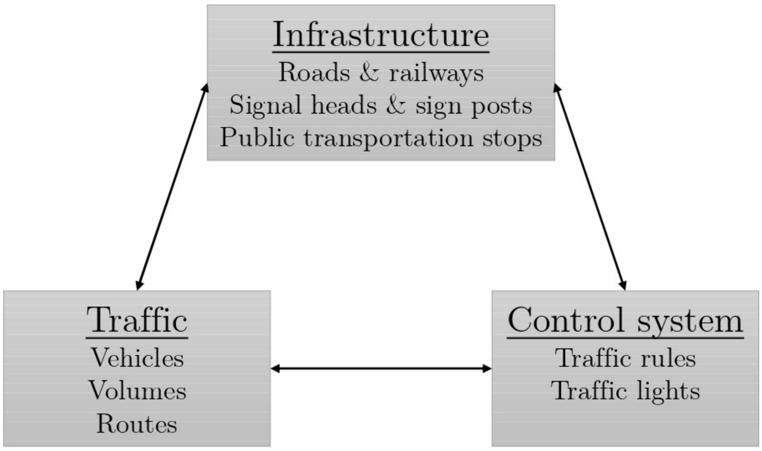

Figure 2.4: The building blocks of VISSIM. Figure modified from Fellendorf and Vortisch (2010)

The model output is the result of the simulation. The output can be in the form of an animation that visualises the traffic situation or presented as Measures Of Effectiveness (MOEs), such as queue length, delay, or travel time (Fellendorf and Vortisch, 2010). The output facilitates analyses of the study area, such as capacity analyses.

2.2.1.1 Basic network objects

The physical infrastructure of the traffic system includes roads and railways. Road networks comprise nodes, representing intersections, and links, representing road segments (Fellendorf and Vortisch, 2010). Links should define the number of lanes and lane width. Connectors connect links where the number of lanes increases or decreases. Vehicle input is where vehicles are generated, usually at the beginning of a link. Figure 2.5 shows an arbitrary roundabout with links (blue), connectors (pink), and vehicle input points (black). In this figure, the network is viewed in wireframe, showing a simplified layout.

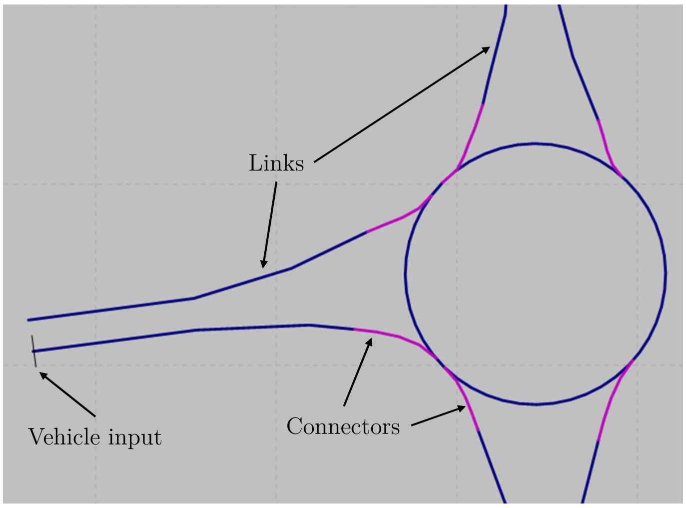

Figure 2.5: Links, connectors, and vehicle input in VISSIM

Traffic volume inputs in VISSIM can be exact or stochastic (PTV, 2023). Exact inputs generate a fixed number of vehicles, while stochastic inputs generate vehicles based on Poisson distribution.

Included in the software traffic block are public- and private transportation. These differ as flexible routes characterise private transportation and public transportation by fixed routes (Fellendorf and Vortisch, 2010). The vehicle types included in private transportation are both motorised and non-motorised, with the former including cars, motorcycles, and trucks and the latter including bicycles and pedestrians. The included vehicle types for public transportation are buses, trams and light rail vehicles.

Traffic volume and route choices can be put into the model by a matrix of trips from origins (rows) to destinations (columns), known as an OD-matrix (Barceló, 2010. The OD-matrix defines vehicle routing by mapping trips from origins to destinations within the study area (Fellendorf and Vortisch, 2010). In VISSIM, the OD-matrix defines the vehicle routing; see Figure 2.6 for an example of one origin (in purple) to three possible destinations (in turquoise).

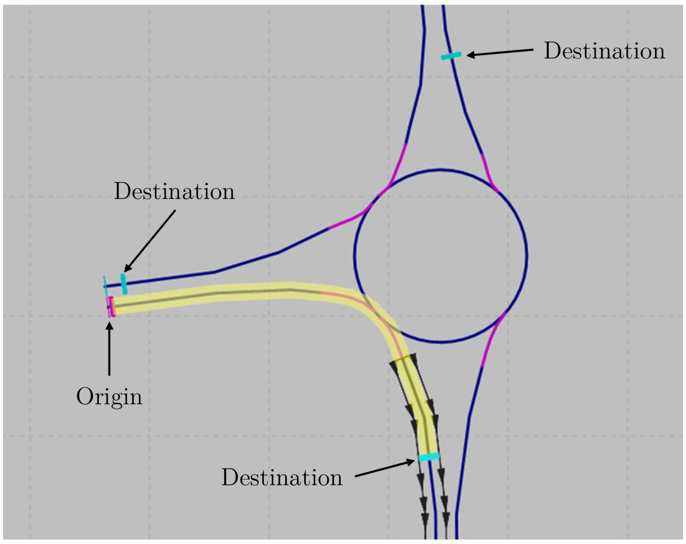

Figure 2.6: Vehicle routing in VISSIM

The control systems include the technical systems and rules that affect traffic behaviour at both unsignalised- and signalised intersections. At unsignalised intersections, merging or branching links, or pedestrian crossings in the network, priority rules or conflict areas can be used to define the right of way and avoid conflict between vehicles (PTV, 2023). Conflict areas are a practical choice due to their ease of interpretation and modification. These are automatically identified in VISSIM, and the prioritisation is managed manually. In Figure 2.7, a conflict area and prioritisation are illustrated in yellow, green and red. Yellow signifies passive prioritisation, green denotes the right of way (major flow), and red indicates giving way (minor flow).

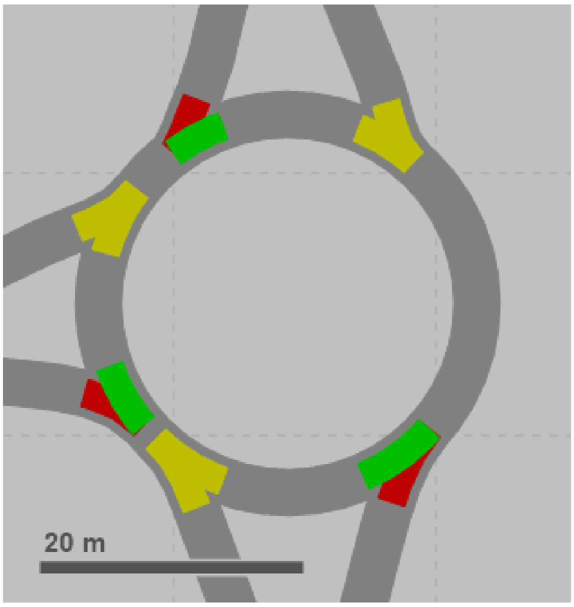

Figure 2.7: Conflict areas in VISSIM

There is also a fourth undefined alternative where all vehicles in the conflict zone can detect one another, unlike passive zones (PTV, 2023). For this alternative, the user sets the conditions for the right of way and giving way. These systems ensure realistic traffic behaviour by simulating right-of-way rules and preventing conflicts.

For each conflict area, there are options to allow or avoid blocking the minor (red) and major (green) flow for vehicles that cannot safely pass the conflict area in one go (PTV, 2023). *Avoid blocking minor flow* makes a share (0%-100%) of vehicles with the right of way to avoid entering the conflict area, and *avoid blocking major flow* make either 0% or 100% of yielding vehicles avoid the conflict area.

Priority rules may be used instead for merging or branching of links, as conflict areas can be insufficient in defining the right of way for the major flow. (PTV, 2023). Priority rules consist of a stop line (red) for the yielding vehicle and at least one conflict marker (green); see Figure 2.8.

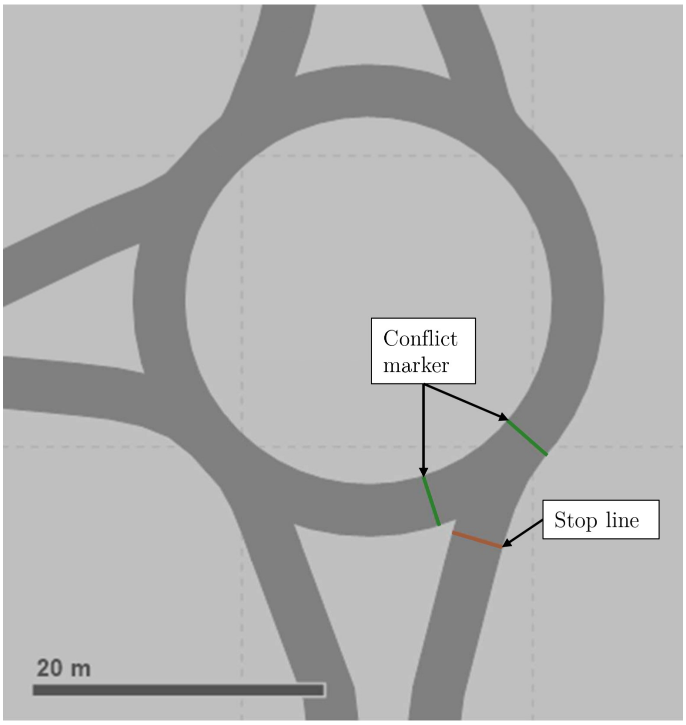

Figure 2.8: Priority rules in VISSIM

The minimum gap time and clearance are defined for each conflict marker. The gap time is the time it will take an upcoming vehicle to reach the conflict marker (default value of 3 s), and the clearance is the corresponding distance (default value of 5 m) (PTV, 2023). The time gap and the clearance control vehicles at the stop line (red) indicate that they should wait to proceed if there is insufficient space or time in the conflict area. Certain vehicle classes, such as cars, can be assigned to give way only to buses, for instance, at each stop line and conflict marker.

Signal settings at signalised intersections and pedestrian crossings define the right of way (PTV, 2023). The signals can be traffic actuated or fixed time. Detectors identify an approaching vehicle for traffic-actuated signal controls and activate the signal head to the linked signal controller. A push-button detector can be used for pedestrian crossings. The detector can link to different vehicle classes of private transportation and public transit lines. The user can define the range in space and time for the detection. In Figure 2.9, a detector (in blue) linked to a signalised crossing (signal heads in red) is displayed in an arbitrary four-way intersection.

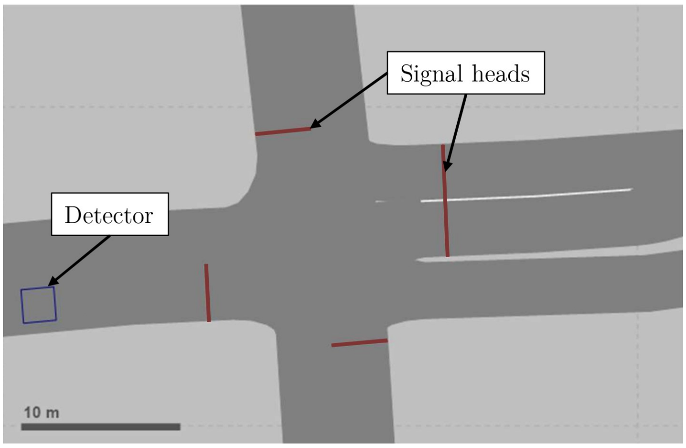

Figure 2.9: Detector and signal heads in VISSIM

These settings and detectors are useful at managing traffic at busy intersections like Åkareplatsen.

2.2.1.2 Traffic flow theory

In traffic flow theory, the interaction between vehicles is described by algorithms for the three phenomena: car-following, lane-changing, and gap acceptance, which all affect the possible speed and capacity of the road (Elefteriadou, 2014). Models used to simulate the traffic flow of vehicles in VISSIM are the car-following model and lane-changing model (PTV, 2023).

The car-following model in VISSIM is based on principles of driver's perception, first developed by Weidemann in 1974 (PTV, 2023). It includes physical and psychological conditions that affect driving behaviour and vehicle movement. According to this model, a driver has four behaviours: free driving, approaching, following and braking. The model describes the movement of the following vehicle as a function of the leading vehicle (Elefteriadou, 2014).

Lane-changing can be described in four steps: decision, lane choice, gap acceptance, and lane change (Elefteriadou, 2014). First, the decision to change lanes can be forced if the circumstances require it or voluntarily to improve the road position or enhance speed. Second, the decision of what lane to change to is performed. This is related to the third step of gap acceptance, as free space in another lane is needed to choose an appropriate lane. The gap is usually described as the distance between the front of the following vehicle and the back of the leading vehicle. Gap acceptance models are used to determine what size gap drivers consider acceptable in different situations. In the fourth and last step of the lane-changing process, the vehicle accelerates or decelerates to perform the change. Which factors play a role in a decision to change lanes is individual; therefore, the lane-changing decision differs depending on the driver.

2.2.1.3 Pedestrian modelling

Pedestrian traffic flows can be included in VISSIM by modelling pedestrians as vehicles or using the add-in software Viswalk (PTV, 2023). Links can be defined as pedestrian and have pedestrians or bicyclists as vehicle input.

In VISSIM, pedestrian walking patterns can be replicated in the car-following model by modifying parameters for pedestrian characteristics (Ishaque and Noland, 2009). In the car-following model, pedestrian trajectories are pre-calculated based on input data (PTV, 2023). As pedestrian characteristics and movement patterns differ from those of vehicles, it is argued that they cannot be captured by models for vehicles (Fellendorf and Vortisch, 2010). In comparison to vehicles that move in lanes, pedestrians can move in several directions within an area. The pedestrian movement in Viswalk is based on the social force model (PTV, 2023). It includes the movement towards the destination, which is impacted by other pedestrians and objects, such as walls. In the social force model, pedestrians move more realistically, and their trajectories result from the simulation.

2.2.2 Model calibration and validation

Traffic simulation models deviate from reality to varying degrees but can be improved through calibration and validation processes (Barceló, 2010). In order to use the model results as a basis in traffic planning, it is imperative to ensure that the model is adequate in simulating actual traffic states (Park and Schneeberger, 2003). Actual data of the studied system is needed to calibrate and validate the model. The availability of actual data affects how the calibration and validation processes are conducted (Wahlstedt et al., 2014).

In the calibration process, model parameters are adjusted for the model to better represent the system under study (Wahlstedt et al., 2014). Microscopic simulation models have various model parameters that help depict human driving behaviour or traffic flow (Park and Qi, 2005). Since many parameters exist in the model build-up, a selection can be chosen for the calibration process (Hollander and Liu, 2008). In VISSIM, the car-following model (Wiedemann 99) is represented by 10 model parameters which regulate the desired distance, speed or behaviour in various situations that can be changed in the calibration (PTV, 2023). Hollander and Liu (2008) suggest that if the number of parameters is around five, manual calibration might be suitable. The parameters are iteratively modified until the simulation results agree sufficiently with field data from traffic measurements. The error between simulated and measured values can be measured differently, such as by absolute values, which give the same weight to all errors, or squared difference values, which give a higher weight to more significant errors. Stochastic models are recommended to have their errors represented by the squared error (SE), root mean squared error (RMSE), or root mean squared normalised error (RMSNE). Once the model is considered sufficient by the calibration process, a validation process is initiated (Wahlstedt et al., 2014).

Validation is a process used to determine whether the model can replicate reality (Barceló, 2010). During this process, the model improves its predictions of the traffic system using data other than that in the calibration. (Wahlstedt et al., 2014). Validation can be performed in various ways, including visual, statistical, and indirect statistical validation (Hollander and Liu, 2008). In validating the model, it is adjusted until the level of deviance between simulated data and field data is considered acceptable (Barceló, 2010). A verified model can simulate road design and traffic load scenarios and determine the most favourable outcome (Wahlstedt et al., 2014).

2.2.3 Performance measures of traffic facilities (MOEs)

Determining the performance of a transportation facility or road segment can be done in several ways, and some measurements better represent the performance of certain facilities. Capacity is a measurement suitable for more extensive facilities, such as highways, to describe the amount of traffic it can bear before speed is affected or congestion-like conditions occur (Elefteriadou, 2014). Other more suitable performance measures for urban multimodal transportation facilities might be travel time, delay and queue length. Additional suitable performance measures for signalised intersections are the demand-to-capacity ratio and Level of Service (LOS). The travel time between an origin and a destination is calculated by the road segment length and the average speed on that road segment (Elefteriadou, 2014). The travel time between two locations in the road network can be evaluated in VISSIM by using *Vehicle Travel Times* (PTV, 2023). Travel time measurements are placed at the starting and finishing positions of interest, and the results are presented as average travel time in seconds for each time interval in the simulation.

The queue length describes the number of vehicles waiting to proceed with their obstructed movement (Elefteriadou, 2014). Queues affect the traffic flow downstream of the location of the queue and can, therefore, be an effective measure of performance. The point at which a vehicle is considered part of a queue varies. In VISSIM, the default setting is that a vehicle is considered as queuing at a speed of less than 5 km/h, until it accelerates to more than 10 km/h (PTV, 2023). The mean and maximum queue length, in meters, can be obtained in VISSIM by placing *Queue Counters* at the positions of interest in the road network. All upstream vehicles that meet the queuing conditions partake in the queue length until they detect another queue counter or reach the maximum defined queue length. For queue counters, the clearance, i.e., the maximum distance between queuing vehicles while still being considered a continuous queue, and the maximum queue length should be defined. The default values are 20 m and 500 m, respectively.

2.2.4 Limitations of microsimulation models

Microsimulation models, such as VISSIM, are more useful in assessing the efficiency of a traffic facility rather than the safety of it (Mahmud et al., 2019). The collision types considered in VISSIM are for merging, crossing and diverging links, in lane changes, and the rear end and right angle of vehicles. Accidents involving pedestrians, as well as frontal and lateral vehicle collisions, cannot be predicted.

Other limitations regard the inability of vehicles to change their planned route. If a vehicle is restricted from performing some planned action, such as changing lanes, it will be removed from the network after 60 seconds to avoid unrealistic queues (PTV, 2023). In reality, this vehicle might have refrained from changing lanes or forced its way through the to-lane. The inability to change a planned route can lead to forming gridlocks that cannot dissolve once they form.

3

Methods

This section includes a description of how the work in this study was conducted to gain enough knowledge and data to answer the research questions and meet the aim. See Figure 3.1 for a flow chart of the main parts of the method.

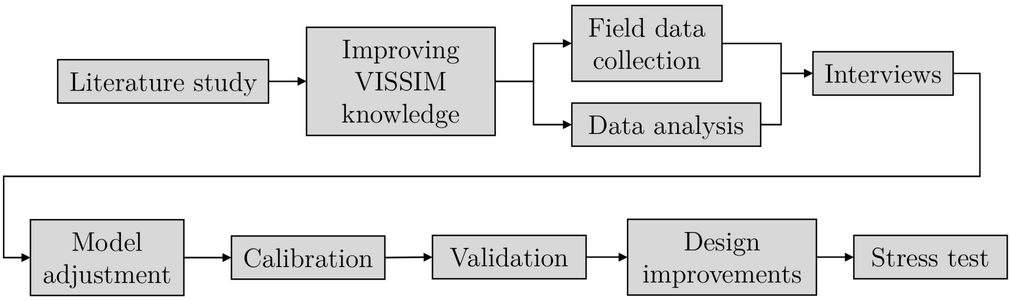

Figure 3.1: A flow chart over the main parts constituting this study

3.1 Literature study and preparatory studies

A literature study on the subject was performed to gain theoretical knowledge about microsimulation software in general and VISSIM in particular. The study's focus was the software's abilities and limitations, its building blocks, and underlying principles.

Data collection, calibration, and validation methods were included in the literature study to have grounds for practical implementation. The reason for this was to find a suitable course of action for the case study and software at hand. Other studies and their methods for a similar setting and manuals and guidebooks provided valuable insight into this.

Parallel to improving theoretical knowledge about VISSIM, practical knowledge was gained from following online tutorials and modelling various intersections, signal timings, and traffic compositions.

3.2 Data collection

Accurate data collection is crucial for creating reliable microsimulation models. This section details the methods used to gather and verify traffic data. For microsimulation models of a roundabout, data on traffic volume, routes, and modes of transportation are needed as model input (Wahlstedt et al., 2014). Line frequencies and stops are also needed for public transportation. The data collection in this study mainly consisted of field observations and contacts with knowledgeable officials.

3.2.1 Official data

The frequency of public transportation lines, routes, timetables and the average delay for all relevant bus and tram lines arriving at or departing from ÅTC, Polhemsplatsen and the Central Station was provided by the regional public transportation provider Västtrafik.

The nearby streets of Åkareplatsen, their cardinal direction: north (N), east (E), south (S), west (W), Stampgatan, and all stops for public transportation in the study area: the Central Station (CS), Polhemsplatsen (P), Åkareplatsen Travel Centre (ÅTC) are presented in Figure 3.2. Burggrevegatan is to the west, Åkerigatan to the north, Odinsgatan to the east and Polhemsplatsen to the south. The travel direction at Stampgatan will henceforth be referred to as Stampgatan-E when travelling along Stampgatan from the Central Station and Stampgatan-W to the Central Station.

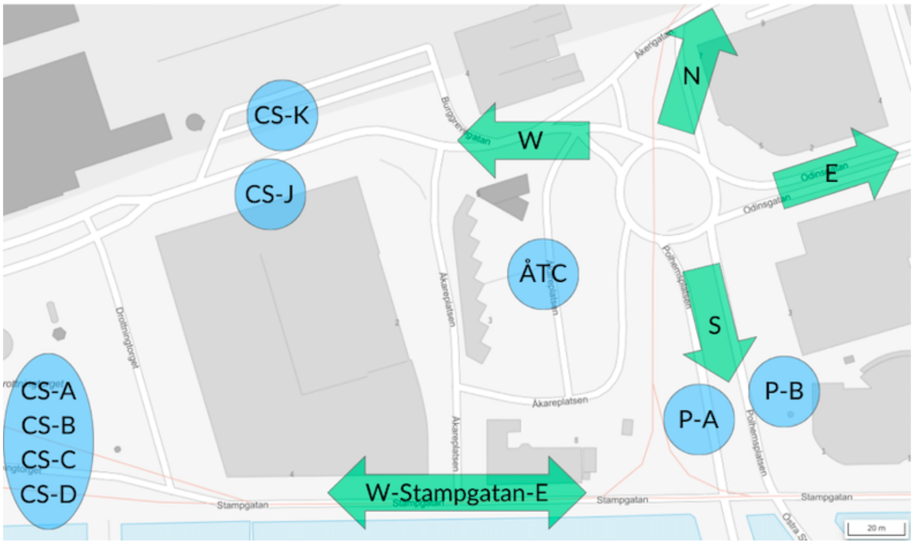

Figure 3.2: Åkareplatsen, the direction of connected streets and stops for public transportation. Modified in the municipal map service (karta.goteborg.se)

The northbound direction is only used by public transportation, the eastbound is only by private transportation, the southbound is by all modes of transportation, and the westbound is by buses and private transportation. Only public transportation on Stampgatan is considered in this study. To include public transportation in the model, input data of line frequencies for buses and trams during peak hours at the most dense traffic states is needed.

The morning peak hours for Västtrafik public transit occur between 06:00-08:30 and the afternoon peak hours at 15:00-18:00 (L. Borgström, personal communication, 14

February, 2024). The line frequencies (LF) at the morning (am) and afternoon (pm) peak hours are presented in minutes in Table 3.1 and indicate how often a transit service is available during these peak hours. All lines marked by (P) are docking at the bus stop of Polhemsplatsen, (CS) at the Central Station, and (ÅTC) at Åkareplatsen Travel Centre. The two directional arrows (⇌) symbolise that the lines travel the same route over the relevant site in both directions. In the column of Direction, the cardinal directions of the routes in terms of north (N), south (S), and west (W) are presented.

Table 3.1: All lines currently passing through Åkareplatsen, retrieved on the 26th of February 2024

Line	Route	Direction	LF am	LF pm
X3 (P)	Gråbo - Särö (⇌)	N-S (⇌)	6.6	10.6
X4 (P)	Kungälv - Mölnlycke (⇌)	W-S (⇌)	5.3	5.2
173 (P)	Heden - Gårdsten (⇌)	S-N (⇌)	14.5	20.3
503 (P)	Furulund - Heden (⇌)	N-S (⇌)	15.3	20.3
510 (P)	Partille - Heden (⇌)	N-S (⇌)	18.8	10.7
513 (P)	Partille - Heden (⇌)	N-S (⇌)	19.9	10.1
17 (CS)	Tuve - Östra Hospital (⇌)	W-N (⇌)	5.9	5.0
21 (CS)	Eketrägatan - Bergsjön (⇌)	W-N (⇌)	10.0	10.1
RÖD (CS)	Landvetter - Lilla varholmen	S-W	6.3	5.7
SVART (CS)	Amhult - Vallhamra (⇌)	W-N (⇌)	6.1	7.6
X1	Partille - Torslanda (⇌)	N-W (⇌)	9.9	10.6
100 (ÅTC)	Göteborg - Borås (⇌)	ÅTC-S (⇌)	8.1	7.8
101 (ÅTC)	Göteborg - Bollebygd (⇌)	ÅTC-S (⇌)	24.8	60
102 (ÅTC)	Göteborg - Borås (⇌)	ÅTC-S (⇌)	12.5	22.5
300(ÅTC)	Göteborg - Kinna (⇌)	ÅTC-S (⇌)	17.0	23.6
GRÅS (ÅTC)	Sjövik - Göteborg (⇌)	N-ÅTC (⇌)	16.7	17.8
LERS (ÅTC)	Tollered - Göteborg (⇌)	N-ÅTC (⇌)	26.3	16.5
Tram 4 (CS)	Mölndal - Angered (⇌)	S-N (⇌)	9	8.3
Tram 7 (CS)	Tynnered - Bergsjön (⇌)	S-N (⇌)	6.4	8.1
Tram 9 (CS)	Kungssten - Angered (⇌)	S-N (⇌)	8.3	7.9
Tram 11 (CS)	Saltholmen - Bergsjön (⇌)	S-N (⇌)	5.9	8.1

In Table 3.2, all lines on Stampgatan and their line frequencies, in minutes, during morning and afternoon peak hours are presented.

Table 3.2: All lines travelling on Stampgatan, retrieved on the 12th of March 2024

Line	Direction	LF am	LF pm
Tram 1 (CS)	W-Stampgatan (⇌)	8.3	8.2
Tram 2 (CS)	W-Stampgatan (⇌)	7.1	8.3
Tram 3 (CS)	W-Stampgatan (⇌)	8.9	8.2
Tram 13 (CS)	E-Stampgatan	20.7*	-
60 (CS)	E-Stampgatan	8	8

* = between the hours of 06:30-07:32

The average delay for public transit docking at ÅTC, Polhemsplatsen (A and B) and the Central Station (A, B, C, D, J and K) was collected. The data regarded the afternoon peak hours at 15:00-18:00 on a weekday in January 2024.

3.2.2 Field data

To simulate actual traffic conditions, data from real-world traffic situations are necessary. This is commonly collected by conducting traffic counting surveys, facilitating broader knowledge on how to reduce congestion in urban areas (Majumder and Wilmot, 2023). In general, traffic counting is divided into two methods: manual and automated, where the former is usually considered the more reliable of the two, as well as the more manageable and affordable (Majumder, 2020; Majumder and Wilmot, 2023).

The manual traffic counting can be carried out in two ways: on-site or by video recording. On-site counting often has disadvantages such as being time- and labour-consuming, weather-dependent, and easily influenced by human error (Paľo et al., 2019). Using video recordings for counting afterwards helps mitigate these disadvantages.

When planning for a successful manual traffic counting to reduce potential errors, Majumder and Wilmot (2023) recommend including the following steps:

1. Site-and time selection
2. Instrument selection
3. Planning of survey
4. Fieldwork execution

The first step is to determine when and where the field observation will occur. Majumder and Wilmot (2023) recommend surveying during spring or fall due to relatively unrepresentative traffic conditions in summer and winter, when schools are closed and unexpected weather conditions may occur. For site observations in urban areas, weekday afternoons are preferred.

The selection of instruments depends on the equipment requirements, specifically on camera properties such as resolution, battery life, and to which extent it can withhold weather and temperature variations (Majumder and Wilmot, 2023). A successful traffic counting survey is dependent on proper planning of the events. A checklist helps to rent and acquire all equipment beforehand, and the actual scheduling of the fieldwork activities involves determining the exact time and place and a recourse allocation plan.

The collection of field data in this study was conducted following the recommended procedure by Majumder and Wilmot (2023). A physical visit to Åkareplatsen and the nearby buildings resulted in the selected site for the video recordings in the office building KvarterETT. After contact with the architecture firm Semrén och Månsson, located on the 6th floor, the usage of their balcony was approved, providing an overview of the roundabout and all the connected roads. See Figure 3.3 for the location and Figure 3.4 for a part of the view.

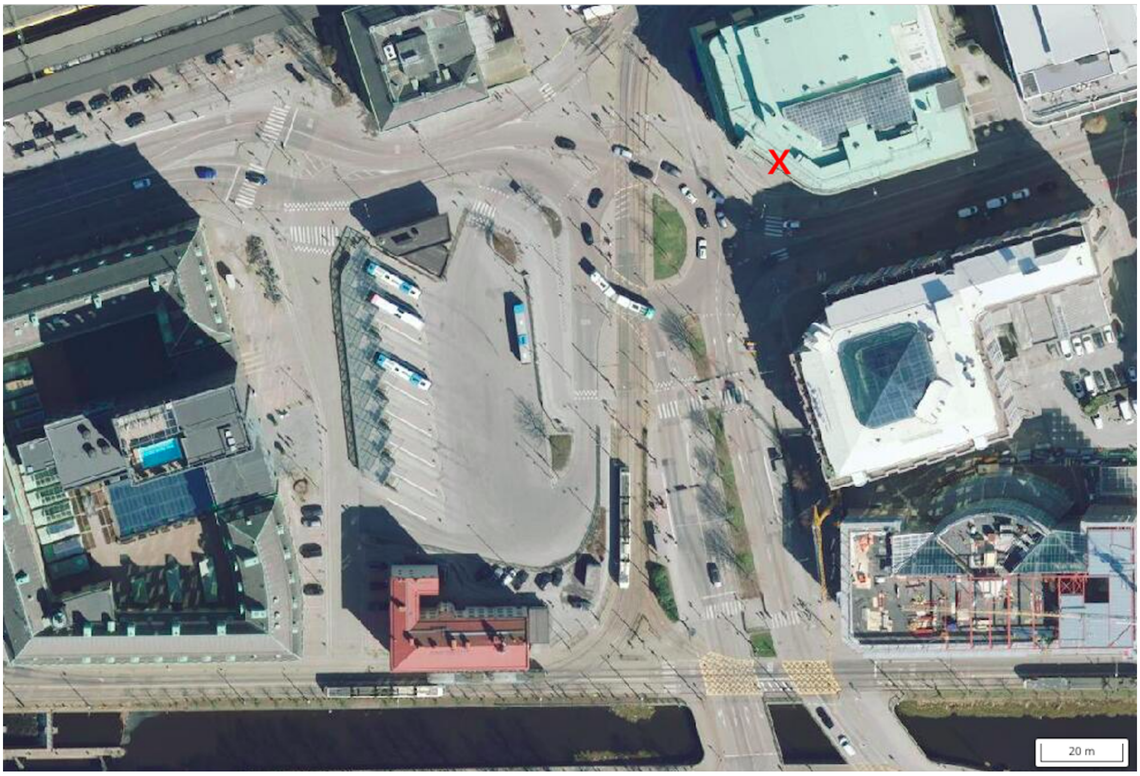

Figure 3.3: The data collection location (red cross). Modified in the municipal map service (karta.goteborg.se)

Figure 3.4: A part of the view from 6th floor balcony of KvarterETT where the data collection took place

The dates and times were set once the necessary equipment for the field data collection was received. To capture daily variations in traffic conditions, which is essential for a proper representation of reality according to Park and Qi (2005), the data was collected on multiple occasions. The field measurements were conducted for three days, from the dates of 4th of March to the 6th of March. To ensure that the traffic conditions during the peak hours were obtained, the observation took place during morning and afternoon rush hours on weekdays, as recommended by Wahlstedt et al. (2014). Weekday peak hour for private transit commonly occurs between 16:00 - 18:00 (Majumder and Wilmot, 2023). This was confirmed after a brief analysis of the field data from the first day of collecting; hence, collection of field data during the morning peak hours was discontinued. See Table 3.3 for the date and times for field observations and video recordings.

Table 3.3: The dates and times for the field data collection

Date	**Day of the week**	**Time**	**Peak hour**
4th of March	Monday	07:00 - 09:00 15:00 - 17:45	Morning Afternoon
5th of March	Tuesday	15:30 - 17.30	Afternoon
6th of March	Wednesday	15:30 - 17:45	Afternoon

Two iPhone cameras on stands positioned at slightly different angles were used when recording, as seen in Figure 3.5. From this position, all connecting legs of the intersection were visible, with a poorer view of Åkerigatan and Odinsgatan, which was not compensated for. The road geometry and objects were inspected during the site observations to be compared with the original VISSIM model. This includes the location of carriageway edges, bus stops, permanent physical structures, and the location of pedestrian crossings (Ishaque and Noland, 2009).

Figure 3.5: The camera setup on the 6th floor balcony of KvarterETT

During data collection to be used in a simulation model, it is essential to pay attention to weather conditions, road work, incidents, accidents, or special events that might affect the accessibility (Wahlstedt et al., 2014). These conditions were noted for Åkareplatsen every field day and were not judged to impact the road traffic or behaviour considerably.

3.2.3 Interviews

Several semi-structured interviews were held with interviewees with different experiences, fields of expertise, and connections to Åkareplatsen. These were conducted to gain insight into the project planning, impressions of the capacity and functionality of the finalised Åkareplatsen, and, most of all, to get inspiration for and input on alternative designs. The interviews were held on Microsoft Teams, except for the last one, which was conducted over the phone. The audio of all interviews was recorded with consent from the all interviewees to decrease the risk of misconceptions and mishearings.

The interview questions varied somewhat to fit the knowledge base of the interviewee. For those involved in the planning- or building process, the questions mainly revolved around their opinion about the reason for the traffic-related problems, whether these problems could have been prevented, and what could be done to improve the site. For those involved in operations at Åkareplatsen, the questions focused on the site's experience and how it can be improved.

The first interview was held on the 11th of March with Claes Johansson, a civil engineer working with traffic planning. The second interview was held on the 12th of March with the community developer Magnus Lorentzon from Västtrafik. Mimmi Mickelsen, manager of infrastructure and track facilities at the City of Gothenburg, was interviewed 13th of March. On the same day, the traffic director and former tram driver Christoffer Liljebjer was interviewed over the phone.

3.3 Data analysis

The collected data for private transportation was analysed and processed to be used as input data in the adjusted model and during its calibration to enable reflection of 2024 traffic flow. The data analysis mainly consisted of a manual traffic counting of the recorded video footage from the field data.

The procedure of the data analysis followed the guidelines in Majumder and Wilmot (2023). First and foremost, the time interval for counting was determined to be 15 minutes based on standardised recommendations for manual traffic counting. A 15-minute time interval has been proven to minimise the risk of human errors compared to a 5-minute interval. All data sets from the recordings were included in the counting. Prior to the counting, the vehicle classes and the vehicle types included were defined to ensure a consistent classification in accordance with the VISSIM vehicle classes. The four vehicle classes in VISSIM and which types were classified as which were:

- Cars (regular cars, taxis, and vans)
- Trucks (larger vehicles, cars with attached trailers, garbage trucks, and buses not part of the Västtrafik fleet)
- Bicycles (bicycles, e-scooters, mopeds, electric wheelchairs)
- Pedestrians (parents with children, people with suitcases, walkers, and wheelchairs)

These classes were clustered based not on their function but on the space they occupy and their movement pattern. For instance, cars with trailers take up more space and might drive more carefully than cars without trailers, and they were therefore classified as tucks.

3.3.1 Counting of cars and trucks

Both of the authors of this study conducted the counting of cars and trucks for each data set, reducing the risk of count errors, one of the most common mistakes made during manual traffic counting (Majumder and Wilmot, 2023). Two other common types of errors are classification and interval errors. The former describes wrongly classified transportation modes, and the latter errors when a count is wrongly distributed into a time interval in which it does not belong. Most of these errors occur due to faster playback speed than reality. Poor weather, video quality, or obstacles in front of the camera are other common reasons for human errors. In this study, the error or obstacles in front of the camera affected the quality of the counting for a few minutes of the video. A manual count can be individually challenging, and at least a 5-minute break per hour of counting was introduced to reduce human errors.

The vehicle counting was conducted by assigning each author one leg (west, south or east) at a time. The recordings were played, and each vehicle (car and truck) that left the leg was traced from origin to destination. Depending on the vehicle flow, the playback speed varied between 1–8 times the actual speed. After each 15-minute interval, origin-destination (OD) matrices were created, and the total traffic counts for each time interval were plotted in Excel. See Figure 3.6 and Figure 3.7 for these plots of the morning peak on the 4th of March and the afternoon peaks, respectively. The red dot in Figure 3.7 marks the traffic flow of the maximum quarter.

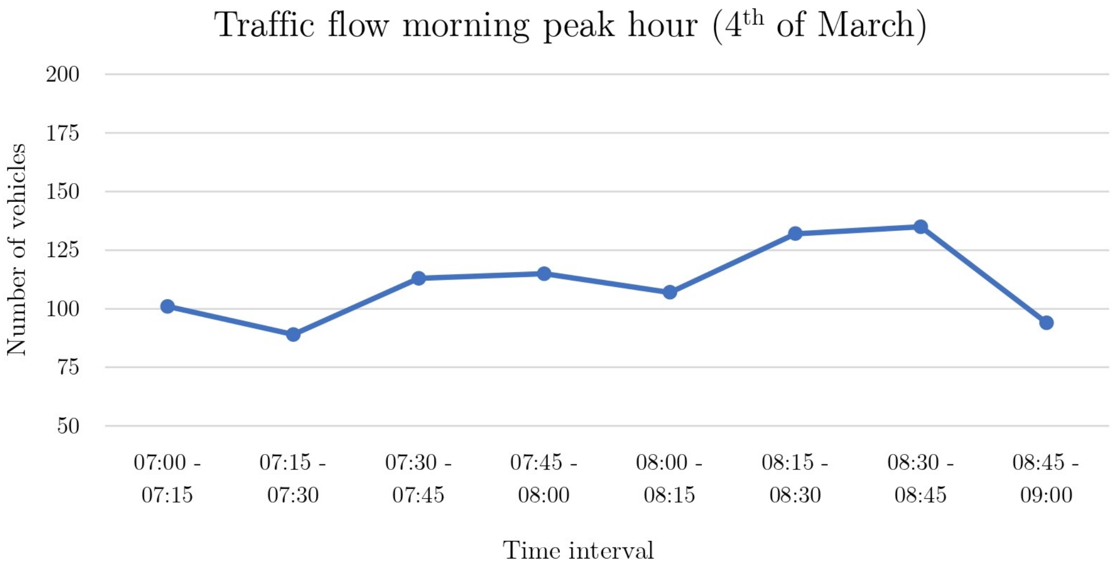

Figure 3.6: Number of vehicles during morning peak hours on the 4th of March

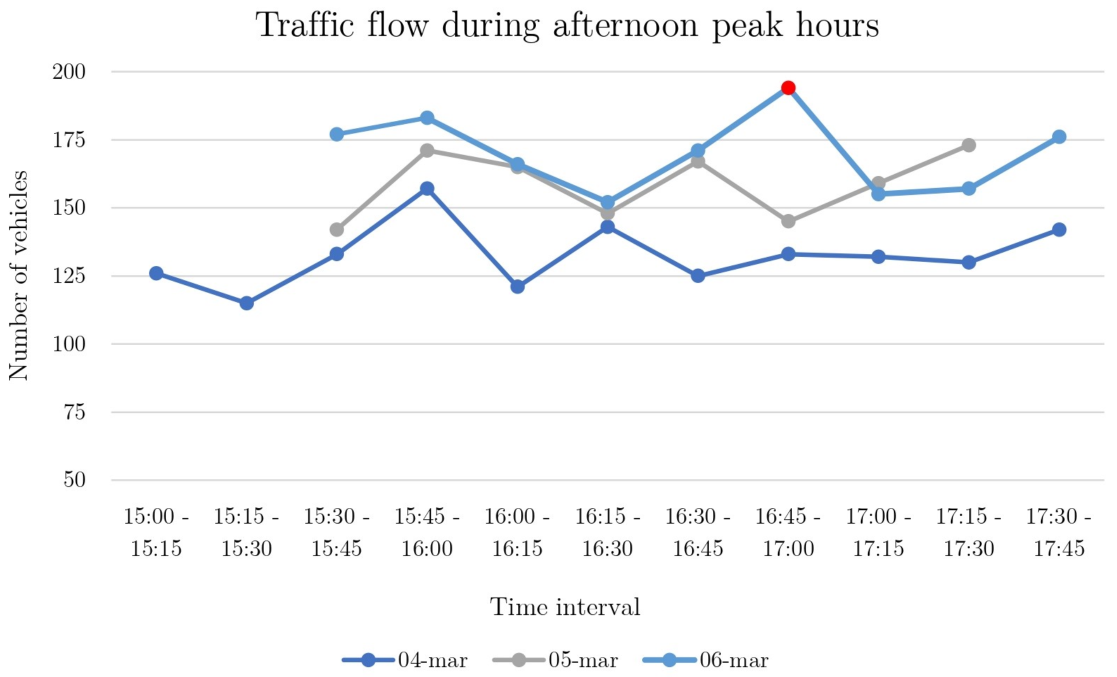

Figure 3.7: Number of vehicles during afternoon peak hours between the 4th- 6th of March

The maximum quarter was observed on Wednesday, the 6th of March, between 16:45-17:00, with a total of 194 cars and trucks travelling within the study area.

3.3.2 Counting of pedestrians and bicyclists

The counting of pedestrians and bicyclists took place during the maximum quarter on the 6th of March between 16:45-17:00. The reason for this was to keep the time-consuming manual labour to a minimum while at the same time considering a sample of representative pedestrian activity during peak hour. The counting was performed using the same procedure for cars and trucks, such as one author focused on one route at a time. At the pedestrian-only crossings, bicyclists were considered as pedestrians. Bicyclists using the roads typically dedicated for motorised vehicles, as well as jaywalking pedestrians, were disregarded.

3.4 Adjusted model and its input data

The original VISSIM model created by Ramboll was initially cropped to better fit the area of interest in this study. The adjusted model is the cropped version of the original and has 2024 traffic input data instead of 2018. The spatial area of the adjusted model and the study area can be seen in Figure 3.8.

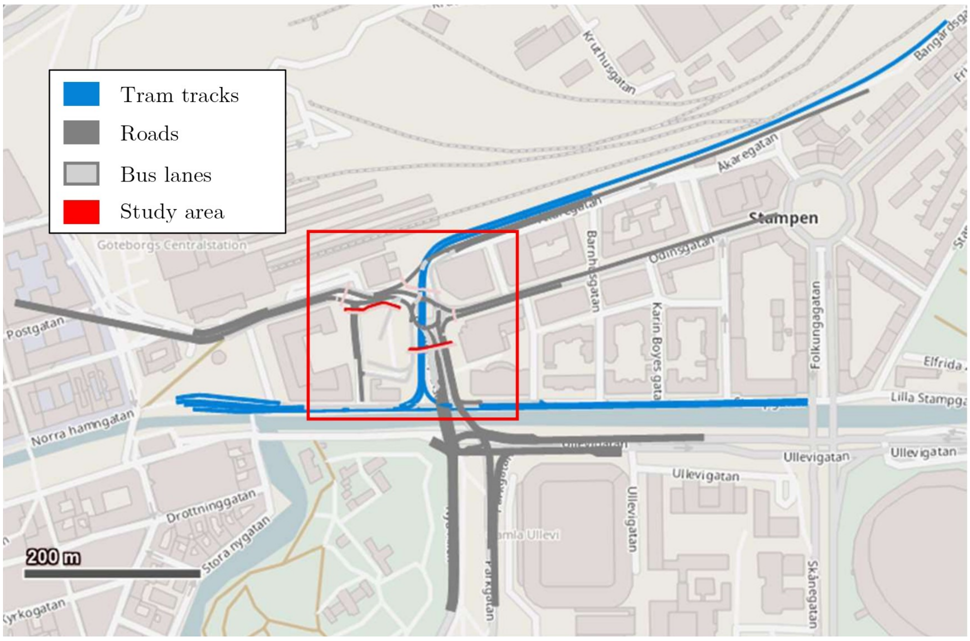

Figure 3.8: The adjusted model in VISSIM and the study area in red

The road design should be based on the traffic demand during weekday peak hours (Wirsenius et al., 2022). The maximum quarter represents the highest vehicle flow during 15 minutes of the peak hours (Trafikverket, 2014). This maximum quarter was multiplied by four to get the traffic volume during the dimensioning peak hour, known as the maximum hour. This method was used for all vehicle classes, i.e., cars, trucks, pedestrians, and bicyclists. The traffic volumes from the OD-matrices were put into VISSIM as a *stochastic* volume type. The line frequencies from actual timetables were put into the model for public transportation to reflect the traffic volume.

3.4.1 Cars and trucks (OD)

The data analysis resulted in origin-destination matrices for cars and trucks during the maximum hour, presented in Table 3.4 and Table 3.5, respectively. The rows represent origins and the columns the destinations.

Table 3.4: OD-matrix for cars during the maximum hour [cars/h]

O/D	Odinsgatan	Polhemsplatsen	Burggrevegatan
Odinsgatan	12	96	68
Polhemsplatsen	40	48	252
Burggrevegatan	60	184	4

Table 3.5: OD-matrix for trucks during the maximum hour [trucks/h]

O/D	Odinsgatan	Polhemsplatsen	Burggrevegatan
Odinsgatan	0	0	4
Polhemsplatsen	0	0	4
Burggrevegatan	0	4	0

These matrices were used to calculate the vehicle composition, which resulted in a share of 98.5 % cars and 1.5 % trucks. The final OD-matrix of cars and trucks used as input data in VISSIM is presented in Table 3.6.

Table 3.6: OD-matrix for cars (98.5 %) and trucks (1.5 %) during the maximum hour [veh/h]

O/D	Odinsgatan	Polhemsplatsen	Burggrevegatan	Sum
Odinsgatan	12	96	72	180
Polhemsplatsen	40	48	256	344
Burggrevegatan	60	188	4	252

The total traffic volume during the maximum hour was 776 vehicles.

3.4.2 Pedestrians and bicyclists (OD)

See Table 3.7 for the OD-matrix of all pedestrians and Table 3.8 for all bicyclists. The position of these pedestrian crossings can be found in Figure 2.3. Note that the origins and destinations that are not connected by a crossing are marked by -.

Table 3.7: OD-matrix for pedestrians during the maximum hour [ped/h]

O/D	Scandic	ÅTC	KvarterETT	CS	Hotel Post
Scandic	0	248	300	-	-
ÅTC	168	0	-	-	200
KvarterETT	204	-	0	524	-
CS	-	-	292	0	208
Hotel Post	-	140	-	244	0

Table 3.8: OD-matrix for bicyclists during the maximum hour [bic/h]

O/D	Scandic	ÅTC	Hotel Post
Scandic	0	56	-
ÅTC	28	0	8
Hotel Post	-	40	0

Note that the crossings of KvarterETT and CS are only pedestrian and, therefore, excluded from the bicyclists OD-matrix. In total, 665 pedestrians and bicyclists were included in the maximum hour input data.

3.4.3 Public transportation

For public transit lines, the input data was the vehicle type, the line frequencies (LF pm) in seconds, the *begin time* at which they entered the model, *delay time* and *dwell time*.

Each bus line could be linked to a specific bus model, such as express, city, articulated, and regional buses. Based on these models, each bus line in VISSIM was assigned a bus type as close to these corresponding lengths as possible. A bus line not used by double-deckers could be assigned a double-decker type in VISSIM to represent the vehicle length better. The vehicle height was not assumed to affect the simulation results. The active tram lines could not be linked to a particular model, and therefore, all trams were assumed to be the longest of the tram models, M33, with a total length of 33 m (Göteborgs Spårvägar, n.d.). See Table 3.9 for the maximum actual vehicle lengths and the closest corresponding vehicle lengths in VISSIM.

Table 3.9: Maximum vehicle lengths from Transportstyrelsen (2023) and corresponding lengths in VISSIM

Type	Real length [m]	VISSIM length [m]
City bus	13.50	13.45
Express bus	15.00	14.12
Regional bus	15.00	14.12
Articulated bus	18.75	19.04
Tram	33.00	32.70

The *begin time* of each line in VISSIM was estimated based on the timetables and the assumed travel time between fixed stations. The travel time for all public transit modes throughout the entire model, from one leg to another, was assumed to be two minutes. For instance, when trams enter the model boundaries from the north and arrive at the CS, it is assumed to take two minutes. The same assumption was made for buses entering the model from the south to stop at the CS, and from the west to travel to the north.

The input data for public transportation can be seen in Table 3.11. Note that tram line 13 and one direction of the bus lines 503 (N-S) and 102 (ÅTC-S) only passed the study area during the morning rush hour and were therefore excluded.

Table 3.10: Input data for public transportation

Line	Vehicle Type	Direction	Begin time	LF pm
X3	Express bus	N-S S-N	60 240	636
X4	Express bus	W-S S-W	180	312
60	City bus	Stampgatan-E	120	480
173	Regional bus	S-N N-S	360 2820	1218
503	Regional bus	N-S S-N	- 480	1218
510	Regional bus	N-S S-N	900 420	642
513	Regional bus	N-S S-N	180 120	606
17	Articulated bus	W-N N-W	180 300	300
21	Articulated bus	W-N N-W	240	606
RÖD	Express bus	S-W	240	342
SVART	Express bus	W-N N-W	120 0	456
X1	Express bus	N-W W-N	720 0	636
100	Regional bus	ÅTC-S S-ÅTC	300 660	468
101	Regional bus	ÅTC-S S-ÅTC	1380 3540	3600
102	Regional bus	ÅTC-S S-ÅTC	- 2220	1350
300	Regional bus	ÅTC-S S-ÅTC	480 720	1416
GRÅS	Regional bus	N-ÅTC ÅTC-N	540 360	1068
LERS	Regional bus	N-ÅTC ÅTC-N	3060 240	990

Continued on next page

Table 3.10: Continued from previous page

1	Tram	Stampgatan-W Stampgatan-E	360 60	492
2	Tram	Stampgatan-E Stampgatan-W	360 660	498
3	Tram	Stampgatan-E Stampgatan-W	480 420	492
4	Tram	S-N N-S	180 300	498
7	Tram	S-N N-S	240 420	486
9	Tram	S-N N-S	360 480	474
11	Tram	S-N N-S	0 180	486

The delay in public transportation was included in the input data as *entry time distribution* for all lines that stop within the case study area. Other lines were not included in the delay. The average delay at the stops of ÅTC, Polhemsplatsen (A, B) and the CS (J, K) were given for each location. At the same time, the CS (A, B, C and D) were based on an average of the four lines 1, 2, 3, and 60, due to limitations in the data as some stops could not be differentiated from others. Their respective delay was 198, 172, 191 and 104 s, resulting in an average of about 166 s. Note that positions A, B, C, and D at the CS position are used solely by trams and bus 60; the rest are only by buses. Instead of entering the delay per line or stop, a practical approach was taken. The time that lines enter the model was adjusted. The entry time was assumed to be normally distributed, consisting of a mean value, which is the average delay, and a default standard deviation of 10 seconds for all stops. The average delay for public transport stops within the study area during the afternoon peak hour at 15:00-18:00, is presented in Table 3.11 (L. Borgström, personal communication, 14 March, 2024).

Table 3.11: *Entry time distribution* for public transit stops during afternoon peak hours

Stop	Position	Average delay [s]
ÅTC	-	122
Polhemsplatsen	A, B	93
Central Station	J, K	181
Central Station	A, B, C, D	166

Dwell time in VISSIM is the time during which passengers are boarding or exiting a stopped public vehicle (PTV, 2023). It was interpreted based on the video recordings of Polhemsplatsen (A, B) bus stop during the maximum quarter, which was selected to capture the dwell time during a high vehicle volume. The mean dwell time was calculated to be 31 seconds with a standard deviation of 11 s. The same dwell time was applied to all public transportation stops within the case study area, regardless of whether or not they stopped within the case study area.

3.5 Original model and its input data

The original VISSIM model created by Ramboll was used to simulate the afternoon peak hour using traffic data from 2018. See Figure 3.9 for the spatial extent of the original VISSIM model and the study area of Åkareplatsen.

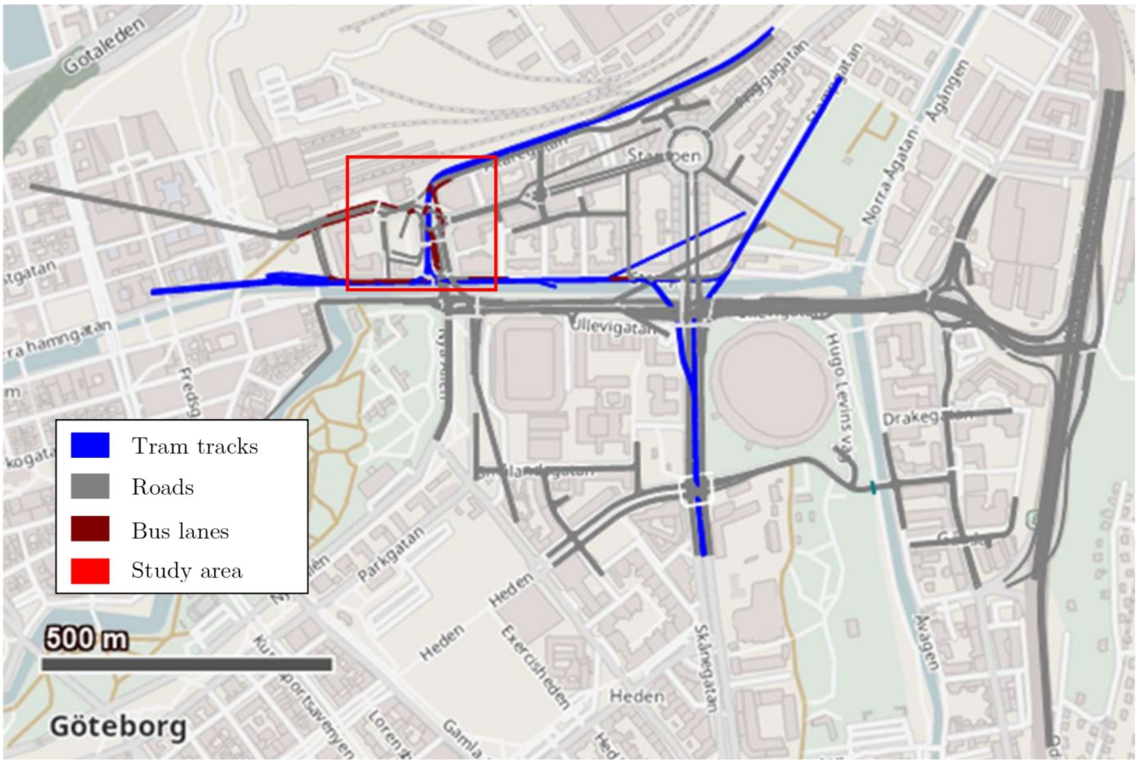

Figure 3.9: The original model in VISSIM and the study area in red

To study the formation and dissolution of queues, the vehicle volumes were initially increased from 0 at the start of the simulation, each time interval of 600 seconds, to the maximum volume at 9000-9600 and 9600-10200 seconds, and decreased again at 10200-10800 seconds. See Table 3.12 for the percentage increase in which all vehicle input followed, regardless of direction.

Table 3.12: The incremental increase of the original vehicle input

Time interval [s]	Volume [veh/h]
0-600	0 %
600-1200	0 %
1200-1800	25 %
1800-2400	25 %
2400-3000	50 %
3000-3600	50 %
3600-4200	55 %
4200-4800	60 %
4800-5400	65 %
5400-6000	70 %
6000-6600	75 %
6600-7200	80 %
7200-7800	85 %
7800-8400	90 %
8400-9000	95 %
9000-9600	100 %
9600-10200	100 %
10200-10800	75 %

The maximum traffic volume at 100 % in the intervals of 9000-10200 seconds was the basis for further investigations, as this can correspond to the traffic volume during the maximum hour. Therefore, this maximum traffic volume was used as input for all time intervals from 0-10800 seconds for the simulation. The OD-matrix for the original model consisting of the maximum vehicle flow can be seen in Table 3.13, where the vehicle share was 98 % cars and 2 % trucks.

Table 3.13: OD-matrix for cars (98 %) and trucks (2 %) [veh/h]

O/D	Odinsgatan	Polhemsplatsen	Burggrevegatan	Sum
Odinsgatan	0	221	253	474
Polhemsplatsen	279	11	341	631
Burggrevegatan	43	183	0	226

The total traffic volume of cars and trucks during the maximum hour was 1331 vehicles.

The input data of pedestrians and bicyclists in the original model are presented in Table 3.14 and Table 3.15, respectively. The OD-matrix refers back to Figure 2.3 in Section 2.1 for an explanation of which pedestrian crossings are which.

Table 3.14: The original OD-matrix for pedestrians during the maximum hour [ped/h]

O/D	Scandic	ÅTC	KvarterETT	CS	Hotel Post
Scandic	0	80	50	-	-
ÅTC	50	0	-	-	80
KvarterETT	50	-	0	50	-
CS	-	-	50	0	80
Hotel Post	-	50	-	80	0

Table 3.15: The original OD-matrix for bicyclists during the maximum hour [bic/h]

O/D	Scandic	ÅTC	Hotel Post
Scandic	0	40	-
ÅTC	40	0	40
Hotel Post	-	40	0

A total of 780 pedestrians and bicyclists were included in the study area of the original model.

The input data in the original model for all public transit lines, their direction, *Begin time* and line frequency (LF pm) in seconds is presented in Appendix Table A.1. There was no *Entry time distribution* (i.e., delay time), and the normally distributed *Dwell time* had a mean value of 20 s and a standard deviation of 2 s.

3.6 Simulation and extraction of MOEs

To capture the stochastic variability of the simulation results, the simulation time was set to 3 hours or 10800 seconds and was repeated in 10 simulation runs. This applies to the simulation of the original model, the adjusted model, the calibrated and validated model, as well as to all scenarios of improvement. The parameters chosen as MOEs in this study are queue lengths and vehicle travel time (Wahlstedt et al., 2014).

3.6.1 Queue length in VISSIM

The average and maximum queue lengths were evaluated for each time interval for Odinsgatan, Polhemsplatsen, and Burggrevegatan streets. This was conducted using the built-in function of *Queue Counters* in VISSIM. The vehicle classes included in this counting were cars, trucks and buses. Adjacent lanes were not considered, and the queue definition for the velocity remained the same as the default values in VISSIM. The maximum clearance and length for queues were set to 10 and 1000 meters, respectively.

The queues' starting and stopping points were placed in the exact locations as the actual queues could be observed in the video recordings. The queue counters were placed in the same positions in the original model, the adjusted and calibrated ones, to compare the outcomes. The starting points of the queue counters were placed where the queues would expectedly begin to form, right at the entrances of the roundabout, see Figure 3.10.

Figure 3.10: The location of the queue counters starting points in VISSIM (original model as reference)

The ending points of the queue counters were placed approximately where the camera's field of vision ended during the data collection. After that, the distances from the beginnings to the ends were measured in VISSIM using the ruler tool; see Table 3.16.

Table 3.16: Actual distance between the starting point and the end of field of vision for maximum queue length

Street	Distance [m]
Odinsgatan	-
Burggrevegatan	153
Polhemsplatsen	105

For all simulation runs, the average queue length per time interval was measured as the mean value of all simulation resolutions (time steps per simulation second). The principle was the same for the average maximum queue length, which measures the mean of all the longest identified queue lengths in all time steps per simulation second and time intervals during all simulation runs. Queue lengths can be reported to be longer than the distance between the starting and ending point of the queue counters in the VISSIM results, and this is because the software can detect the queue length upstream of the queue counter (PTV, 2023). Because of this, all queue lengths reported to be longer than 105 or 153 m were modified to be a maximum of 105 or 153 m.

3.6.2 Vehicle travel time in VISSIM

The average and maximum vehicle travel time for the vehicle classes of cars, trucks, and buses and their travelled distance was measured by placing starting and stopping points for the built-in function of *Vehicle Travel Times* in VISSIM. These parameters were evaluated for the following routes and vehicle classes, where (all) in the list below represents cars, trucks and buses:

- Polhemsplatsen (S) → Odinsgatan (E) (cars and trucks)
- Polhemsplatsen (S) → Burggrevegatan (W) (all)
- Polhemsplatsen (S) → Polhemsplatsen (S) (cars and trucks)
- Polhemsplatsen (S) → Åkerigatan (N) (buses only)
- Burggrevegatan (W) → Polhemsplatsen (S) (all)
- Burggrevegatan (W) → Odinsgatan (E) (cars and trucks)
- Burggrevegatan (W) → Åkerigatan (N) (buses only)
- Odinsgatan (E) → Burggrevegatan (W) (cars and trucks)
- Odinsgatan (E) → Polhemsplatsen (S) (cars and trucks)

The starting point was placed at the same position as the queue counter stopping point, i.e., where vehicles enter or right before leaving the camera view during the data collection. The stopping points for vehicles leaving the roundabout and preceding their routes on Odinsgatan, Burggrevegatan, or Åkerigatan were located just before passing the pedestrian crossings over the respective streets. The stopping point for vehicles bound for Polhemsplatsen was also located right before the pedestrian crossing. All data points were positioned either at the location where vehicles enter or leave the camera view, or at a reference point. This reduces the risk of errors while manually evaluating the actual travel time from the video recordings. See Figure 3.11 for the position of all data points for the travel time evaluation.

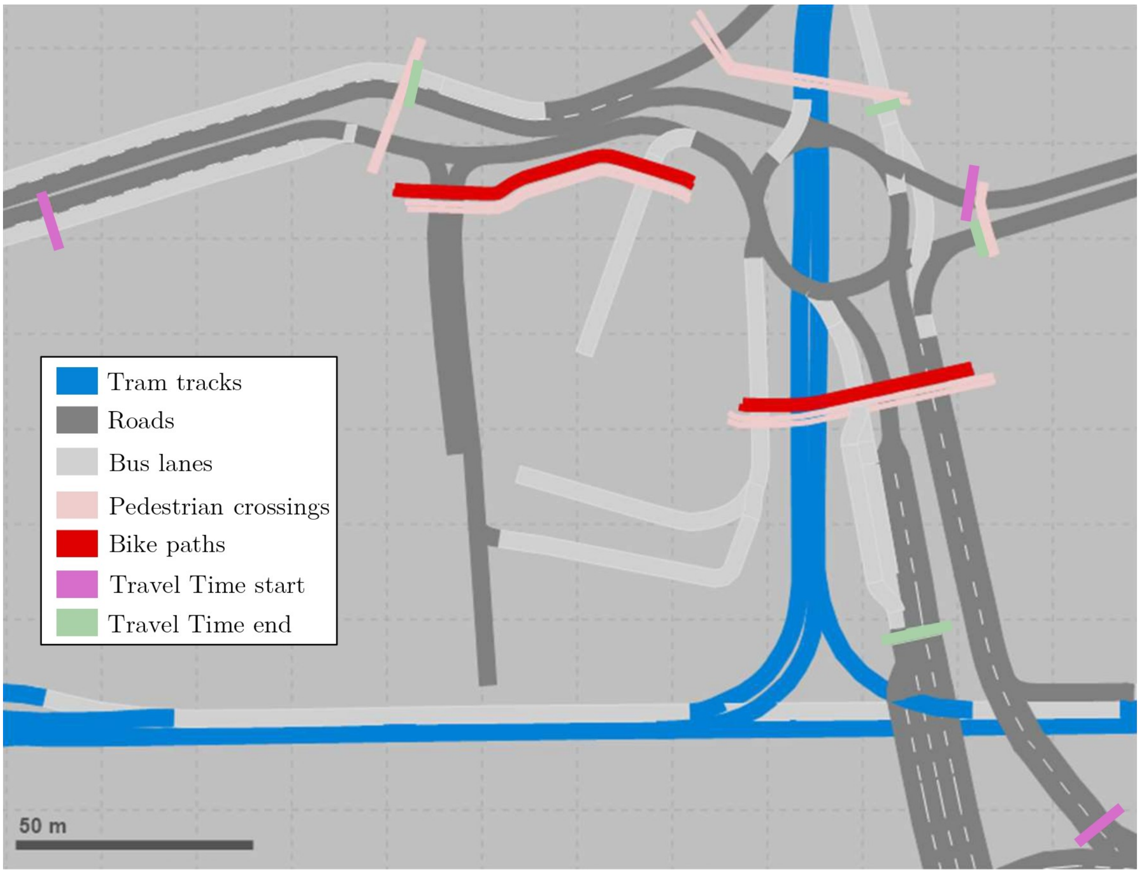

Figure 3.11: The location of the travel time start and end points in VISSIM (original model as reference)

No extreme values from apparent gridlocks were accounted for when calculating the average vehicle travel time since no gridlock occurred during the observed maximum quarter. Travel times considered unrepresentative were those in the time interval directly before a blank space in VISSIM, indicating that no single vehicle managed to travel the distance between the start- and end points during that specific time interval. Another criterion for when a value was deemed divergent was if the travel time in one time interval, multiplied by two, exceeded the observed maximum value. The multiplier of two was based on the accountancy of various natural causes of a longer travel time, such as getting stuck behind buses at bus stops. If the travel time was considered unrepresentative, the value was neither included in calculating the average travel time for that time interval nor the maximum.

3.7 Actual MOEs from field data

The actual queue lengths and vehicle travel times were obtained from video recordings during the maximum quarter. This enabled a comparison between the MOEs from the simulation results of the original, adjusted, and calibrated VISSIM models and the actual MOEs. The queue counting and travel time measurements were conducted under the same terms as in VISSIM, meaning that the start and end points for the measurements were the same in reality as in the models.

3.7.1 Actual queue length

The average queue length was noted 30 seconds after the start of the one-minute interval, resulting in 15 queue lengths on which to base the average. The maximum queue length was noted during the same quarter. The legs visible in the video recordings were Burggrevegatan (W) and Polhemsplatsen (S), the basis for the actual queue measures. The queues were registered from the same position as the queue counter placement in VISSIM.

Queues were noted from the start position at the beginning of the leg and upstream until the field of vision in the recordings ended. The distance was based on measurements in Google Maps and the provided background map in VISSIM.
The same terms regarding VISSIMs queue definition were applied as much as feasible. These were if vehicles drove with velocities of less than 5 km/h until 10 km/h and a clearance of 10 m. When the velocity did not seem to fall below 5 km/h or no cars were present, the queue length was 0. The velocity and clearance were based on visual estimations, and the real velocity or clearance could be higher or lower.

3.7.2 Actual travel time

The average and maximum vehicle travel times in seconds were extracted from the video recordings of the maximum quarter. The start and end points of the queue counting were the same as their placement in VISSIM. The travel time was counted from the front of the vehicle entering the start point until the front of the vehicle reached the endpoint. All vehicles that entered within the time frame of the maximum quarter were included, even if they did not reach the end point within that quarter.

The average travel times for all routes were counted based on all vehicles within the quarter, which ranged from six to 65 vehicles. The maximum travel time was noted during the same quarter.

3.8 Model calibration

In the calibration process, model parameters are adjusted for the model to better represent the system under study (Wahlstedt et al., 2014). The overall process for calibrating simulation models is:

1. Run the model
2. Compare the results from the simulation with field data from traffic measurements
3. Adjust parameters until the level of deviance between the simulated results and traffic measurements is considered acceptable

4. Repeat steps 1-3 until compliance is deemed high enough

The acceptable level of compliance was subjective and a trade-off between visual and statistical outcomes.

The parameters that were changed in the calibration process are the following:
- Road geometry
- Reduced speed areas
- Conflict areas
- Priority rules
- Signal heads
- Vehicle routing
- Blocking of vehicle classes in lanes
- Lane change settings
- Link driving behaviours

This was because their effect on the model was easily interpreted, and they were regarded as sufficient to calibrate the model. Other parameters, e.g. for the car-following model, can also be included in the calibration for more experienced VISSIM users. The level of deviance between the simulation results and the observations was determined both statistically, by comparing MOEs, and visually by comparing them to the observed field conditions.

Statistical error
The squared difference values evaluated the statistical error between the simulated and observed values. The MOEs of average and maximum queue lengths and vehicle travel times were used for this. The root mean squared error (RMSE) was calculated by Equation 3.1 (Hollander and Liu, 2008):

$$RMSE = \sqrt{\frac{1}{N}\sum_{i=1}^{N}(\hat{y} - y)^2} \tag{3.1}$$

Where
$\hat{y}$ are the simulated values
y are the mean observed values
N is the number of time intervals

RMSE weighs larger errors more heavily, and a higher RMSE indicates a larger discrepancy between the simulation results and the observed values. For each measured vehicle travel time and queue length, the RMSE was calculated.

In comparing the original and the adjusted model, the RMSE for the entire simulation run of three hours was calculated to allow traffic build-up in the larger original model. Three hours of 10800 seconds were divided into 12 intervals of 900 seconds each. However, when comparing the adjusted model to each calibration, only one hour of four time intervals between 3600-7200 s was considered. This decision was based on the assumption that the extreme values at the beginning and end of the simulation were less accurate in reflecting the actual traffic state.

In some model versions, gridlocks were formed, causing the result to lack data from some of the simulation runs and in some or all of the time intervals. The error was only calculated for the model versions with a sample size that was large enough. The requirement was that half of all simulations should be successful, i.e. a maximum of five simulation runs with gridlocks. In case fewer than five were successful, the error was not evaluated.

Visual comparison
The visual comparison was made by inspecting the simulation footage and comparing it to the field-recorded video material and photographs taken during field observations. The degree of compliance and whether changes in model parameters led to more or less realistic behaviour were assessed by comparing the simulation footage to the recorded material from all field days. These were noted if any unrealistic behaviour was observed during the simulation runs, and relevant parameters were changed iteratively after that.

3.8.1 Changes to the base network

Before the model modifications (mod), changes were made to the base network of the model to replicate the current design.

To replicate today's design, the crossing for pedestrians and bicyclists at the bus entry of ÅTC was changed from a crossing with a pedestrian right-of-way to one for buses. The signal heads for bicycles and pedestrians were removed according to the current design.

Tram priority was accounted for by using conflict areas in the roundabout in addition to the already modelled signals. There was a right of way for buses entering the bus lane from the south instead of vehicles exiting the roundabout to the east. This was changed so no vehicle would wait in the roundabout to exit to comply with traffic rules.

3.8.2 Modification 1: Road geometry

In the original and adjusted model, all road widths in the roundabout had the default width of 3.5 m. This was changed to better comply with the road widths and driving behaviour observed during field observations. Buses' turning radius requires wider lanes, which cars wrongfully utilise as two lanes. The changes in modification 1 consisted of increasing the number of lanes for the east and west entrances to the roundabout. These changes were:

- From one to two lanes from Odinsgatan (E) to the tram tracks of the roundabout. Two lanes of 3.5 m width each result in a total 7 m road width.
- From one to two lanes from Burggrevegatan (W) to the tram tracks of the roundabout. Two lanes of 3.5 m width each result in a total 7 m road width.

The increased number of lanes called for more route choices and some existing routes for public- and private transportation to be modified so that left-turning vehicles used the left lane, and so forth. All bus routes were placed in the outer lanes of turns to capture their turning movements. Buses were also blocked from the inner lanes of the two-lane links to avoid two buses occupying the same roundabout section simultaneously. The signal heads over the tram tracks were also moved to better fit the two-lane layout. See Figure 3.12 for the changes to the road geometry of the roundabout.

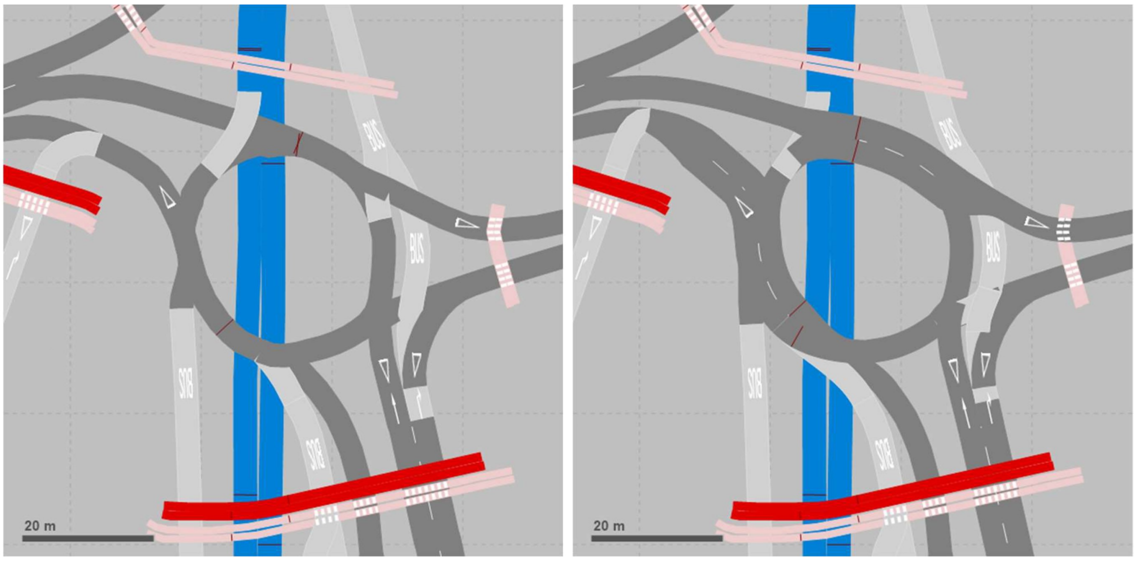

Figure 3.12: One-laned adjusted model (left) and two-laned modified (right)

In the adjusted model, all conflict areas were either red-green or all yellow, i.e. passive. In passive conflict areas, vehicles can not detect other vehicles and thereby drive straight through each other. The conflict areas were changed in modification 1 as the added lanes resulted in new and more conflict areas. See Figure 3.13 for the conflict areas in the adjusted model and the first modification.

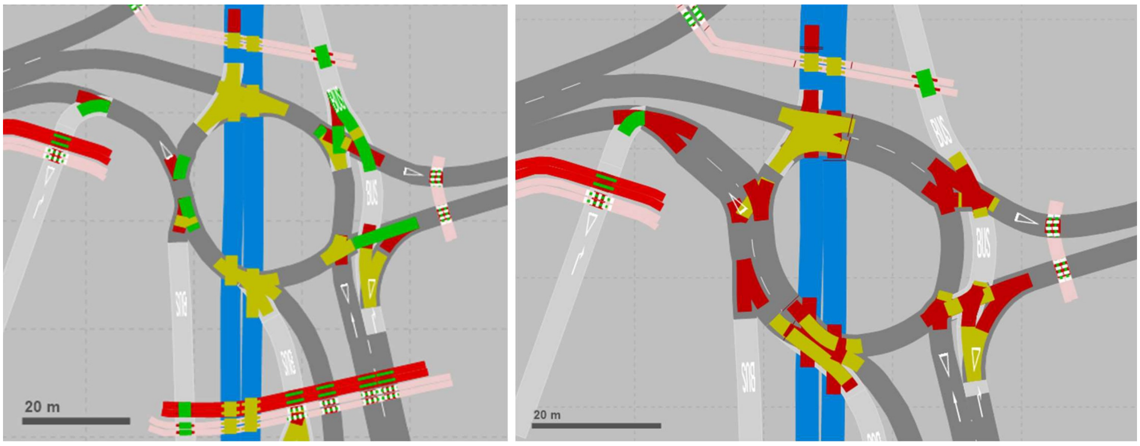

Figure 3.13: Conflict areas in the adjusted model (left) and in mod 1 (right)

In the adjusted model, the standard setting was to avoid blocking both minor and major flow. The three entrances of private transportation into the roundabout had different settings, giving the vehicle in the roundabout the right of way while avoiding blocking the major flow, but not the minor flow. At the exit of ÅTC, buses had the right of way and were allowed to block other flows. This was not changed in the modification.

In the first modification, some conflict areas were set to the undetermined status of red-red. In all conflicts with crossing tram traffic, the status was set to red-red to avoid all blocking and ensure no vehicle type stopped at the crossing. At other locations, the general setting was also changed to undetermined, allowing all blocking since this type of behaviour was observed in reality. This pattern was general throughout all conflict areas, except for some inconsistencies at the entrances to the roundabout from south and east. At first, their setting was the same as the adjusted model but was changed iteratively as conflicts appeared after peeking at the simulations.

As some conflicts did not seem to be resolved using conflict areas, priority rules were implemented for the entrances to the roundabout and specifically for the two-laned links. Buses' turning radius led to them taking up two lanes, and for this priority, rules were used to block buses and trucks from entering a lane already occupied by a bus. The changes made for the priority rules can be seen in Figure 3.14.

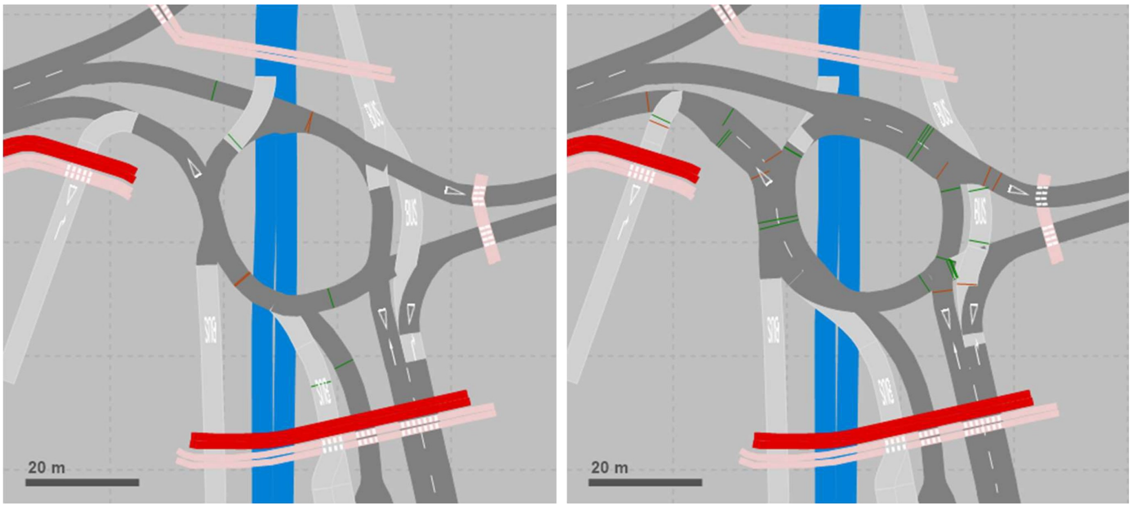

Figure 3.14: Priority rules in the adjusted model (left) and in mod 1 (right)

The position and settings of each stop line (in orange) and conflict marker (in green) were determined based on recommendations from the PTV manual.

3.8.3 Modification 2: Reduced speed areas

The second modification continued to build on the first with the changed road geometry. The field observations and video recordings showed that the 50 km/h speed limit was rarely met. This behaviour was replicated in the VISSIM model using *Reduced Speed Areas* (RSA).

In the original and adjusted model, these were the *Desired Speed Distributions* per vehicle class:
- Cars and trucks: 50 km/h
- Trams: 50 km/h
- Bus: 50 km/h
- Pedestrians: 5 km/h
- Bicyclists: 15 km/h

Initially, the desired speed distributions were checked for each road used by the vehicle classes to see if they complied with the road speed signs. For turning movements from Stampgatan to the roundabout, the speed limit was changed from 50 km/h to 40 km/h in alignment with road signs. The same was made for buses approaching the roundabout from the north.

In the adjusted model, the reduced speed differed for buses, cars and trucks. Cars consistently had a reduced speed of 5 km/h, faster than buses and trucks. The speed for buses and trucks varied between 15-20 km/h, and for cars, 20-25 km/h. The trams generally had a reduced speed of 12 km/h at turning movements, lane changes and signal heads. In the roundabout, cars had a speed of 20 km/h, and trucks and buses 15 km/h.

The video recordings showed that vehicles drive consistently and at a low speed into and inside the roundabout. Therefore, reduced speed areas were placed all over the roundabout but with less speed reduction. Taxis were observed to have a more aggressive driving style. However, they were not separated from private cars as their share of the total volume was unknown. The reduced speed areas in the roundabout were 30 km/h for cars and 25 km/h for trucks and buses.

It was also observed that vehicles reduce their speed before unsignalised, raised crossings for pedestrians and bicyclists, at sharp turns, and at merging or branching links. Therefore, RSA was implemented at these locations, with 25 km/h for cars and 20 km/h for buses and trucks.

The road segments with the original and modified RSA are presented in Figure 3.15.

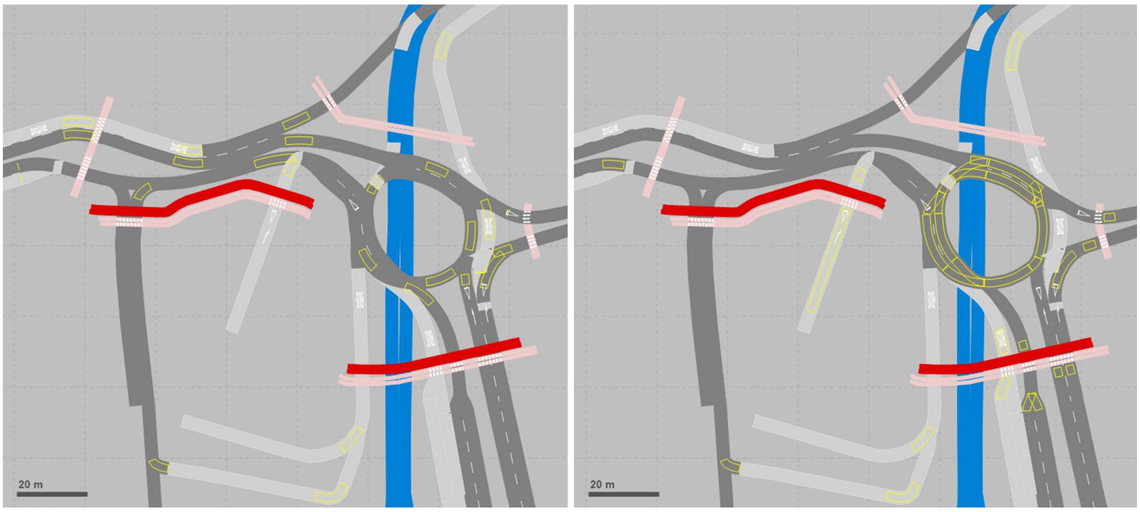

Figure 3.15: The RSA in mod 1 (left) and mod 2 (right)

3.8.4 Modification 3: Tram priority

Some unrealistic gridlocks and tram blockings were seen during the simulation of modification 2. To reduce these occurrences, tram priority was the main focus of the third modification, which continued to build upon the second modification.

First, the signal head for the south-going trams before the pedestrian crossing and bike lane between ÅTC and Scandic was removed. The reason for this was to give a clear way to the trams once they had a green light before entering the roundabout and to avoid trams blocking the vehicles waiting at the signal heads. Instead, trams were prioritised using *conflict areas*.

In the adjusted model and previous modifications, all conflict areas over the tram tracks were red-red, i.e. undetermined, and had the setting of avoiding blocking all flows. This was changed to see what settings resulted in tram priority, as it was unknown which flow was the major and the minor. The other changes to the conflict areas were:

- Allow blocking of all flows
- Allow blocking of only major flow
- Allow blocking of only minor flow

After each setting change, a quick control of the simulation was performed to see whether the changes had a desired impact. As these settings still seemed to make tram-crossing traffic block the trams, these red-red conflict areas were changed once more to red-green. Traffic flow from the tram tracks was the major (green) flow, and tram crossing traffic was the minor (red) flow. The settings were changed again as the detection of the flows was clear: the major and the minor. The settings of the conflict areas were:

- Avoid blocking of only major flow

A quick control of the simulation showed that the desired impact might have been reached, as no trams seemed to be obstructed as in previous modifications.

3.8.5 Modification 4: Bus priority

The fourth calibration consisted of all previous modifications as well as changes focused on the eastern entrance to the roundabout. The reasoning behind this modification was that buses were seen to be obstructed in their movement due to conflicts with traffic from Odinsgatan, which seemed to be a common cause for gridlocks; see Figure 3.16.

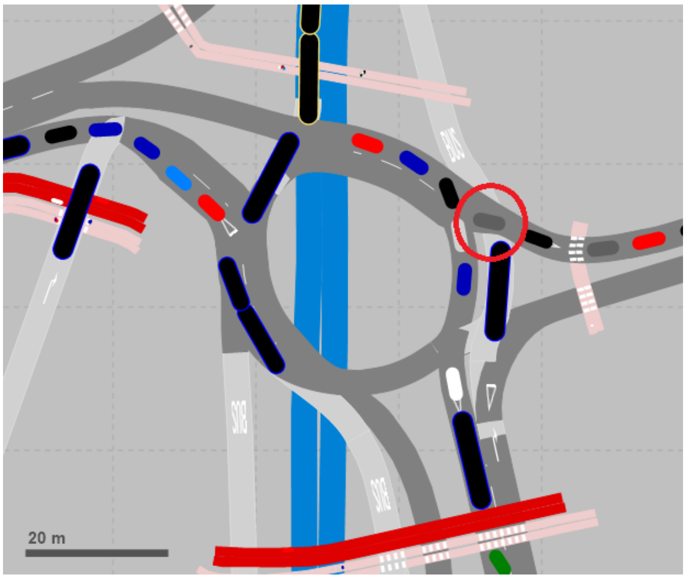

Figure 3.16: A car that stops and blocks the bus in the bus lane

This particular behaviour, where cars block the bus lane, eventually leading to a gridlock, was noted during field observations. Replication of this behaviour is realistic, but in the model simulations, this behaviour was unwanted. As VISSIM is unable to unlock the gridlocks this causes, it results in unrepresentative and unrealistic MOEs.

The settings were changed for some conflict areas, from only avoiding blocking the major flow to allowing all blocking to increase the bus priority, thereby reducing the number of bus blockings. After catching a glimpse of the simulation footage, the situation worsened, immediately causing gridlocks. To avoid all blocking, these links' settings were thereby changed again. This led to reserved behaviour among vehicles in the roundabout, which was changed yet again to ensure that only conflicts straight across the bus lanes were avoided.

Another change of blocking settings was made at the southern entrance to the roundabout, where the same avoiding behaviour of the vehicles in the roundabout was observed. The conflict areas were all changed from allowing blocking of major flow but not minor to allowing all blocking.

Several combinations of the conflict area settings were tried for the eastern entrance to the roundabout, where buses were blocked by vehicles during the simulation. Ultimately, giving the bus lane the right of way in the conflict area (green-red) with the settings to only avoid blocking the major flow showed promising visual results.

3.8.6 Modification 5: Final touches

From the vehicle travel time results from the fourth calibration, it was observed that the average and maximum travel time was underestimated for all routes except from Polhemsplatsen to Odinsgatan. In modification 5, changes were made to adjust the speeds once again. Other changes were regarding driving behaviour and link-changing behaviour.

From the actual results, the velocities were estimated for each route by travel time and travelled distances. The distance (in km) divided by the mean travel time (in hours) resulted in a mean velocity (km/h). These were the mean velocities for each route during the maximum quarter:

- Polhemsplatsen-Odinsgatan (S-E): 30 km/h
- Polhemsplatsen-Burggevegatan (S-W): 20 km/h
- Polhemsplatsen-Polhemsplatsen (S-S): 15 km/h
- Polhemsplatsen-Åkerigatan (S-N) (bus): 5 km/h
- Odinsgatan-Burggevegatan (E-W): 25 km/h
- Odinsgatan-Polhemsplatsen (E-S): 10 km/h
- Burggevegatan-Åkerigatan (W-N) (bus): 20 km/h
- Burggevegatan-Polhemsplatsen (W-S): 10 km/h
- Burggevegatan-Odinsgatan (W-E): 5 km/h

All listed velocities above are below the speed limit. These velocities were used to decide on reduced speed areas for each link. From Polhemsplatsen, the velocities were decided based on the fact that bus velocities were affected by bus stops, and the routes that pass the roundabout get a speed reduction due to the signal heads. Therefore, the speed from Polhemsplatsen was determined to be 30 km/h for cars and 5 km/h lower for buses and trucks. From Odinsgatan, the same reasoning led to a reduced speed of 25 km/h for cars and 5 km/h lower for buses and trucks. From Burggrevegatan, all mean velocities are affected by passing the roundabout. As the measured bus velocities were 20 km/h, this was the reduced speed for buses and trucks, and cars were set to 25 km/h.

Vehicle conflicts during lane changes were also discovered during the simulation runs, mainly at the pedestrian crossing at Polhemsplatsen. In modification 5, changes were made to avoid these conflicts by changing the diving behaviour and the lane-change location. The conflicts occurred as vehicles changed lanes at Polhemsplatsen, either by driving into preceding vehicles from behind in the from-lane or into vehicles in the to-lane during the change, see Figure 3.17.

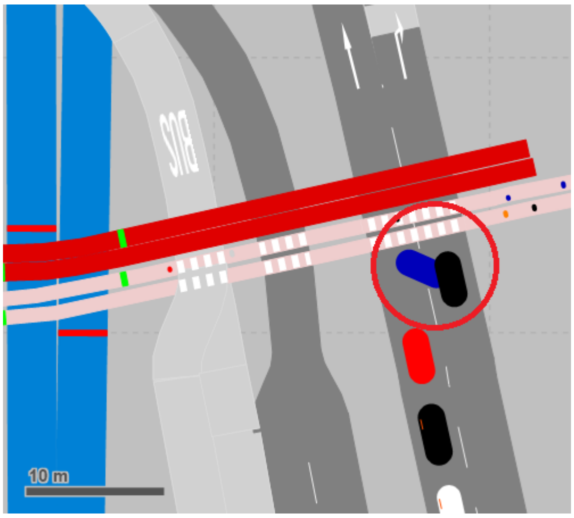

Figure 3.17: A conflict at Polhemsplatsen where the vehicle in the right lane (black) does not account for the lane-changing vehicle (blue)

The lane-changing behaviour had to be improved, and therefore, the link behaviour type was further investigated. The links where this behaviour was observed had a different link behaviour type than the majority of the links in the network, freeway instead of urban.

Lane changing behaviour

For the freeway link behaviour, the general behaviour allowed free lane change. Contrary to the urban link behaviour, the parameters of *Cooperative lane change* and *Rear correction of lateral position* were set. *Zipper merging* were not set for any link behaviours. To investigate what could be changed in the freeway driving behaviour to avoid collisions, one of the three parameters was changed one by one, and the times of collisions were noted upon simulating the modifications for a few minutes.

The zipper merging seemed to reduce the number of collisions but resulted in other odd driving behaviours.

The freeway driving behaviour was based on Wiedemann 99, and the urban driving behaviour on Wiedemann 74. According to PTV (2023), the urban driving behaviour type is suitable for urban city roads. In addition, the safety distances are greater for urban driving behaviours than freeway driving behaviours at low speeds. Therefore, the links on the routes from Polhemsplatsen towards the roundabout were changed in their driving behaviour from freeway to urban.

To avoid all lane changes from taking place right before or on the pedestrian crossings, the setting for lane change on an upstream connector was changed from an emergency stop position of 10 m to 15 m.

3.9 Model validation

After calibration, the model was validated to investigate whether it was sufficient to replicate reality. The validation was performed visually and statistically, weighing both the behaviour observed during the simulation runs and the simulation results of travel time and queue length. The calibration version that was deemed best at replicating real driving behaviour and accurately estimating the travel time and queue length was used in the validation process.

In the validation process, a different data set of the traffic flow than the one used in the calibration was used. Initially, cross-validation was to be performed. However, since extracting the travel time and queue length from field data was too time-consuming, the data set used in the validation was simply from a different quarter. Since the model should be valid for other traffic states than the maximum quarter, all other quarters were gathered in a random number generator. The quarter on which the validation would be based was assigned from the generator, and this quarter turned out to be during the first field observation day on a Monday from 15:15 to 15:30. This quarter had the lowest traffic flow during the afternoon peak hour, and so the validation was thereby performed for the minimum quarter.

The vehicle input for the minimum quarter was extracted using the same approach as for the maximum quarter in section 3.3. The vehicle input data for the minimum quarter was multiplied by four to get the flow by the hour, and the share of cars and trucks was calculated. The OD-matrix can be seen in Figure 3.17.

Table 3.17: OD-matrix for cars (98.2 %) and trucks (1.8 %) during the minimum hour [veh/h]

O/D	Odinsgatan	Polhemsplatsen	Burggrevegatan	Sum
Odinsgatan	4	68	40	112
Polhemsplatsen	44	24	164	232
Burggrevegatan	32	76	8	116

The input data resulted in a total vehicle volume of 460 vehicles, a reduction of about 40 % from the initial input of 776 vehicles. The input for bicyclists and pedestrians was unchanged, as they were assumed not to affect the overall traffic situation. The input for public transportation was also unchanged, as the quarter is within the weekday peak hours for public transit at 15:00-18:00.

The MOEs of queue length and travel times were extracted from the video recordings following the same procedure as in section 3.7. However, one of the video recordings with a good view of Burggrevegatan had been lost and could not be restored. The other camera's view was obstructed as some duct tape used to keep the camera stands in place had come off. This led to some routes and queue lengths being excluded in the extraction of MOEs. The MOEs were extracted for the queue length (average and max) of Polhemsplatsen and the average and maximum travel time for the routes:

- Polhemsplatsen-Odinsgatan (S-E)
- Polhemsplatsen-Polhemsplatsen (S-S)
- Polhemsplatsen-Åkerigatan (S-N)
- Odinsgatan-Polhemsplatsen (E-S)

In summary, 10 MOEs could be extracted from the video material.

The errors between calibration 5 and its actual data obtained from the maximum quarter were compared with the errors between the validated simulation results and the MOEs from the actual validation data set, i.e., the minimum quarter.

3.10 Scenarios

To investigate what changes in design and traffic state have the potential to improve Åkareplatsen, different scenarios were created in VISSIM. Ideas for improvements to be implemented in VISSIM were based on field observations and the interviewees involved with Åkareplatsen. The improvements were categorised according to the national transport authority's four-step principle and simulated thereafter.

The four-step-principle and the changes belonging to which step are (Trafikverket, 2021):

1. Rethink: changes to the need for, or use of, the transportation infrastructure
2. Optimise: more efficient use of the infrastructure at hand
    - Change relevant bus routes from entering the roundabout to going through the roundabout instead
    - Remove signal heads in the roundabout and use warning lights for tram-crossing traffic instead
3. Rebuild: smaller changes to the infrastructure
    - Elongate the roundabout to ensure that a tram can fit inside of it and two buses around it
4. Build new:

- Create a four-way crossing instead of having a roundabout

The scenarios were created based on modification 5. The first step of rethinking was not implemented as there was no reasonable way to model this. The last step of building new was also not implemented into a scenario because of the study's time restrictions.

3.10.1 Optimise

A link from the tram tracks to the bus lane was added to be able to reroute the affected routes of lines X3, 173, 513, and 510 from Åkerigatan (N) through the roundabout to Polhemsplatsen (S). See Figure 3.18 for the before and after the rerouting.

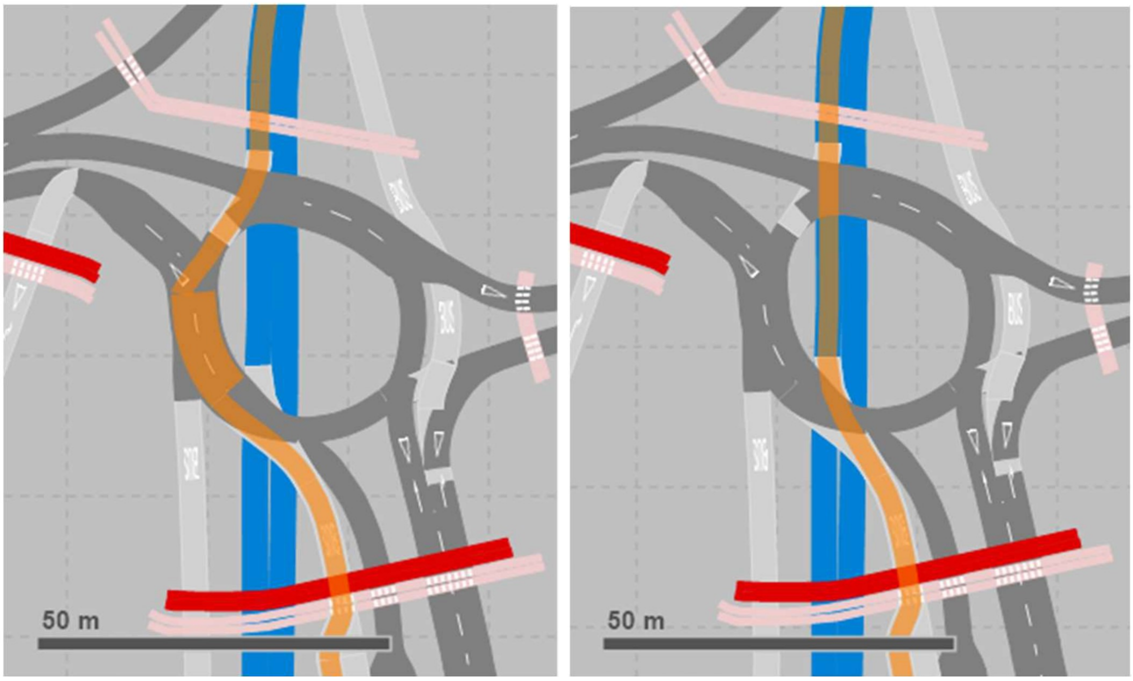

Figure 3.18: The old bus route in the roundabout (left) and the new straight through (right)

The fact that buses and trams share the tramway for a longer distance was approved by the manager of the track facilities, with a disclaimer that this will wear on the tracks (M. Mickelsen, personal communication, 13 March, 2024).

New conflict areas appeared with the new link and routing, which got new prioritisation to ensure buses, like trams, have the right of way through the roundabout. All signal heads in the roundabout were removed and replaced with bus- and tram priority in conflict areas. Instead, warning signals notify all tram track crossing traffic of trams and buses. This change was suggested by M. Lorentzon (personal communication, 12 March, 2024), but can negatively affect traffic safety according to M. Mickelsen (personal communication, 13 March, 2024). Trams should be prioritised over buses according to customary practice (C. Liljebjer, personal communication, 12 March, 2024). Based on this, conflicts involving buses and trams at Åkerigatan were changed so that trams have the right of way of buses.

3.10.2 Rebuild

The elongation of the roundabout can lead to enough space for a tram to come to a hold inside of it without obstructing the vehicles in the roundabout using the roads. This alternative design also means that two buses can stop inside the roundabout without doing so in the middle of a turn, which might cause the end of the bus to block the tram tracks. This alternative with elongating the roundabout was approved by C. Liljebjer (personal communication, 12 March, 2024) and M. Mickelsen (personal communication, 13 March, 2024). The trams are 33 m, and the longest bus is about 19 m. Therefore, the roundabout was elongated until there was room for one tram and two buses. With these changes, the queue counter for Polhemsplatsen was adjusted.

During field observations, pedestrians were jaywalking between Åkareplatsen Travel Centre and the Central Station. The signalised pedestrian crossing was moved about 40 m east, closer to the roundabout, to facilitate their needs and increase safety. The changes to the layout of the roundabout and the pedestrian crossing are seen in Figure 3.19.

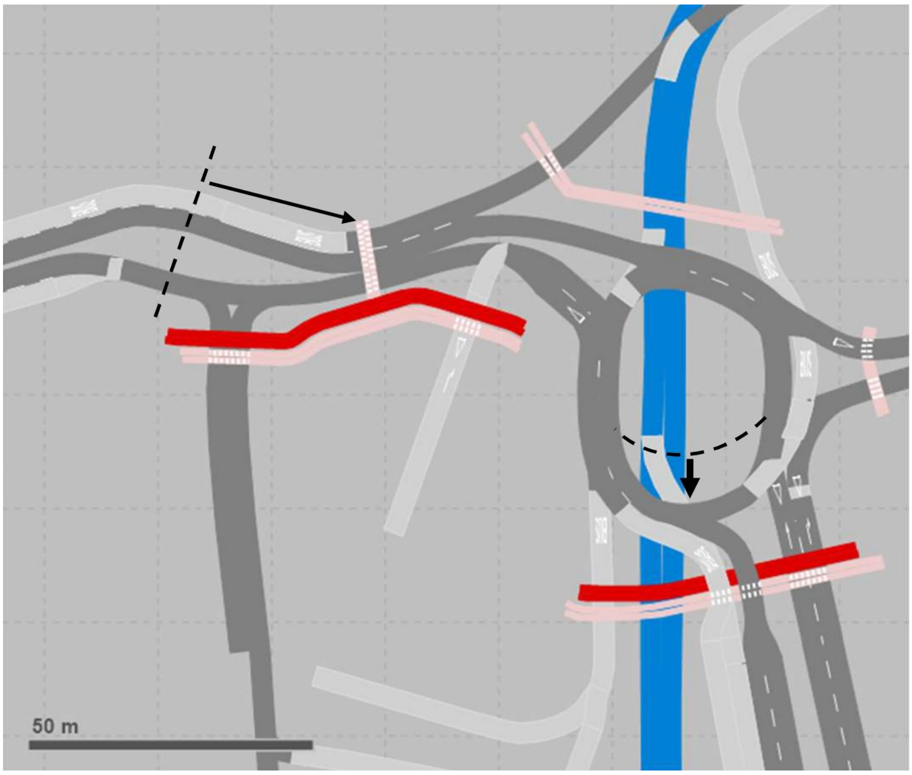

Figure 3.19: Changes to the layout in the rebuilding scenario

3.11 Stress test

For the last and final scenario, a stress test was conducted to see how an increase in public transportation load affects the alternative improvement design to account for any future need. The load increases were 50% and 100%.

The original input data for all public transportation line frequencies before the load increase can be seen in . The increase in line frequencies means that a line frequency of 312 seconds, as for line X4, was increased to a higher frequency of 234 seconds for a 50 % increase and 156 seconds for a 100 % increase. This means that the amount of public transportation vehicles is 150 % and 200 % of the original input.

4

Results

This section includes all partial findings of this study, comments on these findings, and consecutive answers to the research questions.

4.1 Site observations

The somewhat unconventional design of Åkareplatsen and the many modes of transportation make the traffic situations at the site, in many cases, different from the normal and expected. The traffic conditions and problems that were observed during the site observations are presented in this section.

4.1.1 Gridlocks

Roundabout gridlocks where traffic is blocked in all directions were observed on multiple occasions, and they took longer time to recover from than usual queues. The gridlocks were consistently due to high public transport densities. They occurred if there were too many buses in the roundabout or if a bus obstructed the movement of passing trams. Buses entering ÅTC or Polhemsplatsen bus stop A were found blocking the tram tracks multiple times as they exited the tram tracks and moved into the roundabout, leading to gridlocks. Figure 4.1 and Figure 4.2 are examples of gridlocks.

Figure 4.1: A gridlock due to a bus blocking the trams in both directions

Figure 4.2: A gridlock caused by the vehicles in the roundabout blocking a bus trying to enter the bus lane

4.1.2 Queues

Queue formations were mainly observed on the west and south legs of the roundabout in the direction of the roundabout. They also appeared on the southern leg, away from the roundabout. During observations, the queues were usually quickly formed and dissolved in a 5-10 minute interval. Longer queue build-ups were observed at the passing of several trams or, in the case of system gridlocks. Buses, and occasionally trams, were involved in the queues and were the main cause of them. Cars were rarely observed to be the cause of queues, even if the car density was relatively high. This was likely due to their relatively small size and their routes having fewer potential conflicts. See Figure 4.3 for a queue forming at Burggrevegatan.

Figure 4.3: Observed queue formation at Burggrevegatan

4.1.3 Driving behaviour

The driving behaviour differed between the modes of transportation, but one thing they all had in common was the low speed that rarely seemed to reach the speed limit of 50 km/h. Generally, taxis and buses drove more confidently and determined than car drivers, who occasionally seemed confused. Buses and taxis seemed to have less gap acceptance than car drivers. In addition, car drivers were treating the wider lanes from the west and east into the roundabout as two lanes and were occasionally blocking the bus lane to the north. This behaviour, where cars treat the roundabout's eastern leg as two lanes, can be seen in Figure 4.4.

Figure 4.4: Cars wrongfully queuing in two lanes, blocking the bus from entering the dedicated bus lane

4.1.4 Movement of cyclists and pedestrians

Generally, bicyclists and pedestrians were using their destined paths. People on bicycles and e-scooters were also seen riding on the pedestrian sidewalks and on the road. This behaviour was observed when there was a lack of bicycle lanes, mainly from Odinsgatan in the east to Central Station in the west. Pedestrians were seen jaywalking at several locations. Some walked across the entire roundabout, over car lanes and tram tracks, but most took the shortcut from ÅTC to the Central Station. However, this behaviour did not appear to interrupt the road traffic; see Figure 4.5.

Figure 4.5: Pedestrians jaywalking from ÅTC to the Central Station.

4.1.5 Vehicle behaviour at pedestrian- and bicycle crossings

Pedestrians and bicyclists were given their right of way. However, cars and buses were observed to be blocking pedestrian crossings while queueing several times, mainly at the unsignalised crossings between Hotel Scandic Crown and ÅTC and the ÅTC exit. A bus blocking the crossing between Scandic and ÅTC can be seen in Figure 4.6.

Figure 4.6: Bus blocking pedestrian- and bicycle crossing while queuing

4.2 Initial simulation results

The results from the original model, the adjusted model and actual data from video recordings were compiled in Excel graphs. The simulation results are from a 3-hour simulation of 10800 seconds in intervals of 15 minutes or 900 seconds. The results from video recordings of field data were from the maximum quarter and presented over the same time period of three hours. At Odinsgatan (E), the queue length could not be observed during the field data collection, and therefore, no actual queue lengths at this street could be obtained. In Figure 4.7 and 4.8, the average queue lengths at Polhemsplatsen (S) and Burggrevegatan (W) are presented. Note that the actual is the average value throughout the entire observed data set.

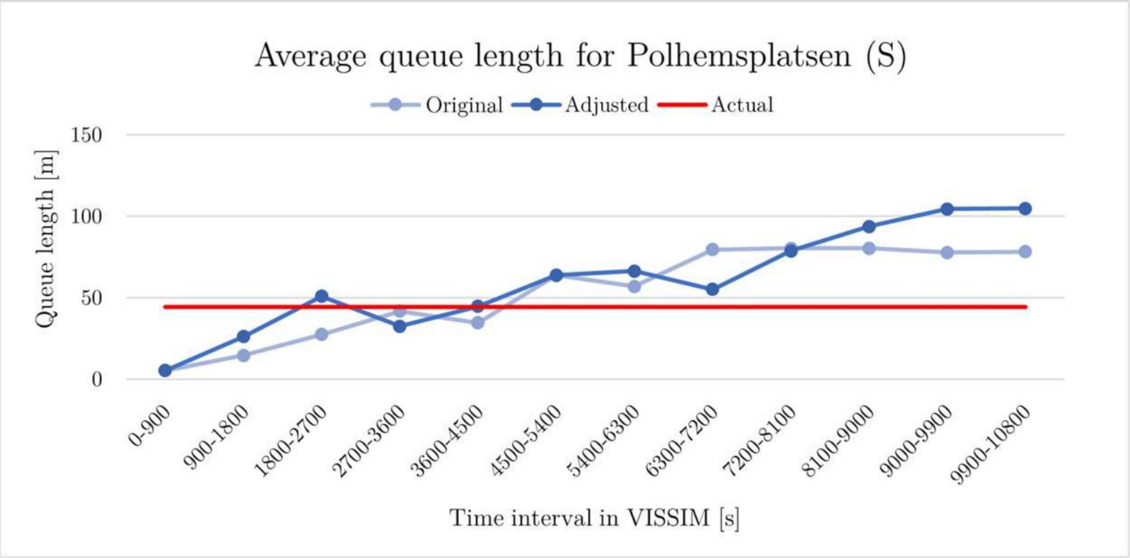

Figure 4.7: The average queue length at Polhemsplatsen (S)

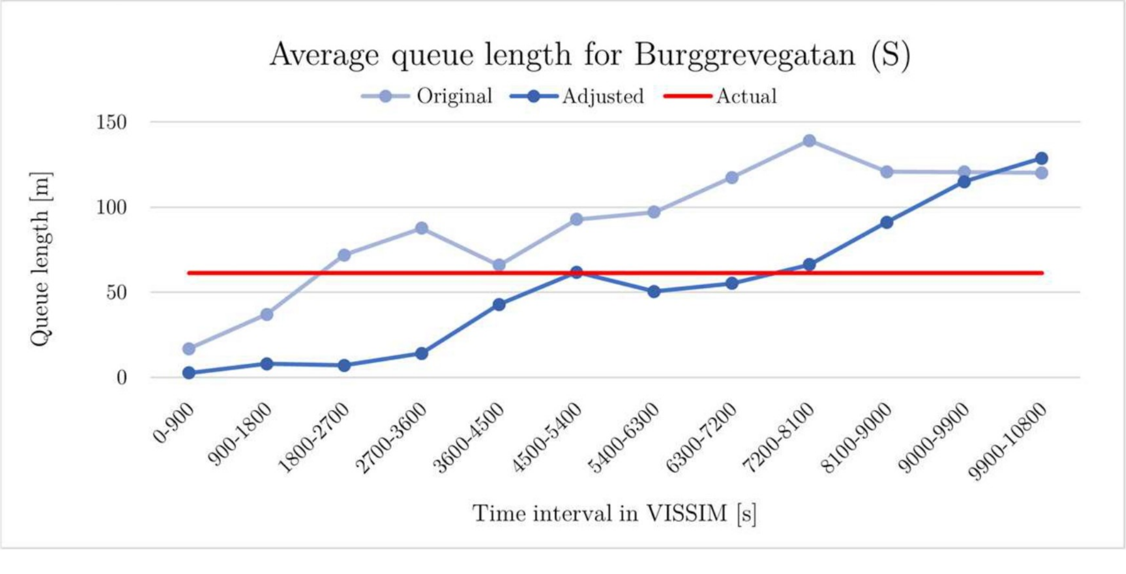

Figure 4.8: The average queue length at Burggrevegatan (W)

Both the original and the adjusted model show average queue lengths below the actual mean at the beginning of the simulation and above the actual mean at the end. At Polhemsplatsen, the two models estimate the queue length similarly, except for at the very beginning and end.

In Figure 4.9 and 4.10, the average vehicle travel times between Polhemsplatsen (S)-Burggrevegatan (W) and the other way around are presented. Note that the thin red lines represent the minimum and maximum observed values, respectively.

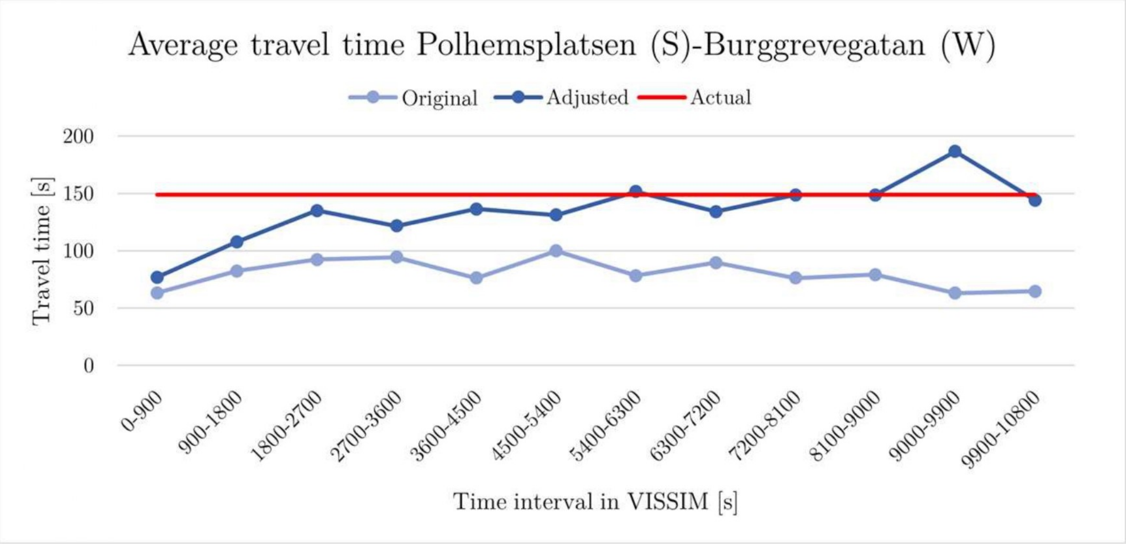

Figure 4.9: The average vehicle travel time for Polhemsplatsen (S)-Burggrevegatan (W)

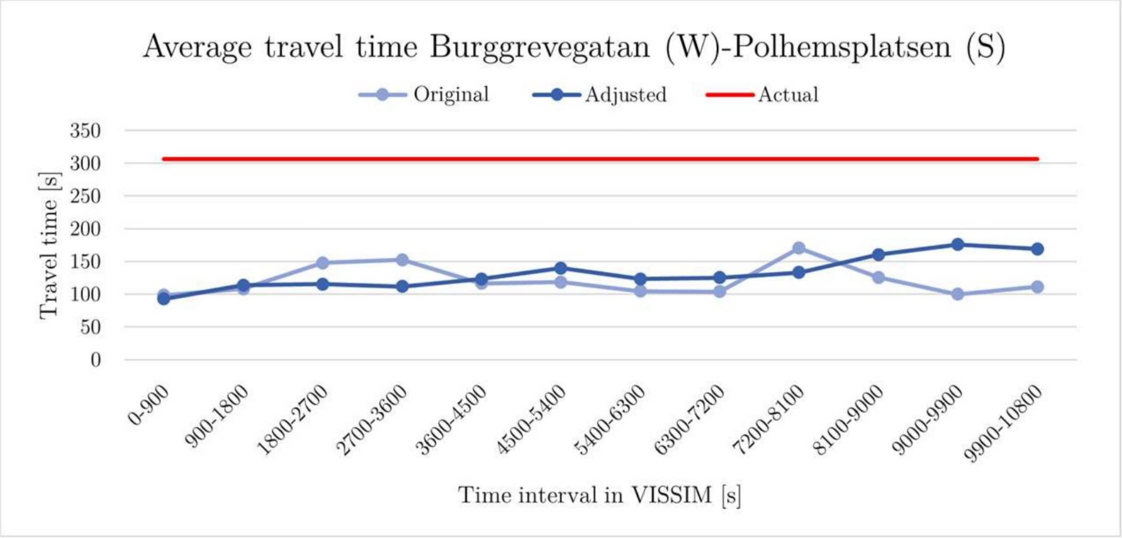

Figure 4.10: The average vehicle travel time for Burggrevegatan (W)-Polhemsplatsen (S)

The results show that the adjusted model more accurately estimated the mean travel time between Polhemsplatsen-Burggrevegatan than the original model and that they perform similarly for Burggrevegatan-Polhemsplatsen.

In Figure 4.11, the average vehicle travel times between Polhemsplatsen (S)-Odinsgatan (E) for cars and trucks are presented.

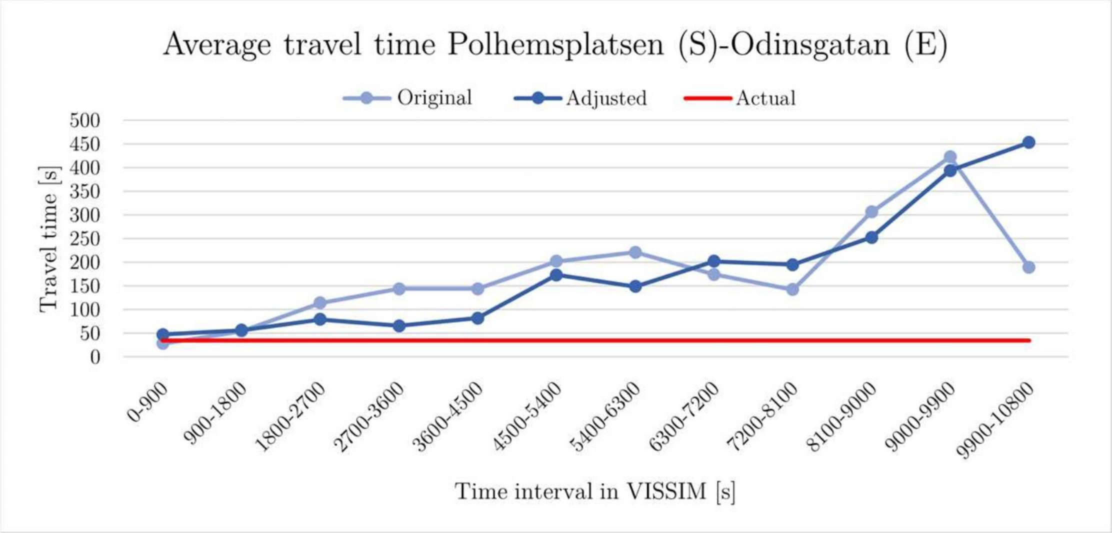

Figure 4.11: The average vehicle travel time for Polhemsplatsen (S)-Odinsgatan (E) for private transportation

As can be seen, the actual average travel time was measured to be consistently lower than the simulated travel times, except for the very first time interval for the original model.

In Figure 4.12 and 4.13, the average vehicle travel times between Burggrevegatan (W)-Odinsgatan (E) and Odinsgatan (E)-Polhemsplatsen (S) for cars and trucks are presented.

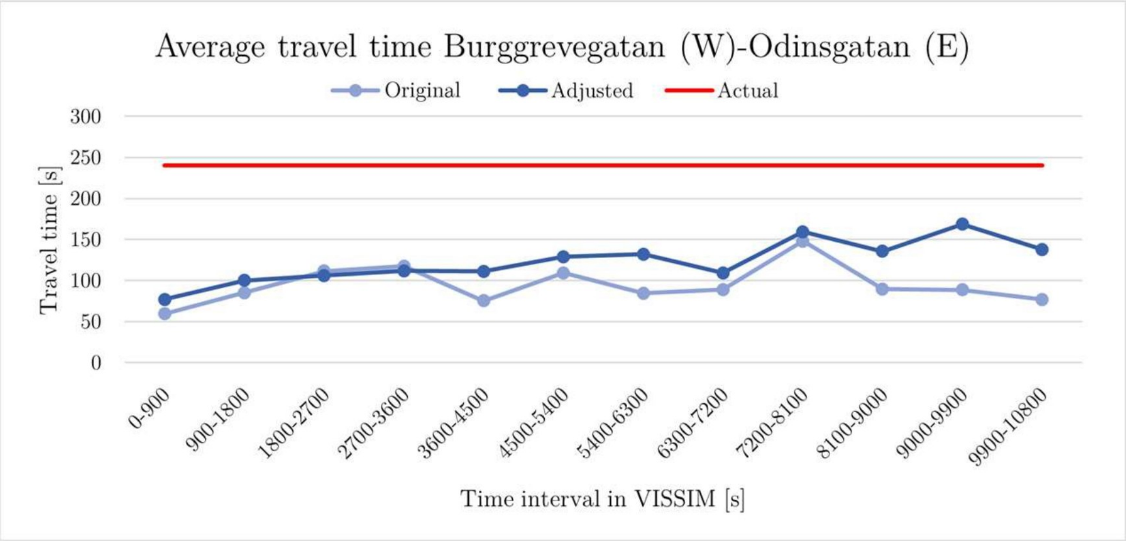

Figure 4.12: The average vehicle travel time for Burggrevegatan (W)-Odinsgatan (E)

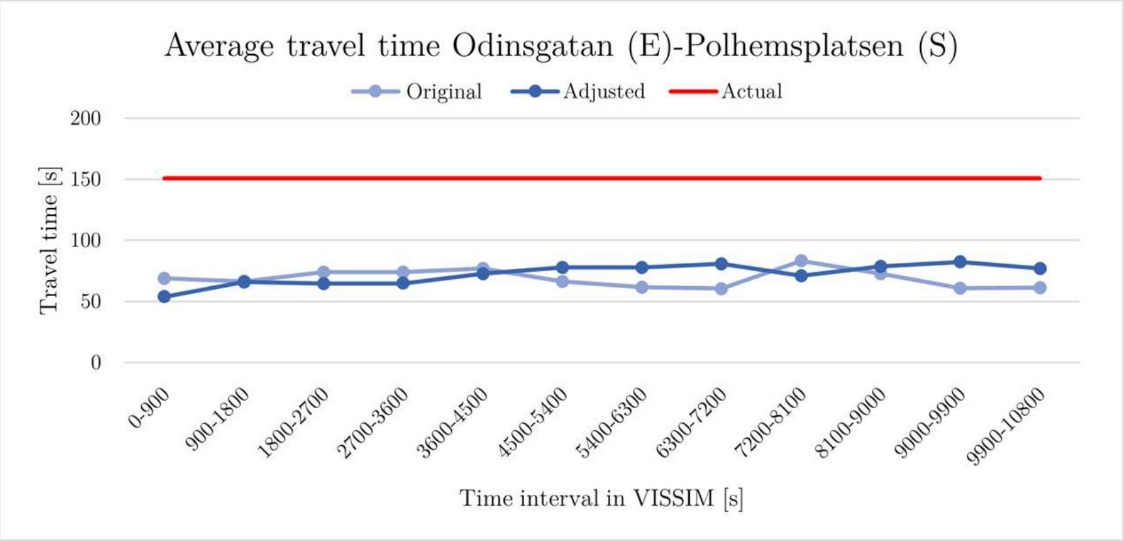

Figure 4.13: The average vehicle travel time for Odinsgatan (E)-Polhemsplatsen (S)

The results show that the actual travel time is consistently higher than the simulated travel times for both the original and the adjusted model.

In Figures 4.14, 4.15, 4.16, and 4.17, the overall mean values of the average and maximum queue lengths and vehicle travel times from the original model, the adjusted model, and the actual values are presented.

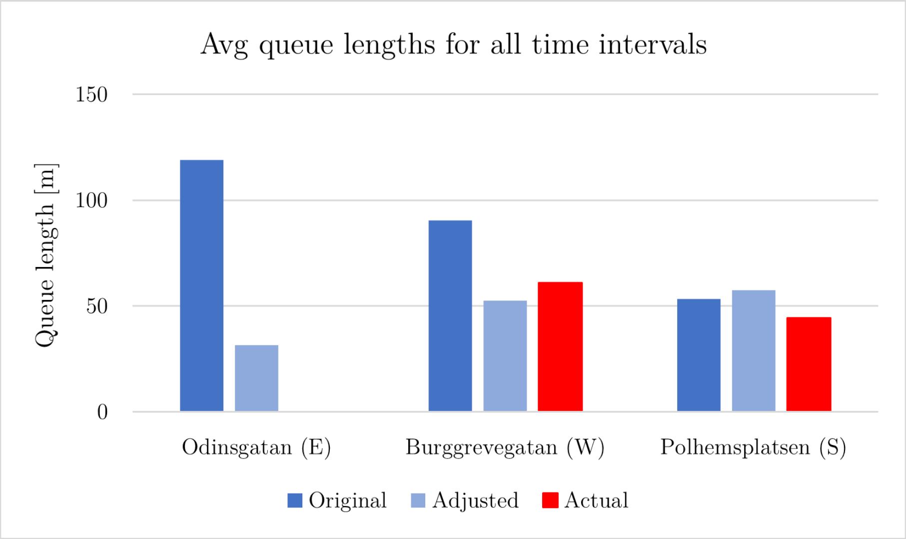

Figure 4.14: The mean of the average queue lengths

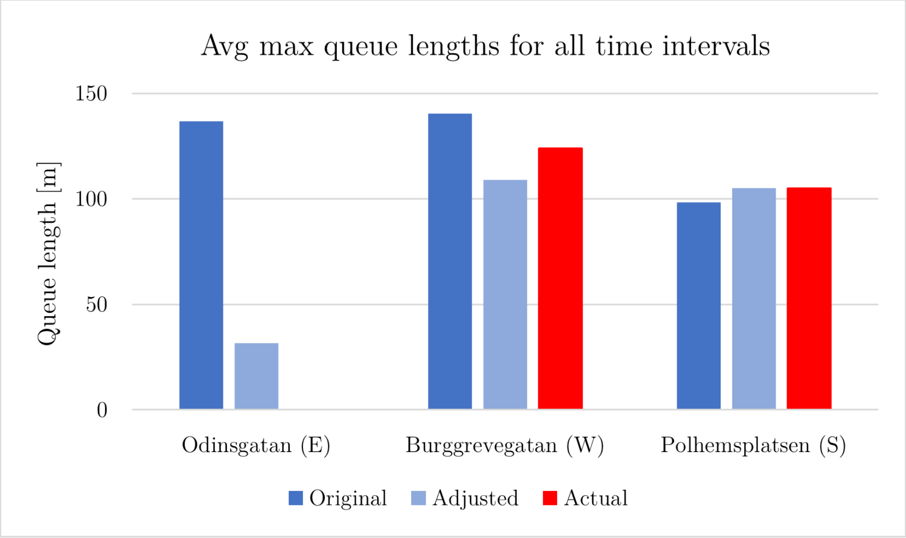

Figure 4.15: The mean of the maximum queue lengths

The actual values for the average mean and maximum queue length at Burggrevegatan are intermediate between the original model's higher estimation and the adjusted model's lower estimation. At Odinsgatan, a significant difference of about 50-100 meters is found between the average and maximum queue lengths.

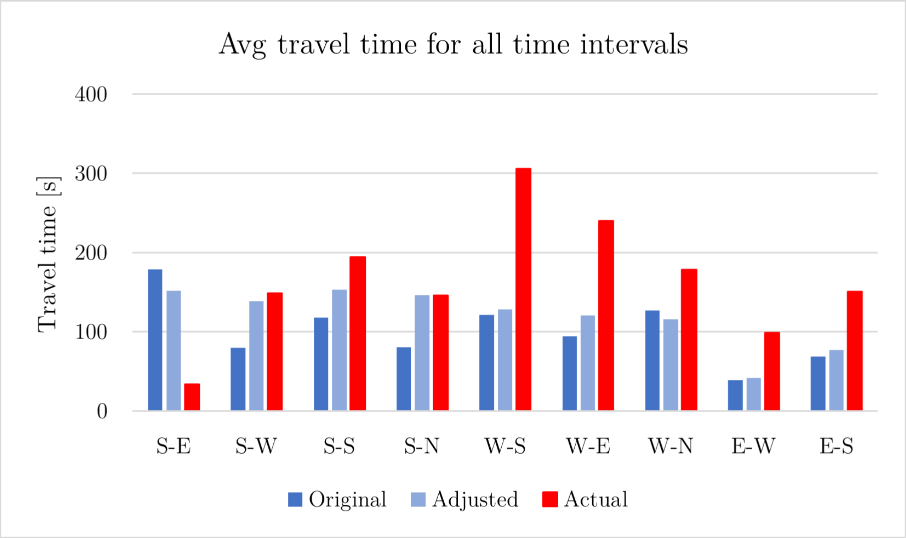

Figure 4.16: The mean of the average vehicle travel times

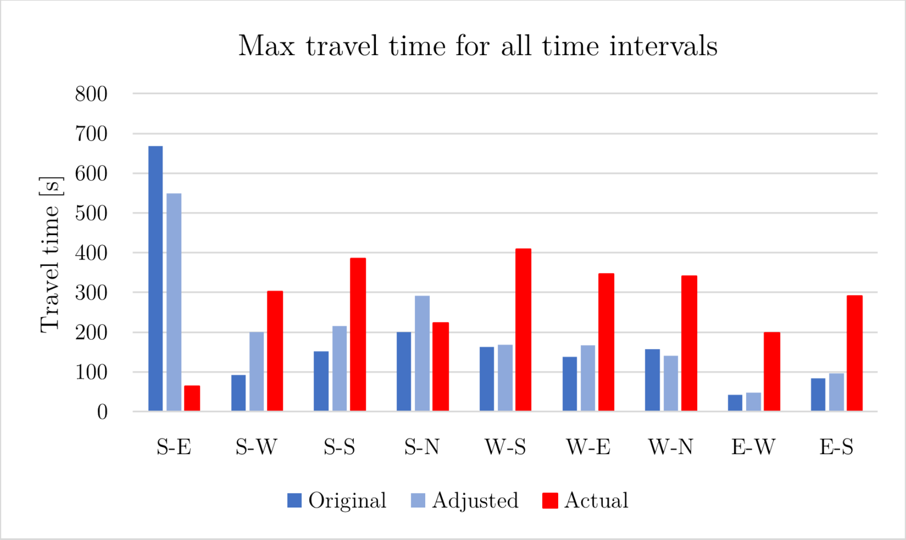

Figure 4.17: The mean of the maximum vehicle travel times

The results show that the models underestimate the average and maximum travel time, especially from Burggrevegatan (W) and Odinsgatan (E). This is the case for most routes, except for Polhemsplatsen (S)-Odinsgatan (E), where the trend is the opposite.

4.2.1 Initial error

To what extent the original and adjusted models deviate from the actual queue length and travel time is measured with the root mean square error (RMSE). The errors are presented in Appendix Table A.2 and A.3 for queue lengths and travel times, respectively. The RMSE for the original and the adjusted models, both for average and maximum queue length and travel time, can be seen in Figure 4.18.

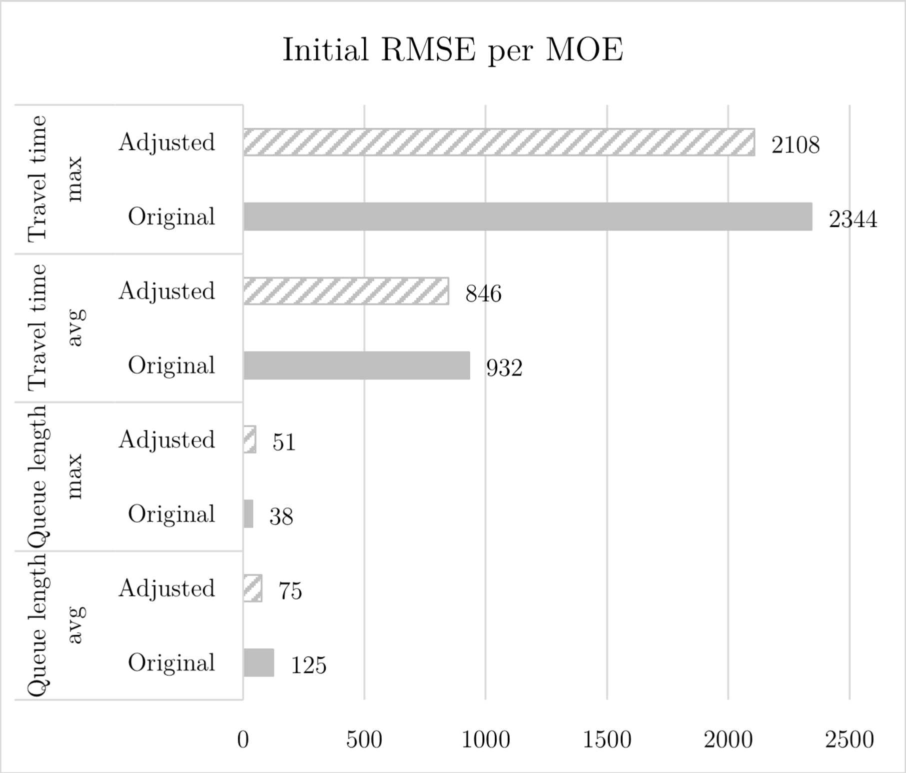

Figure 4.18: The total RMSE for queue length and travel time for the initial results

As can be seen, the adjusted model has a lower RMSE compared to the original model for all MOEs except for maximum queue length. The difference is marginal, and the largest deviance of 50% between the two models is the RMSE for the average queue length; see Table 4.1.

Table 4.1: The difference of RMSE for all MOEs between the original and the adjusted model

MOE	**Difference**	**Difference [%]**
TT max	236 s	11
TT avg	86 s	10
Q max	-13 m	29
Q avg	50 m	50

The summarised RMSE for the original and the adjusted model are presented in Figure 4.19.

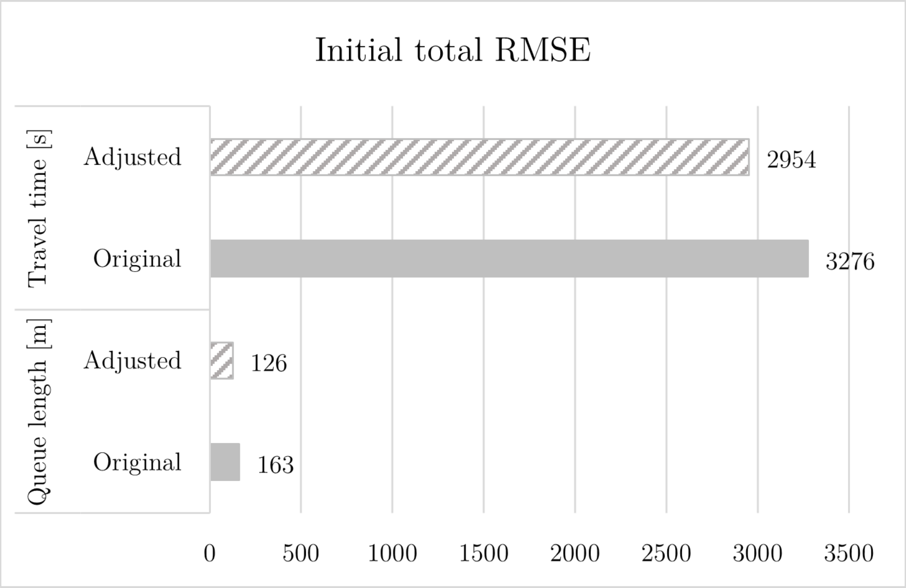

Figure 4.19: RMSE for queue length and travel time from the initial results

In summary, the adjusted model deviates less from the observed data. The absolute and percentage difference between the two models outcomes of RMSE can be seen in Table 4.2, where the difference in travel time is about 10 % and queue length about one quarter.

Table 4.2: The difference of the total RMSE for QL and TT between the original and the adjusted model

MOE	Difference	Difference [%]
TT	322 s	10
QL	37 m	26

4.3 Calibration results

This section includes the results from the simulations of the calibrated adjusted model versions, including descriptions of the driving behaviour, the MOEs of queue length and vehicle travel time, and the RMSE. All calibration results are from one hour of the three-hour simulation for the time intervals of 3600-7200 seconds.

4.3.1 Modification 1: Road geometry

The first calibration consisted of the first modification of changes to the road geometry to match the actual physical appearance of the study area.

Driving behaviour
Car- and truck drivers were using the wider lanes from the west and east into the roundabout as two lanes, and the first modification consisted of changing from one

to two lanes to capture this behaviour. The original road geometry and the changes made in the first modification can be seen in Figure 4.20.

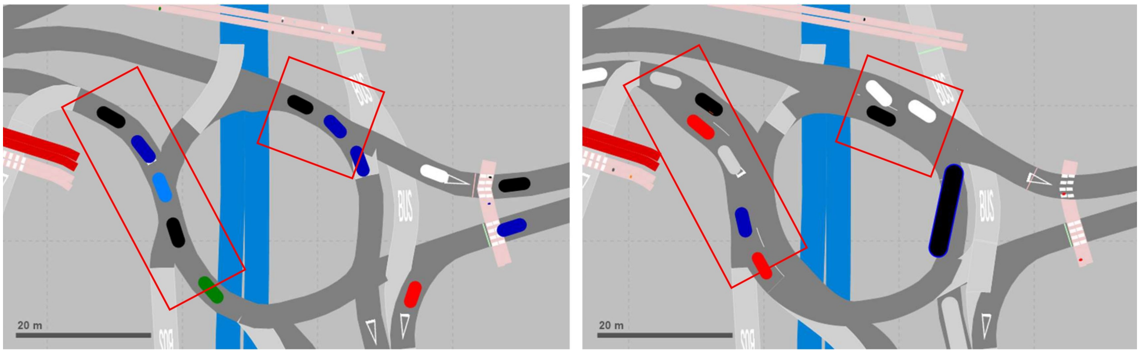

Figure 4.20: Behaviour in the one-laned adjusted model (left) and two-laned modified model (right)

As can be seen, the behaviour of using the one wide lane as two lanes was successfully captured in the first modification. During the simulation, the trams were observed not continuing their path into the roundabout, thereby blocking the flow of other trams and buses from Åkerigatan. This may have resulted in fewer public transit vehicles in the roundabout, which also might have affected the visual appearance of the simulation as well as the MOEs of the first calibration.

Other temporary gridlocks were observed, where buses in the bus lane were blocked by vehicles that stopped and began queuing across the bus lane when entering the roundabout from the east, see Figure 4.21.

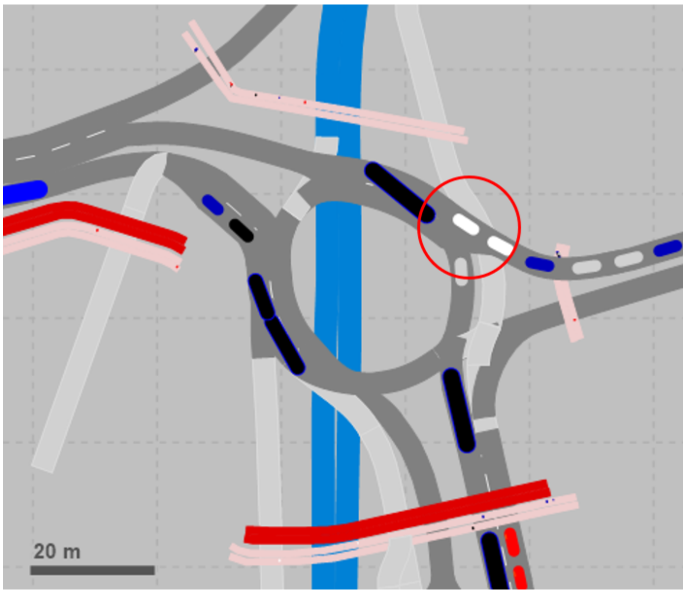

Figure 4.21: A car blocking the path of the articulated bus to enter the bus lane

MOEs
The average queue length at Burggrevegatan after the first calibration, compared to the adjusted and actual results, can be seen in Figure 4.22.

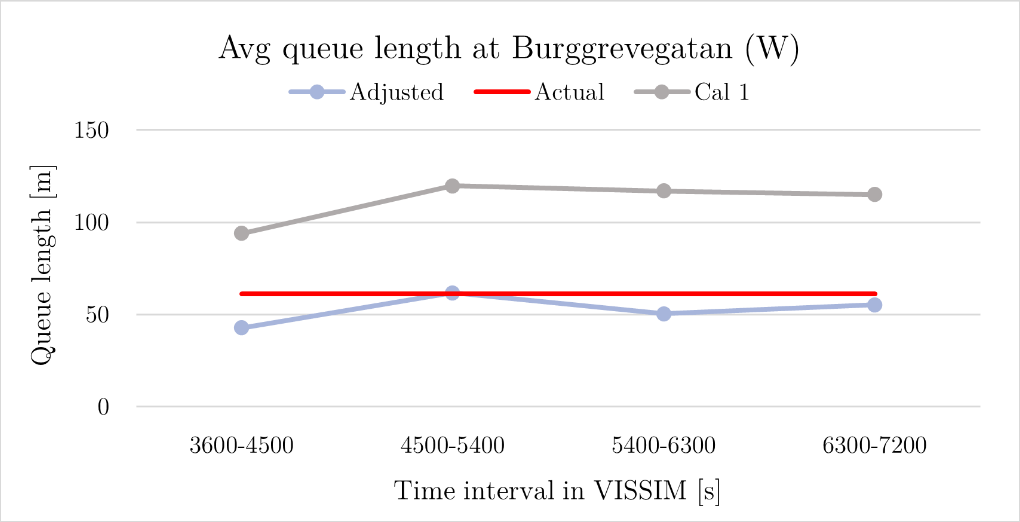

Figure 4.22: Average queue length at Burggrevegatan after calibration 1

As can be seen, the first calibration captures the average queue length at Buggrevegatan less accurately than the adjusted model.

The vehicle travel time from the adjusted model and after the first calibration can be seen in Figure 4.23 for trips from Burggrevegatan to Polhemsplatsen and in Figure 4.24 and vice versa. The average vehicle travel time between Polhemsplatsen and Odinsgatan can be seen in Figure 4.25 and in Figure 4.26 the other way around.

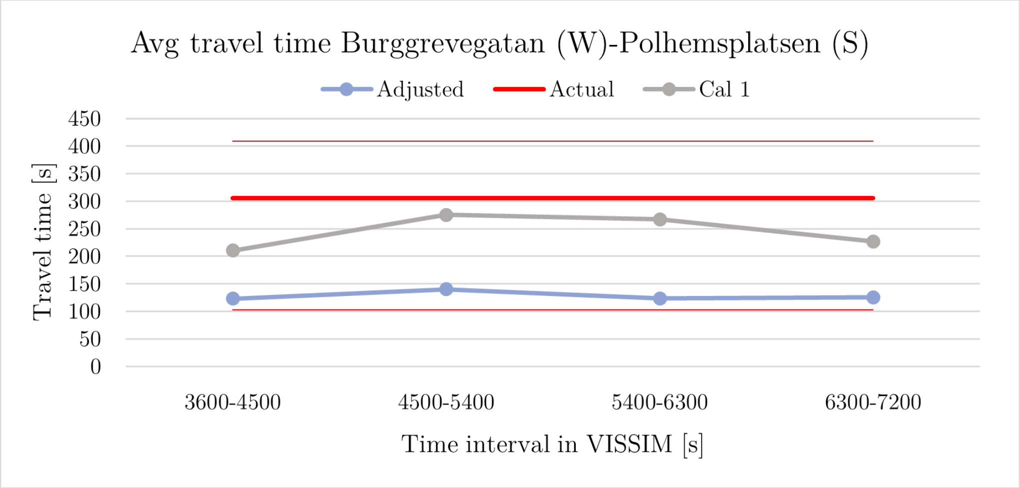

Figure 4.23: Average vehicle travel time for Burggrevegatan-Polhemsplatsen after calibration 1

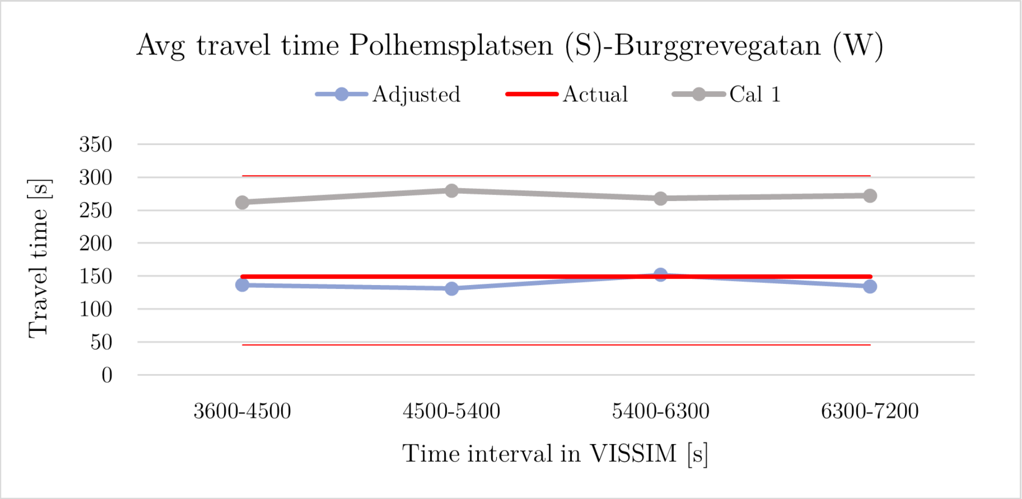

Figure 4.24: Average vehicle travel time for Polhemsplatsen-Burggrevegatan after calibration 1

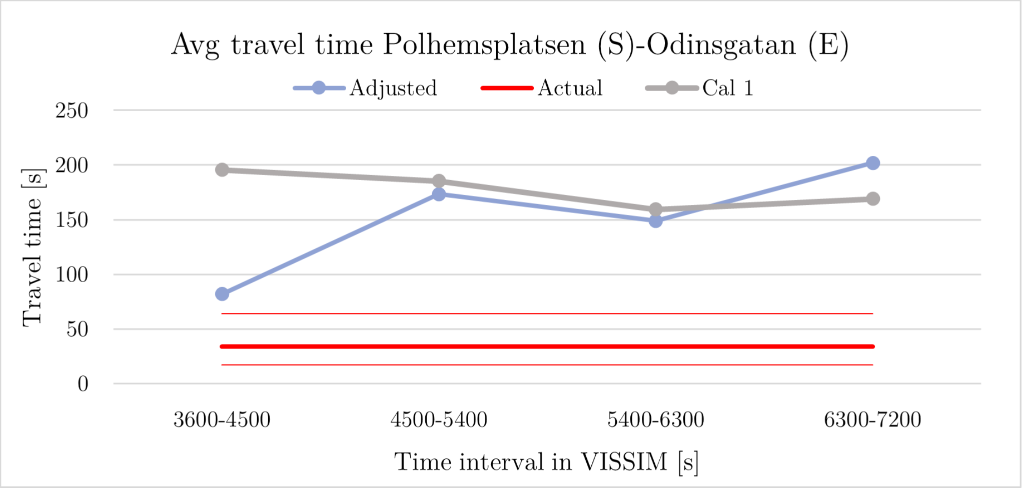

Figure 4.25: Average vehicle travel time for Polhemsplatsen-Odinsgatan after calibration 1

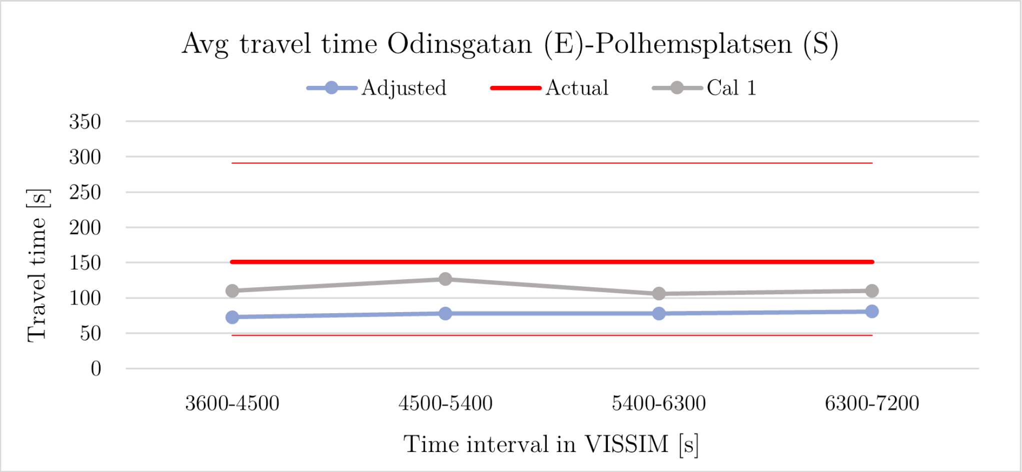

Figure 4.26: Average vehicle travel time for Odinsgatan-Polhemsplatsen after calibration 1

The calibrated model estimated the travel time more accurately for Buggrevegatan to Polhemsplatsen and the adjusted model for Polhemsplatsen to Burggrevegatan. From Polhemsplatsen to Odinsgatan, both models highly overestimate the travel time above the maximum observed values at all time intervals. This route does not involve interactions with the roundabout and only accounts for cars and trucks. From Odinsgatan to Polhemsplatsen, the travel times for both models were for all time intervals kept within the range of what was observed, where calibration 1 performed slightly better than the adjusted.

In Figures 4.27, 4.28, 4.29, and 4.30, the overall mean values of the average and maximum queue lengths and vehicle travel times from the first calibration, the adjusted model, and the actual values are presented.

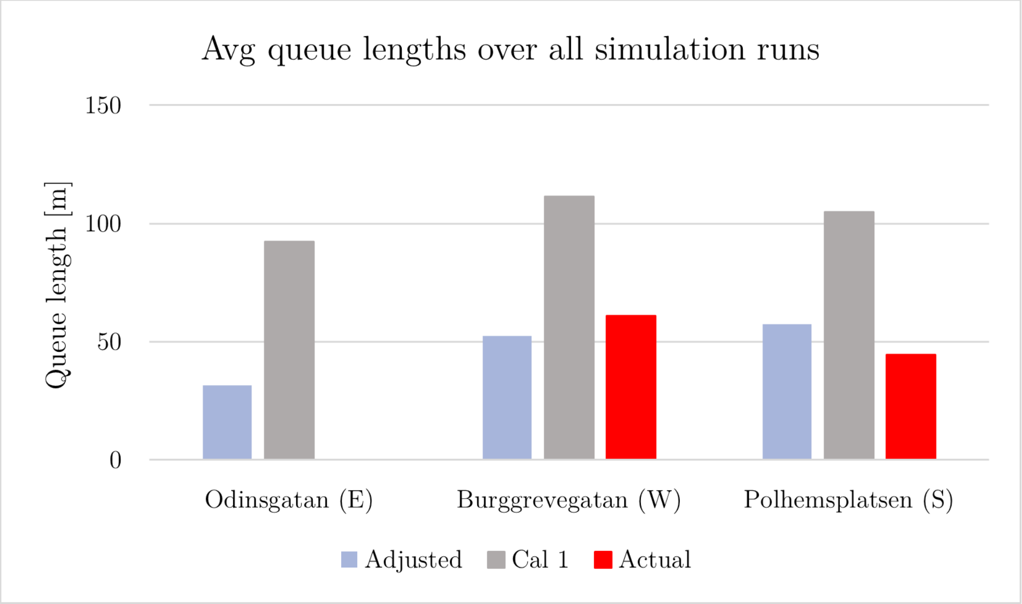

Figure 4.27: The mean of the average queue lengths for the first calibration

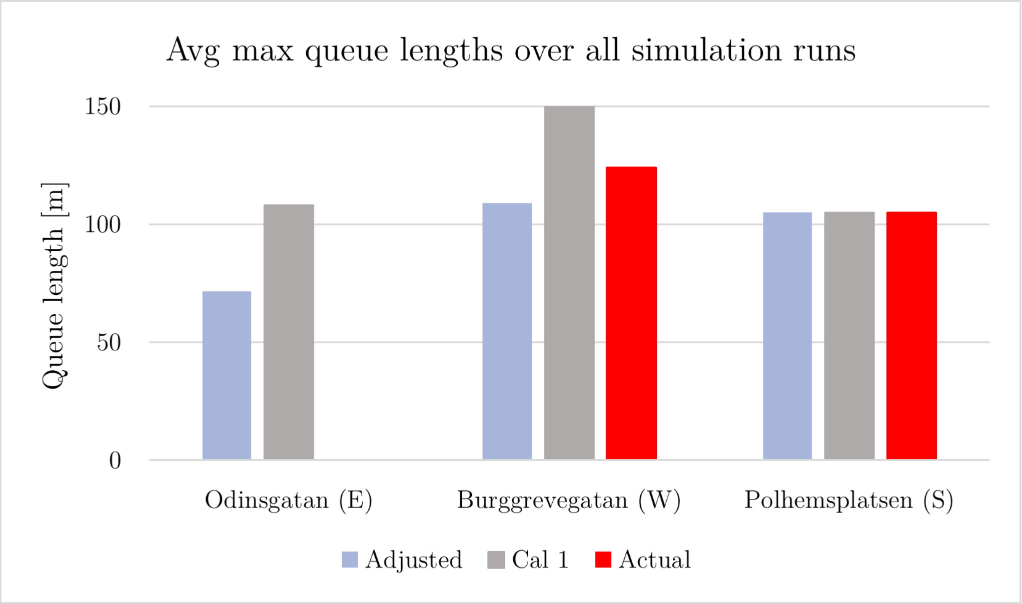

Figure 4.28: The mean of the maximum queue lengths for the first calibration

The first calibration overestimated the queue lengths at all legs, except for the maximum queue length at Polshemsplatsen (S), where both models reached the maximum possible length of 105 m, as was seen during the field observation.

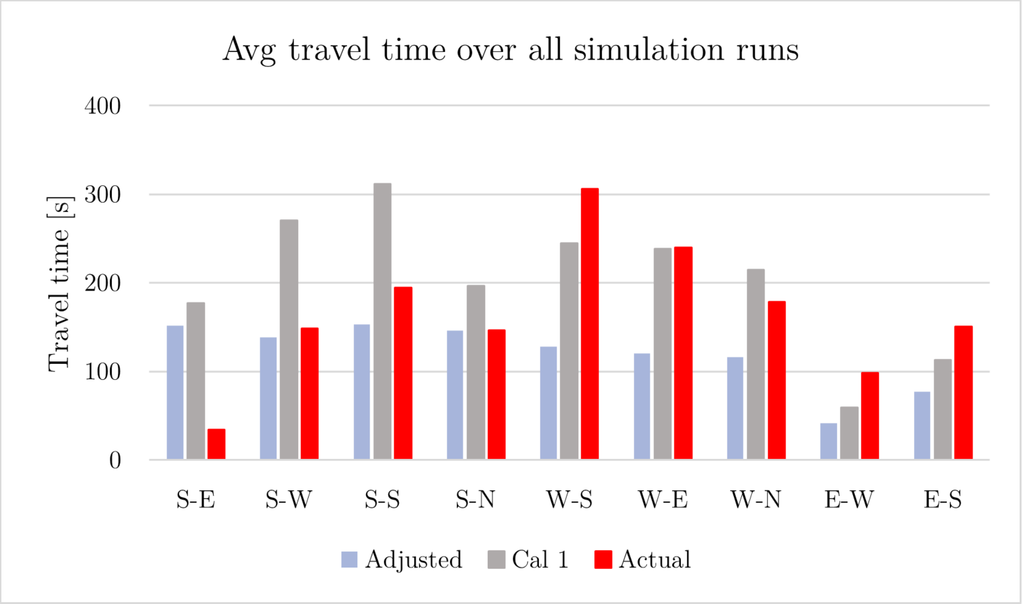

Figure 4.29: The mean of the average vehicle travel times for the first calibration

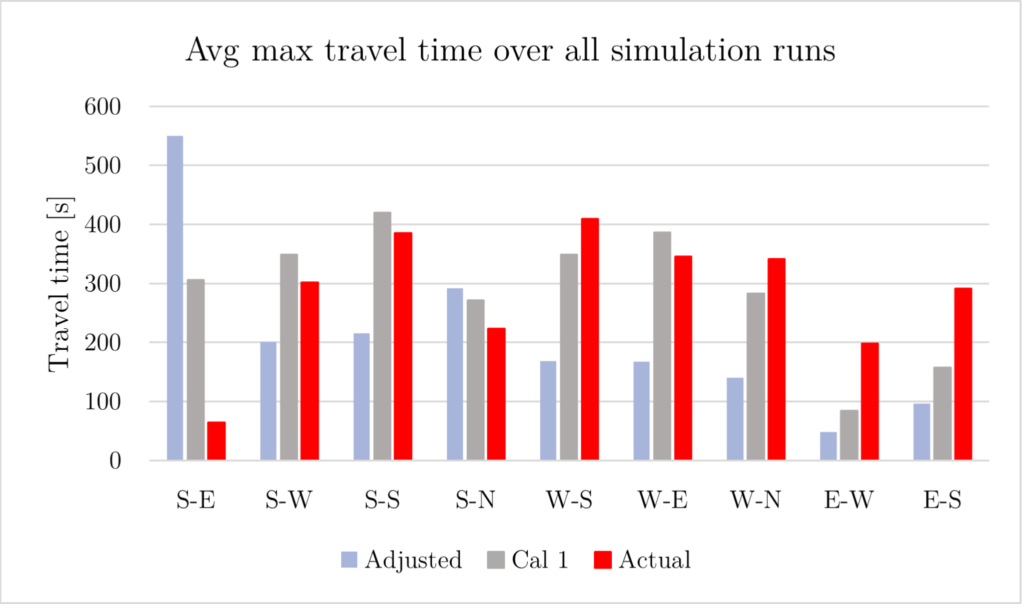

Figure 4.30: The mean of the maximum vehicle travel times for the first calibration

The average and maximum travel time is overestimated from Polhemsplatsen (S) and underestimated from Odinsgatan (E) for calibration 1.

Error
The RMSE for all MOEs followed the same pattern, meaning that the adjusted models, both average and maximum queue lengths, had more significant errors than those of the first calibration. The comparison between the accumulated RMSE for the first calibration and the adjusted model can be seen in Figure 4.31.

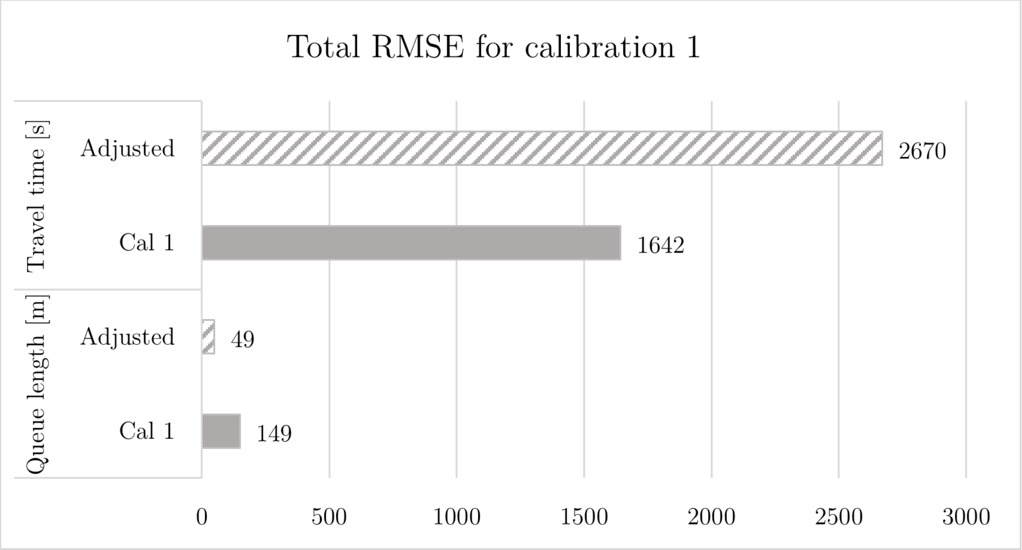

Figure 4.31: The total RMSE for queue length and travel time for the first calibration

The results show that the RMSE for calibration 1 is about 27 minutes off the actual travel time and 149 meters off the actual queue length. Changing the model parameters of the road geometry led to a lower total error than the actual values. As seen in Table 4.3, the travel time was improved by 48 % in the first calibration compared to the adjusted model, while the queue length became less accurate by 101 %.

Table 4.3: The difference in total RMSE for the MOEs between the adjusted model and the first calibration

MOE	Difference	Difference [%]
TT	1028 s	48
QL	-100 m	101

4.3.2 Modification 2: Reduced speed areas

Driving behaviour

The second modification, composed of reduced speed areas, resulted in a more consistent speed in the entire study area and a consistently lower speed in the roundabout. This driving behaviour complies with how the traffic moves about in reality.

During some of the simulation runs, the trams from Polhemsplatsen and Åkerigatan were still obstructed from continuing through the roundabout, such as in Figure 4.32. These partial gridlocks did not dissolve once they were formed.

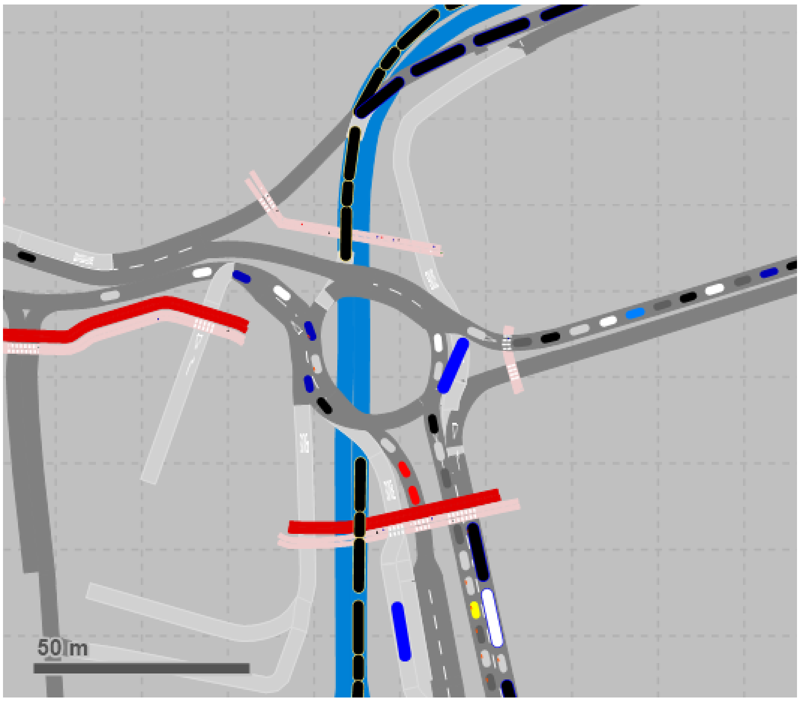

Figure 4.32: A two-way tram gridlock observed in calibration 2

Another gridlock, including trams, buses, and all transportation modes in the roundabout, occurred during the simulations. See Figure 4.33 for an example of a gridlock like this.

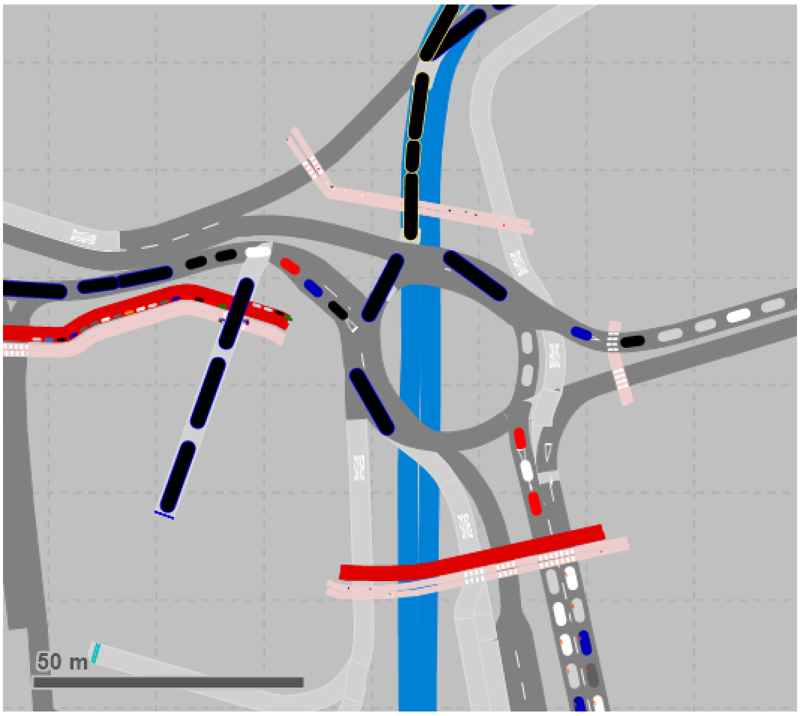

Figure 4.33: A gridlock consisting of trams and buses observed in calibration 2

MOEs
In 8 out of the 10 simulation runs for the second calibration, total system gridlocks appeared, which never dissolved. Vehicle travel time could be obtained for all time intervals and routes in two simulation runs.

In Figures 4.34 and 4.35, the overall mean values of the average and maximum queue lengths and vehicle travel times from the performed calibrations, the adjusted model and the actual values are presented.

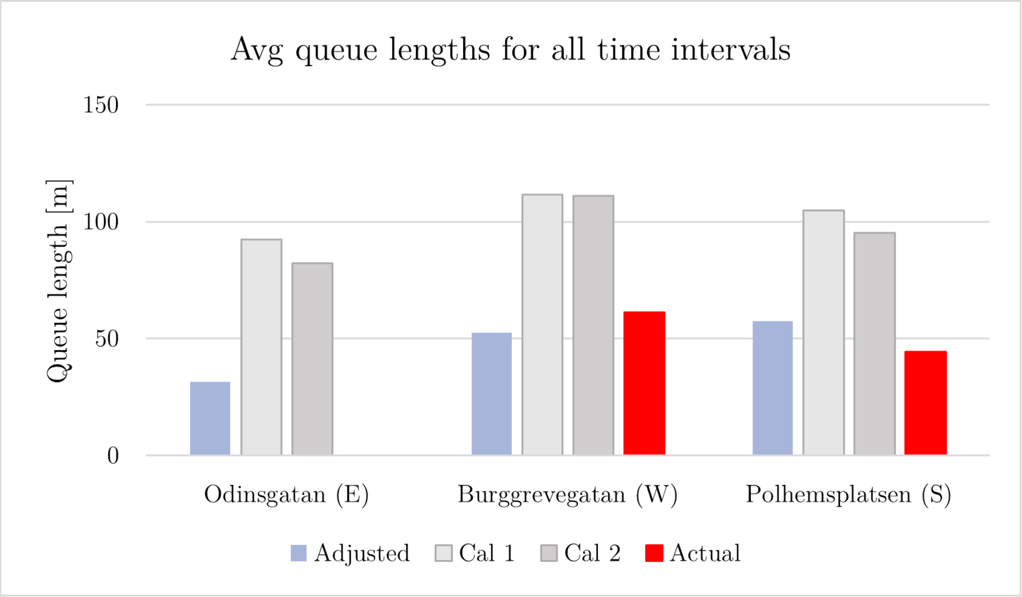

Figure 4.34: The mean of the average queue lengths for the second calibration

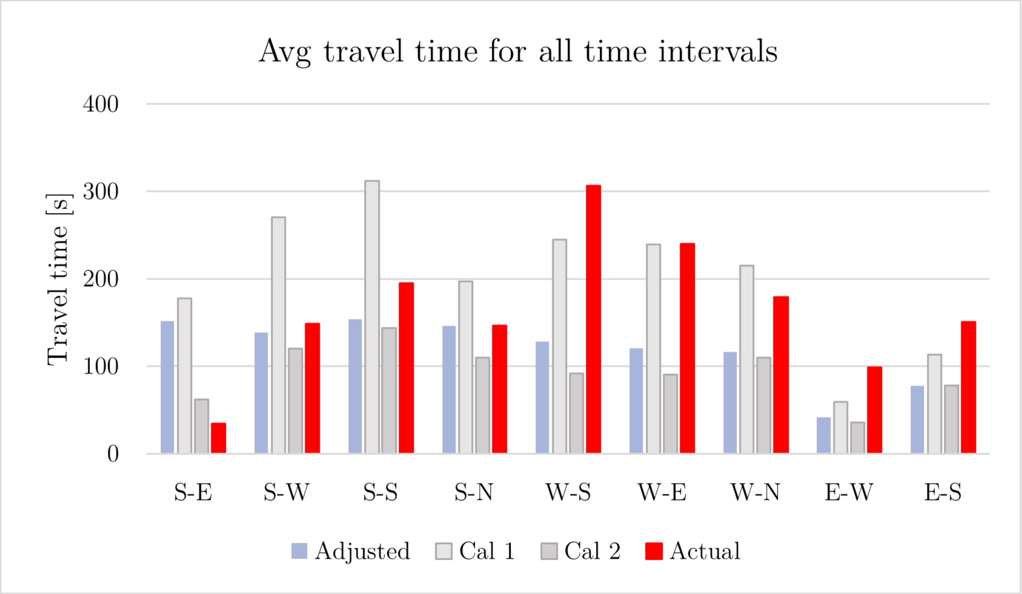

Figure 4.35: The mean of the average vehicle travel times for the second calibration

Calibration 2 has a slightly more accurate average queue length compared to calibration 1. It is more accurate when estimating the average travel time from Polhemsplatsen (S), which successfully decreased. On the other hand, it performs worse than calibration 1 from Burggrevegatan (W) and Odinsgatan (E), where it undesirably decreased.

Error
Only two complete simulation runs could obtain stochastic variability, which is why

the MOEs' error was not calculated in this calibration. In other words, this simulation did not produce any realistic gridlocks, so further calibration was necessary.

4.3.3 Modification 3: Tram priority

The third calibration included modified road geometry, reduced speed areas and ensured tram priority by changing conflict areas, among other things. The simulation results for the intervals of 3600-7200 showed that there had been gridlocks, causing the measurements of travel time and queue length to be faulty at some of the simulation runs.

Driving behaviour
The simulation showed an improvement in the trams' driving behaviour, as they no longer stagnated at the roundabout road crossings. The gridlocks observed in this case seemed realistic and not caused by faulty tram behaviour; see Figure 4.36 for an example of this situation.

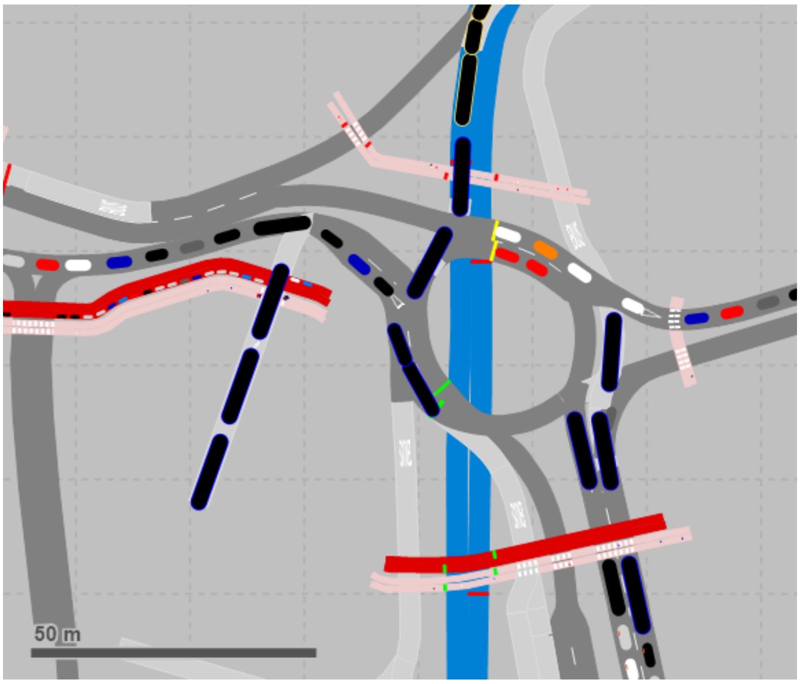

Figure 4.36: A gridlock seen during simulation of calibration 3

The reason for this gridlock was the white queueing cars at the eastern entrance to the roundabout that obstructed the north-going bus in the bus lane, causing the articulated bus in the roundabout to not proceed in its path. This behaviour was seen multiple times during field observations, making this gridlock realistic. However, in reality, they were eventually dissolved due to the obstructing cars' attempt to make room for buses by reversing or squeezing into the roundabout.

MOEs
The average and maximum travel time and queue lengths were calculated for all

simulation runs and all time intervals which showed no signs of gridlocks. The mean average queue lengths and vehicle travel times from the performed calibrations, the adjusted model, and the actual values are presented in Figures 4.37 and 4.38.

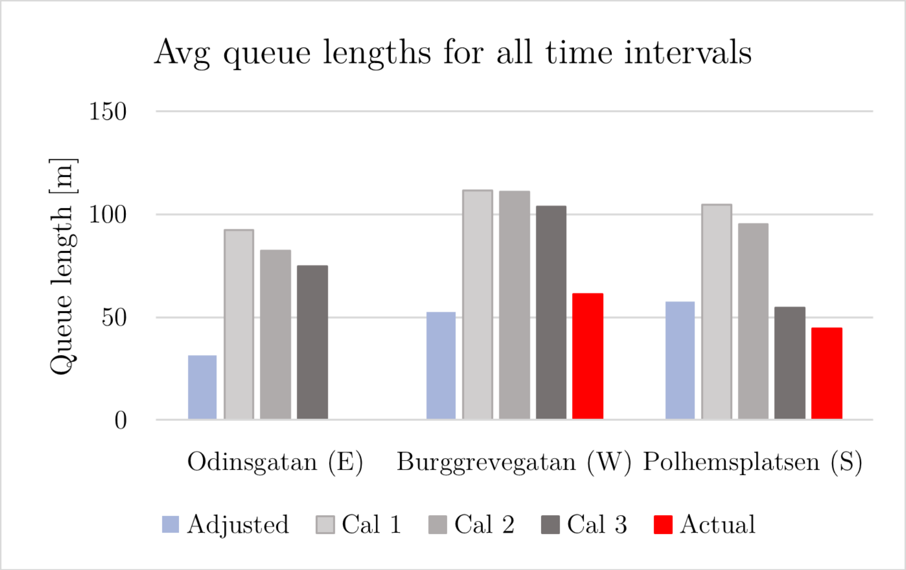

Figure 4.37: The mean of the average queue lengths for the third calibration

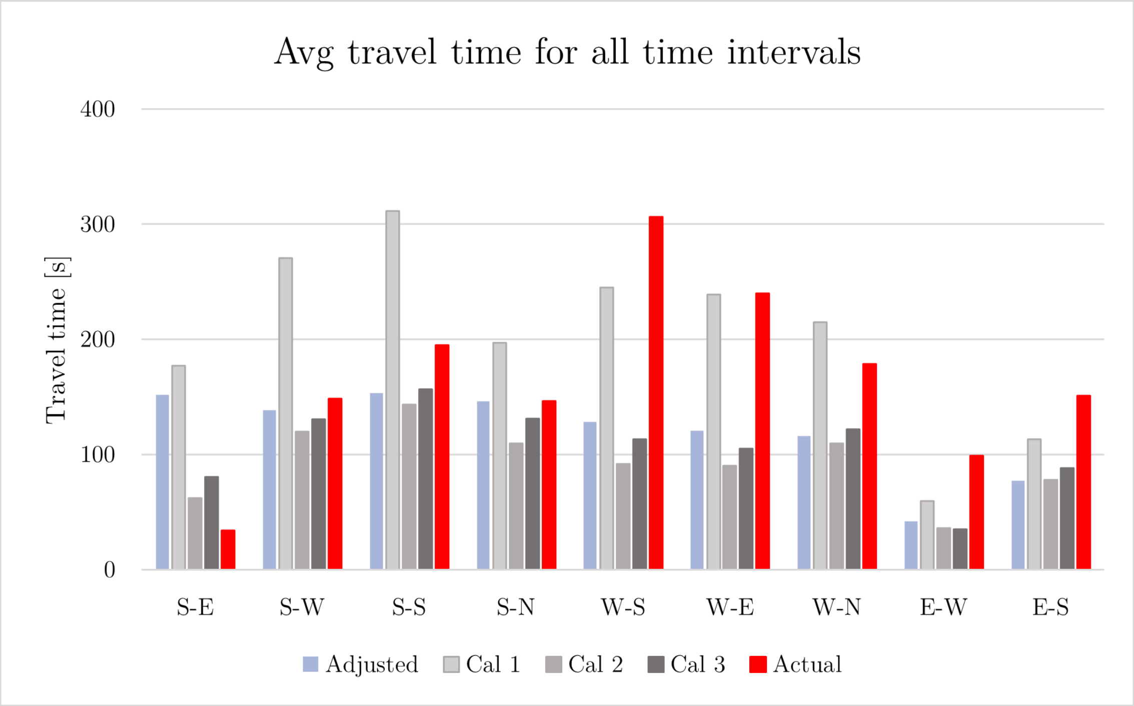

Figure 4.38: The mean of the average vehicle travel times for the third calibration

As can be seen, the third calibration more accurately represents the actual average queue lengths at Buggrevegatan and Polhemsplatsen. It also seems to accurately estimate the travel time from Polhemsplatsen (S-W, S-S, S-N), but other routes are less accurate than the first calibration.

Error

Like the second calibration, the gridlocks prevented the results from capturing the stochastic variability. Even though the queue lengths had data from all 10 simulation runs, the error was considered too unrepresentative to be included. For vehicle travel time in the different time intervals, the number of successful simulation runs varied from 1 to 7, which was considered too sparse.

4.3.4 Modification 4: Bus priority

In the fourth modification, at least six simulation runs produced values for all time intervals and routes, meaning that no gridlock appeared during the time intervals between 3600-7200 seconds for these six runs.

Driving behaviour

The bus priority was achieved at the southern and eastern interactions with the dedicated bus lane, resulting in a better traffic flow and fewer gridlocks.

A more realistic driving behaviour could be seen in the fourth calibration, where vehicles were more aggressive in the roundabout, blocking gaps for other entering vehicles, similar to what was observed in reality. See Figure 4.39 for such a situation in the simulation.

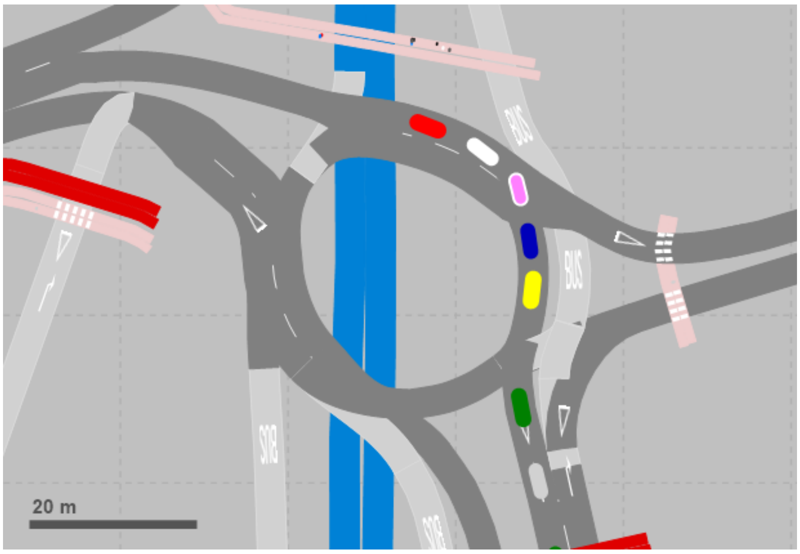

Figure 4.39: More realistic and aggressive driving behaviour in the roundabout in the fourth calibration

Not only realistic driving behaviour could be observed during the simulation of the fourth calibration, but also realistic gridlocks where the roundabout was completely saturated. See Figure 4.40 for an example of a realistic gridlock, where the southern exit is blocked by the rear end of the tram, ultimately causing the gridlock. On the other hand, the northern part is blocked by a bus, impermissibly stopping at the tram tracks.

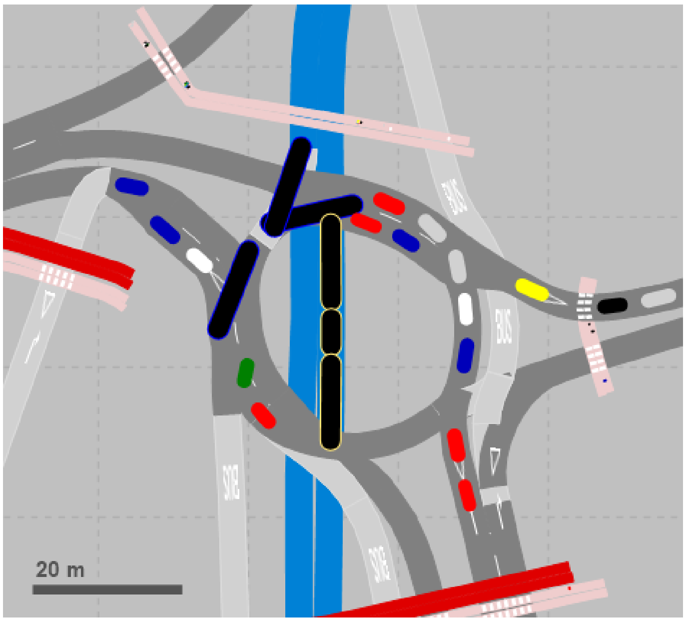

Figure 4.40: A realistic gridlock formed during simulation of calibration 4

During the simulation, some vehicle conflicts were observed at Polhemsplatsen.

MOEs

The mean of the average queue lengths and vehicle travel times from the performed calibrations, the adjusted model, and the actual values are presented in Figures 4.41 and 4.42.

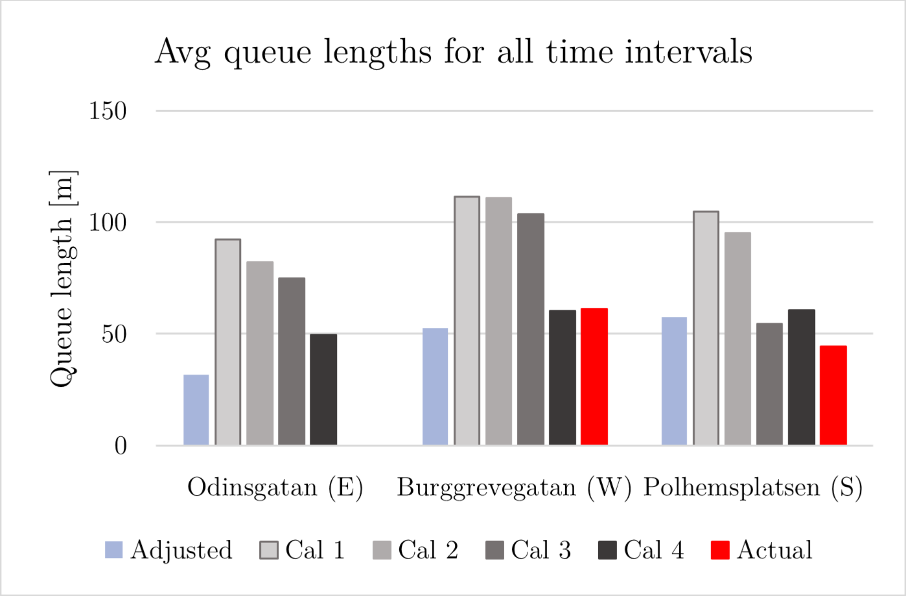

Figure 4.41: The mean of the average queue lengths for the fourth calibration

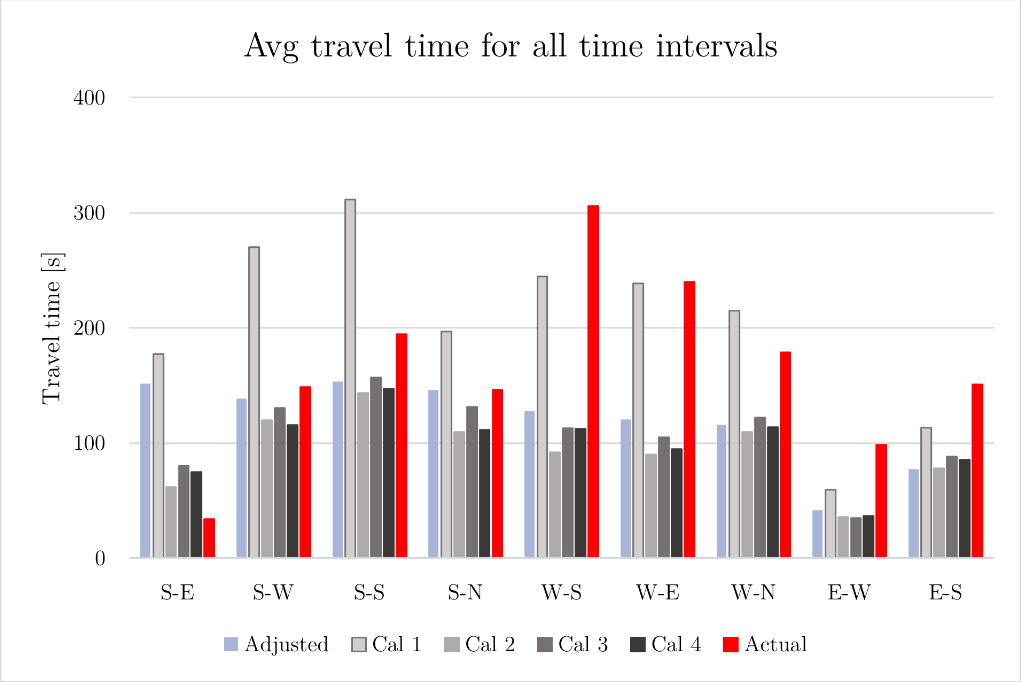

Figure 4.42: The mean of the average vehicle travel times for the fourth calibration

As can be seen, the average queue length decreased at all locations except for Polhemsplatsen compared to calibration 3. The average travel times were also reduced from the previous calibration at all routes except for Odinsplatsen-Burggrevegatan (E-W). The estimated travel time in the fourth calibration poorly resembles the actual travel time between all routes except for Polhemsplatsen.

Error
The accumulated RMSE per MOE for the fourth and first calibration can be seen in Figure 4.43.

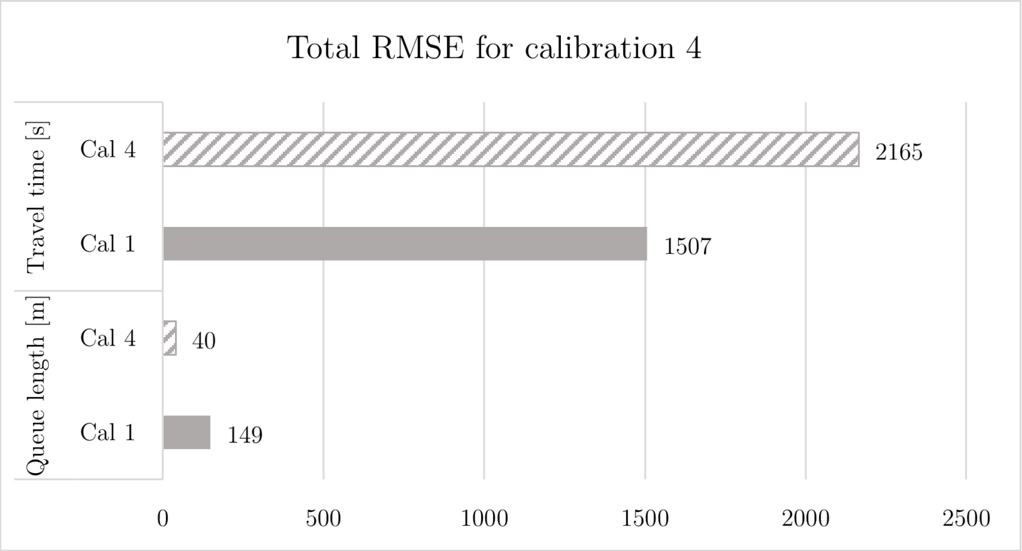

Figure 4.43: The total RMSE for the fourth calibration

Calibration 4 shows larger errors than calibration 1 for travel time and the reversed for queue length. The calibration is inaccurate in representing the real average travel time by about 36 minutes and the queue length by about 40 meters.

As can be seen in Table 4.4, the travel time worsened by 73 % in the fourth calibration compared to the first, while the queue length was improved by 115 %.

Table 4.4: The difference in total RMSE for QL and TT between the fourth and first calibration

MOE	Difference	Difference [%]
TT	-658 s	73
QL	109 m	115

4.3.5 Modification 5: Final touches

The fifth calibration includes all modifications: road geometry, reduced speed areas, tram and bus priority and final touches. Five out of ten simulation runs were successful for all routes and more for some time intervals. The basis for time interval 3600-4500 was nine simulation runs, while time interval 6300-7200 was five.

Driving behaviour
After the fifth and final modification, conflicts during lane changes at Polhemsplatsen were still observed, as no combination of the parameters changed seemed to have a positive impact. This could be due to VISSIM having trouble positioning one vehicle in two lanes simultaneously, signalising to other vehicles that one of the lanes is free to perform an overtake.

Most of the lane changes at Polhemsplatsen moved upstream, further away from the pedestrian crossing; see Figure 4.44. This corresponds well to where most of the actual lane changes occur.

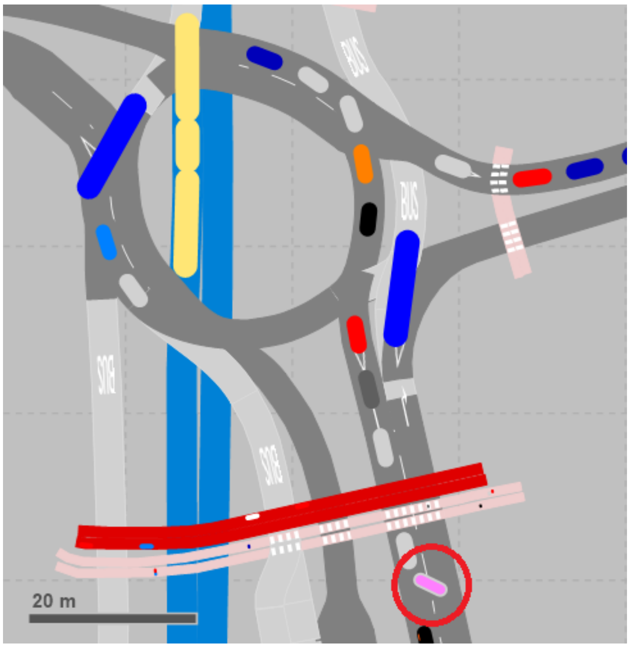

Figure 4.44: The new position where most lane changes at Polhemsplatsen occur in the fifth calibration

The simulated velocities were observed to be even slower and steady than after the second calibration with the reduced speed areas. Another phenomenon that occurred several times during the simulation was the queue formations in the roundabout, as vehicles had to stop in the roundabout before entering the leg at Polhemsplatsen, see Figure 4.45. This type of behaviour was, on many occasions, also observed in reality.

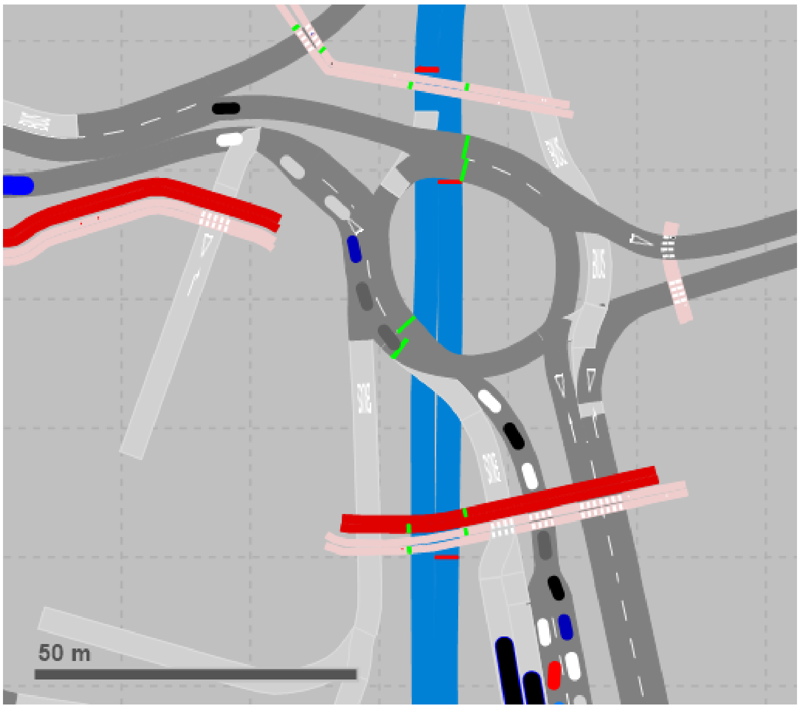

Figure 4.45: Queue formation in and before the roundabout for vehicles continuing at Polhemsplatsen

In one of the 10 simulation runs, a realistic gridlock was formed, caused by a car blocking the bus lane despite the conflict areas and priority rules prohibiting this, see Figure 4.46. Similar causes for actual gridlocks have been observed, providing visually promising results of the fifth calibration.

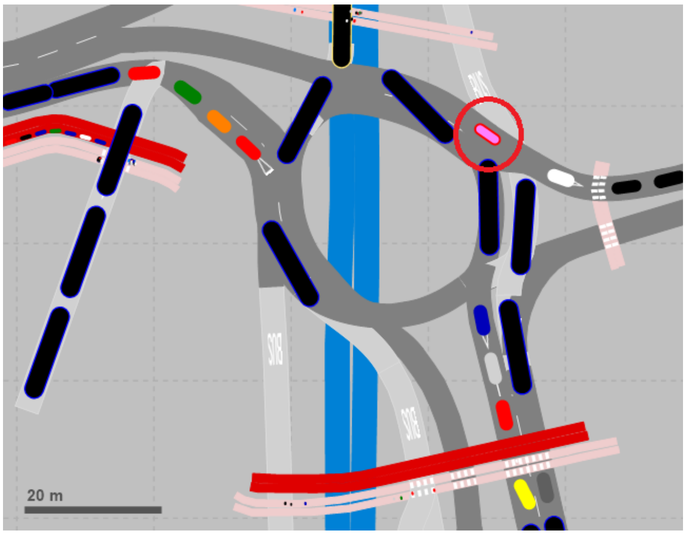

Figure 4.46: A realistic gridlock in the fifth calibration

Another realistic gridlock could be observed, caused by a car inadmissibly blocking the tram tracks on Stampgatan, see Figure 4.47. This led to a snowballing effect, where one vehicle's path was obstructed, in turn obstructing the path of another vehicle and so forth.

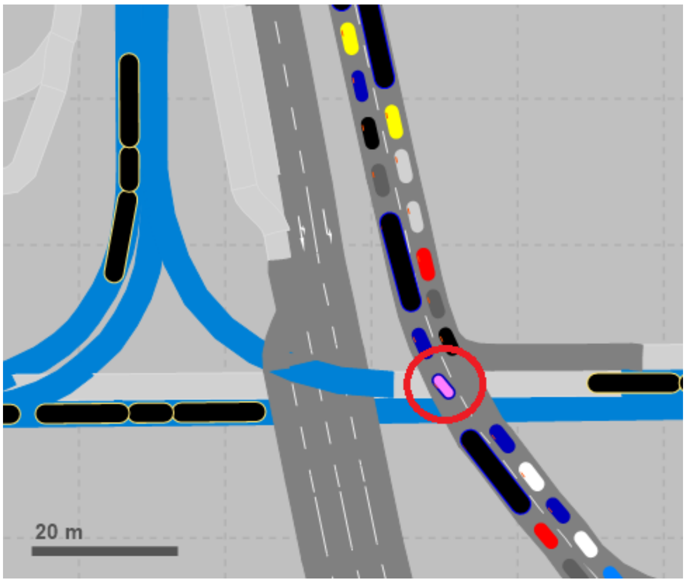

Figure 4.47: Another realistic gridlock in the fifth calibration

MOEs

In Figures 4.48, 4.49, 4.50, and 4.51, the overall mean values of the average and maximum queue lengths and vehicle travel times from all calibrations, the adjusted model, and the actual values are presented.

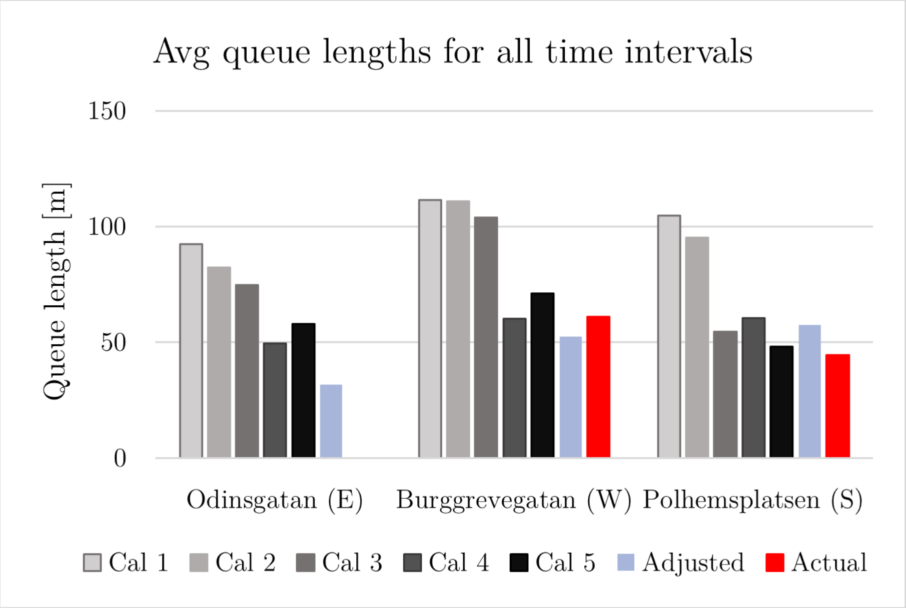

Figure 4.48: The mean of the average queue lengths for the fifth calibration

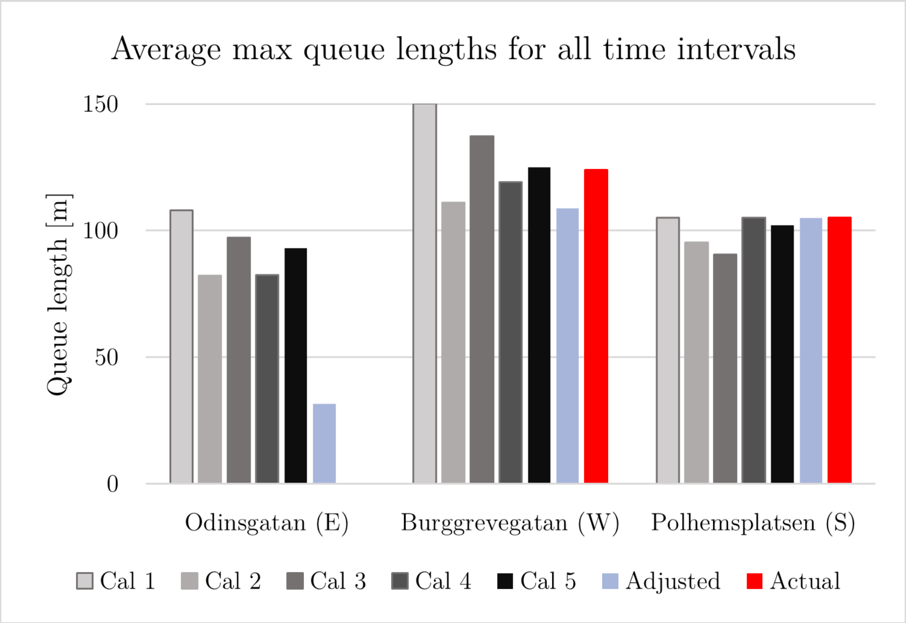

Figure 4.49: The mean of the maximum queue lengths for the fifth calibration

The fifth calibration is the most accurate of all models for estimating the average queue length at Polhemsplatsen and the second most accurate at Burggrevegatan. When comparing calibration 5 with calibration 4, the average queue lengths at Burggrevegatan increased for the worse but decreased at Polhemsplatsen for the better. This suggests that changes in driving behaviour and lane-changing distance were a success. The reversed pattern can be seen for maximum queue lengths, as it increased for the better at Burggrevegatan and decreased for the worse at Polhemsplatsen.

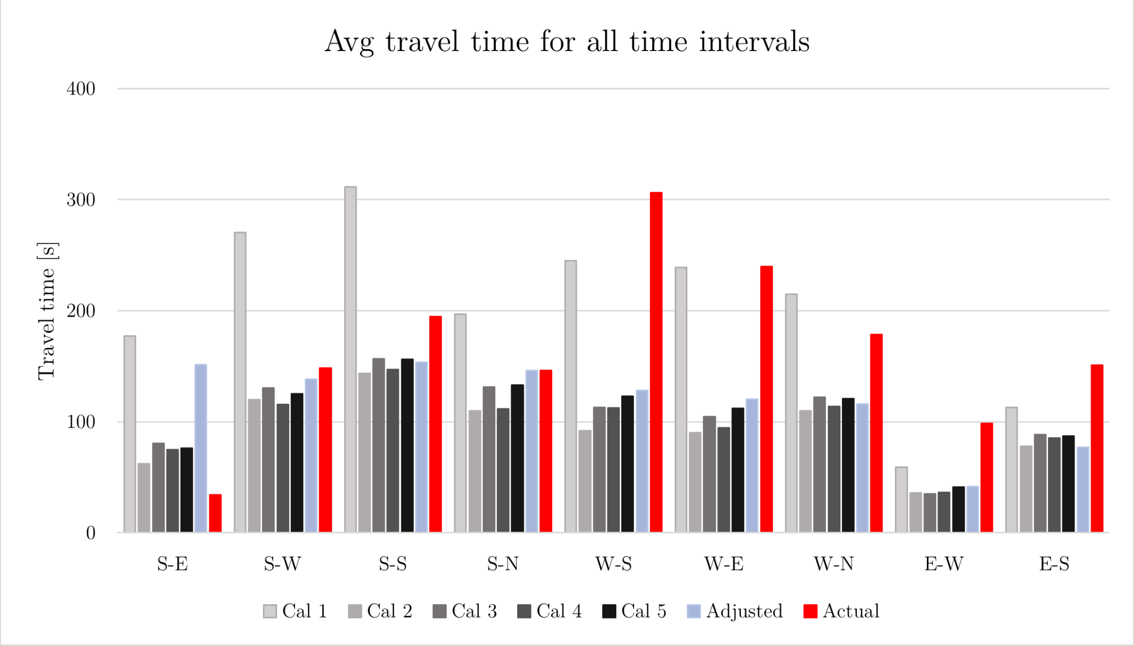

Figure 4.50: The mean of the average vehicle travel times for the fifth calibration

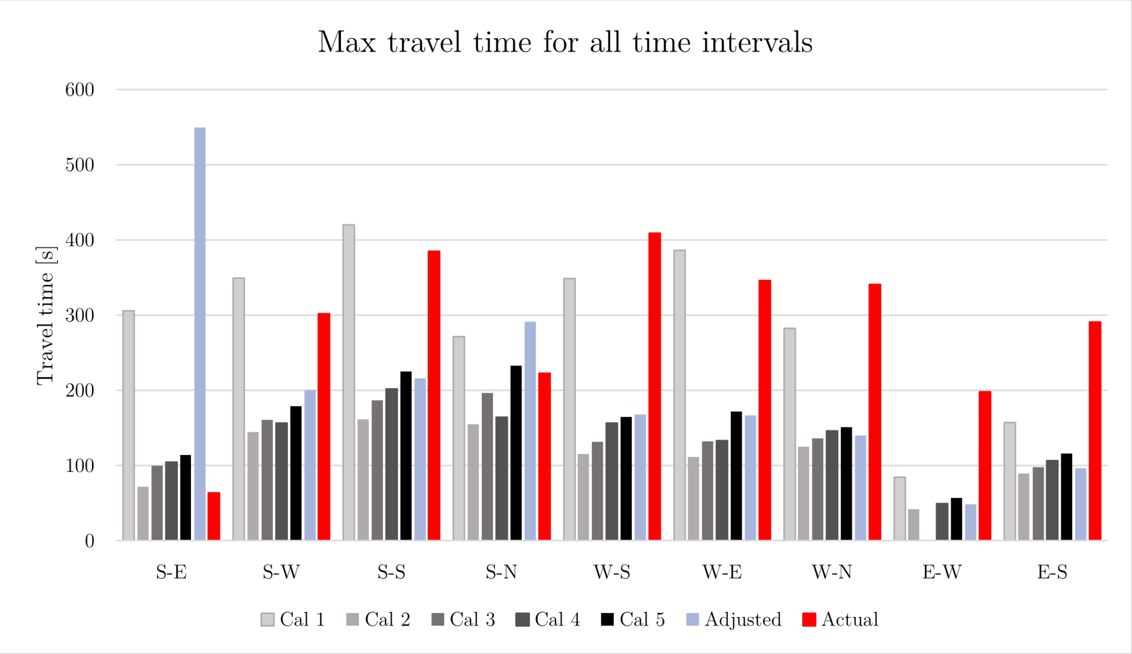

Figure 4.51: The mean of the maximum vehicle travel times for the fifth calibration

The average travel time was increased for all routes in calibration 5, thereby closing the gap between the actual and calibrated values, compared to calibration 4, for all routes, except for Polhemsplatsen (S) - Odinsgatan (E). When comparing calibration five with calibration one, the former simulates the average travel times at Polhemsplatsen more accurately than the latter but is less satisfactory for Burggrevegatan and Odingsgatan. Generally, the fifth calibration desirably produces longer travel times than all previous calibration models, except for the first one, which is more accurate for all routes, but Polhemsplatsen (S) - Odinsgatan (E) and Polhemsplatsen (S) - Åkerigatan (N).

Error

The RMSE for the fifth and final calibration can be seen in Figure 4.52, together with the calibration that produced the best results for each MOE (calibration one and four).

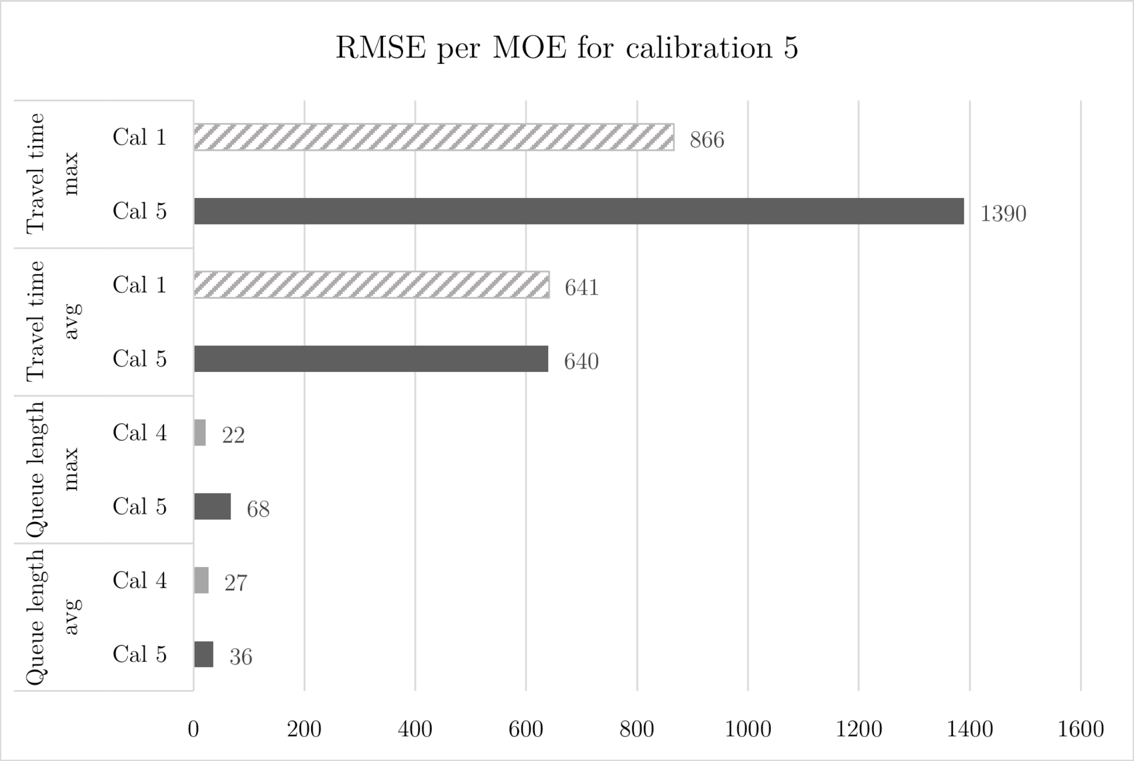

Figure 4.52: The RMSE per MOE for the fifth calibration

The total RMSE for the fifth calibration can be seen in Figure 4.53, together with all previous calibrations as well as the RMSE for the adjusted model.

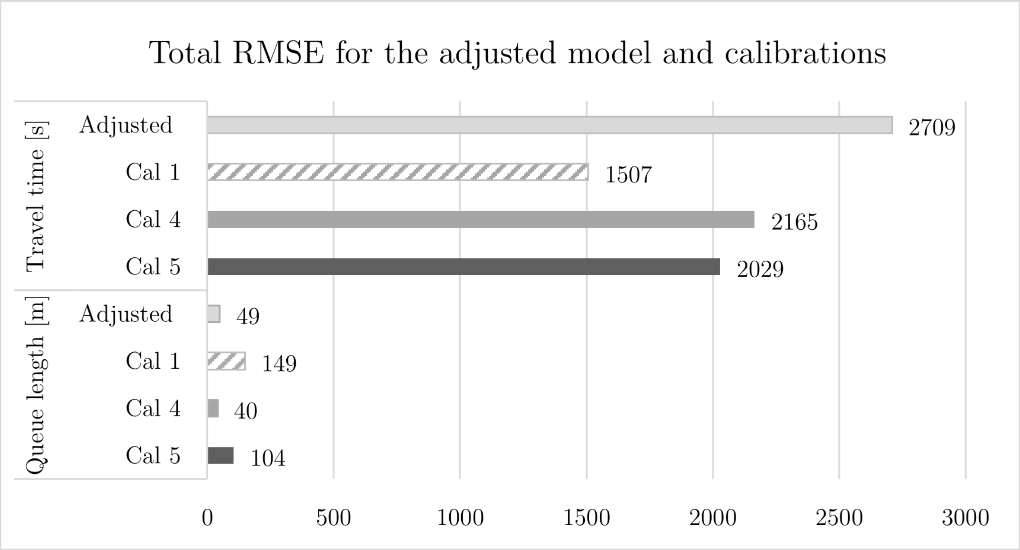

Figure 4.53: The total RMSE for the fifth calibration

As can be seen, the first calibration was best at estimating travel time. Worth mentioning again is that trams were obstructed during the simulation, leading to less obstruction and a lower travel time for the rest of the transportation modes. The calibration process of changing model parameters with the adjusted model as a reference improved travel time estimation by 680 seconds or 29 %, whereas it was worse when estimating the queue length by 55 meters or 72 %. See Table 4.5 for comparing the total RMSE for the MOEs between the adjusted model and the fifth calibration.

Table 4.5: The difference in total RMSE between the fifth calibration and the adjusted model

MOE	Difference	Difference [%]
TT	680 s	29
QL	-55 m	-72

4.3.6 Summary of results

Figure 4.54 is a compilation of the reason for all modifications, their connections to each other, which parameters were changed and whether it had the expected impact. The grey boxes represent each modification, the green the desired effect, the blue the parameters changed, the white boxes contain comments, and the pink represent the outcome. If one problem arose, the arrow connected to another modification symbolises the need for action to improve the model.

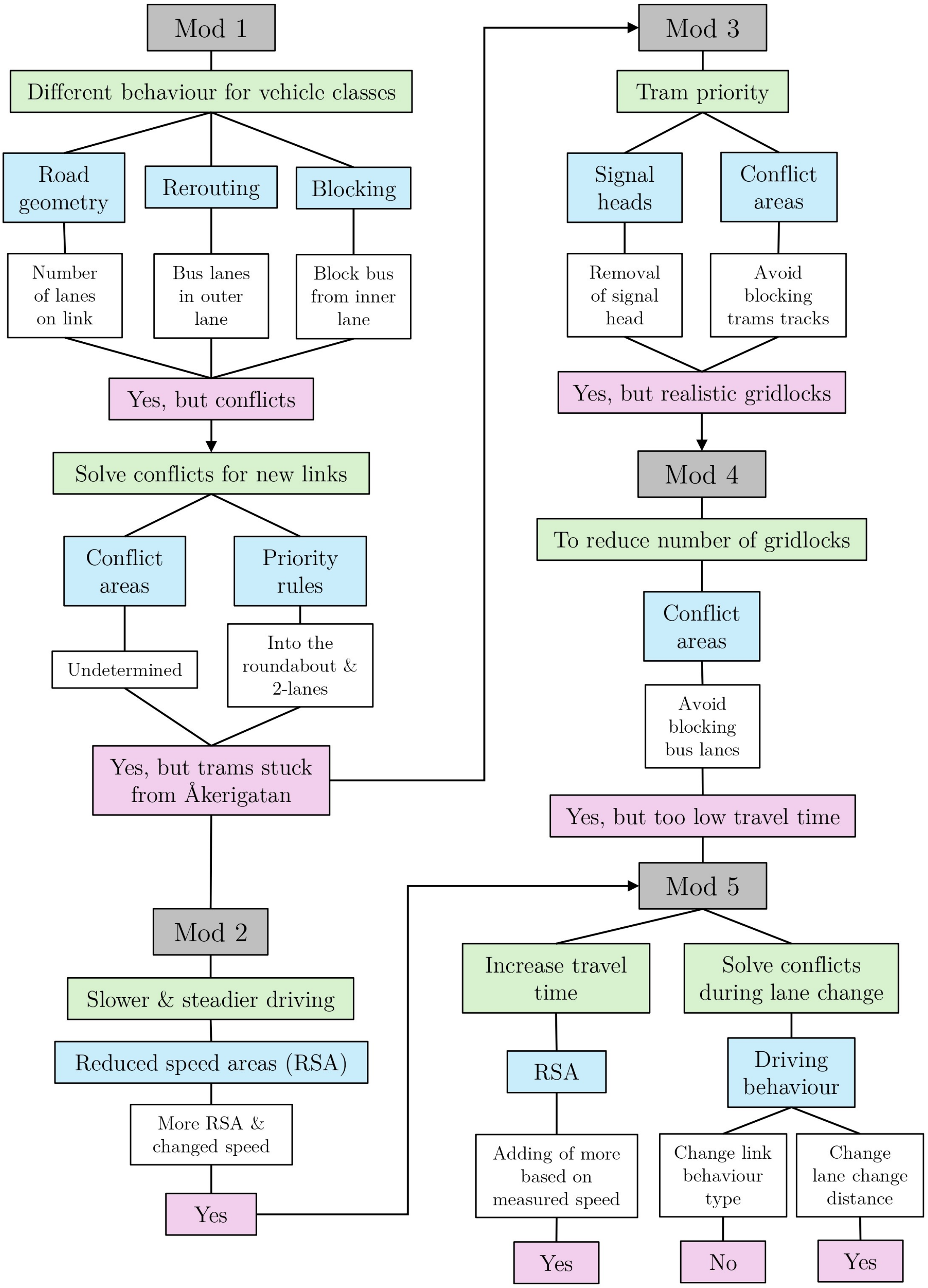

Figure 4.54: A compilation of all modifications and their relations, changed parameters and outcome

Gridlock occurrences and causes
In the first modification, no gridlocks were formed, but trams from Åkerigatan were seen to be obstructed in continuing on their path. However, temporary gridlocks were observed due to cars blocking the buses in the bus lane. The leading cause for gridlocks in the second calibration seemed to be that buses found their continued path too narrow despite not visually being blocked. Trams were still seen to be obstructed from Åkerigatan. When simulating the third calibration, only realistic gridlocks were formed when all vehicles were prevented from continuing in the roundabout due to the blocking of the preceding vehicle. The gridlocks in the fourth calibration were mainly formed due to vehicles blocking the bus lane, thereby wrongly obstructing their further movement. Similar situations caused gridlocks in the fifth calibration. Another reason for gridlocks was when vehicles stopped on the tram tracks at Stampgatan, preventing one tram from continuing and blocking another tram, ultimately leading to congestion and gridlocks in the roundabout. The number of gridlock formations in each calibration simulation can be seen in Table 4.6.

Table 4.6: Number of formed gridlocks per calibration out of 10 simulation runs

Calibration	**Number of gridlocks**
1	0
2	8
3	9
4	4
5	5

As previously mentioned, the one-hour intervals between 3600 and 7200 were only considered in evaluating each modification. Worth mentioning is that most gridlocks were formed in the second time interval, 4500-5400 seconds. The first time interval, 3600-4500 seconds, had the largest sample size, while the fourth interval, 6300-7200 seconds, had the smallest.

4.4 Validation results

The model was considered visually validated since it behaves similarly to the most visually successful calibration, namely the fifth. The gridlocks observed during the simulation were similar to those in the fifth calibration. Gridlocks were observed in two of the ten simulation runs, meaning that the error was calculated based on 8 simulation runs.

As for the statistical validation, see Figure 4.55 for how much the total RMSE of the validation and the fifth calibration differed. Note that the MOEs for the validation are compared with observed data from another data set rather than those for the calibration. This validation data set is the minimum quarter, whereas the calibration data set is based on the maximum.

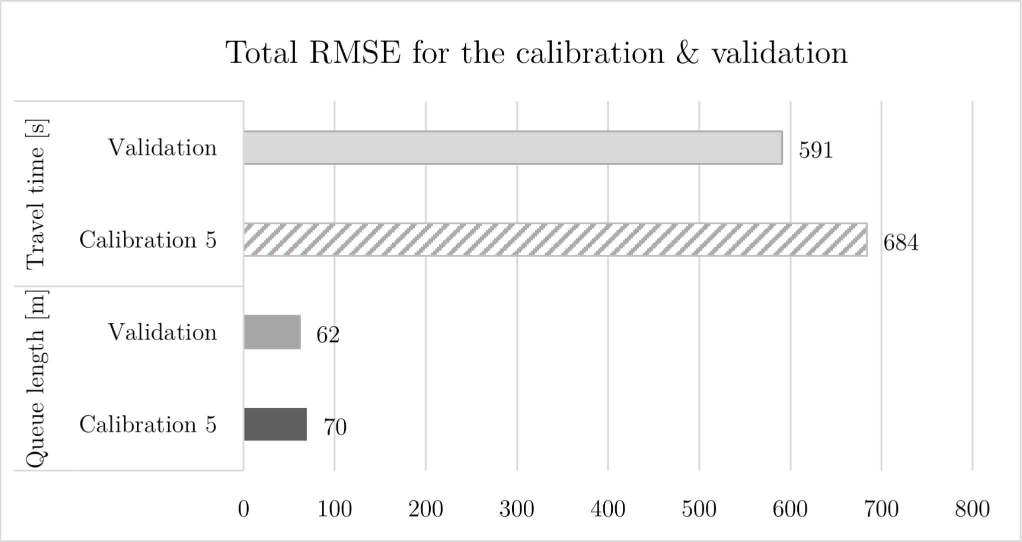

Figure 4.55: The total RMSE for the validation and calibration 5

The difference between the model results and the observed values is about the same for the calibrated and validated model; see Table 4.7.

Table 4.7: The degree of compliance in RMSE between the calibration and the validation

MOE	**Degree of compliance [%]**
QL	89
TT	86

The calibrated model had an error of 70 m regarding the queue length and the validated model of 62 m, leading to a compliance degree of 89% between the models and a difference of 8 m. The calibrated model unsuccessfully estimated the travel time by 11 minutes and 24 seconds, and the validated model by 9 minutes and 51 seconds. In this matter, the models comply with 86%, with a 1-minute and 33-second difference.

The model can be considered to realistically capture driving behaviour in different traffic states during peak hours. The deviance between the simulations and reality is both visually and statistically considered acceptable.

4.5 Scenarios results

This section includes the simulation results of the alternative designs and changes to determine whether they had the desired impact in improving the traffic situation at Åkareplatsen.

4.5.1 Scenario 1: Optimise

In the first scenario, four bus routes were changed, and the signal heads in the roundabout were removed. The simulated traffic was observed to have a steadier flow with fewer queue formations and somewhat fewer buses in the roundabout. The mean of the average queue lengths and vehicle travel times from the finalised calibrated model and the first scenario can be seen in Figures 4.56 and 4.57.

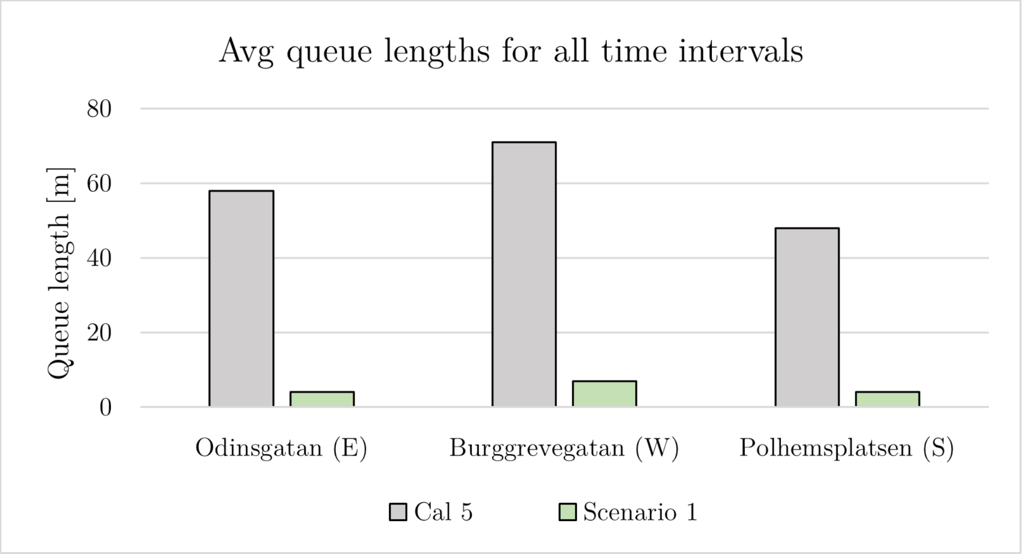

Figure 4.56: The average queue length for the calibrated model and first scenario

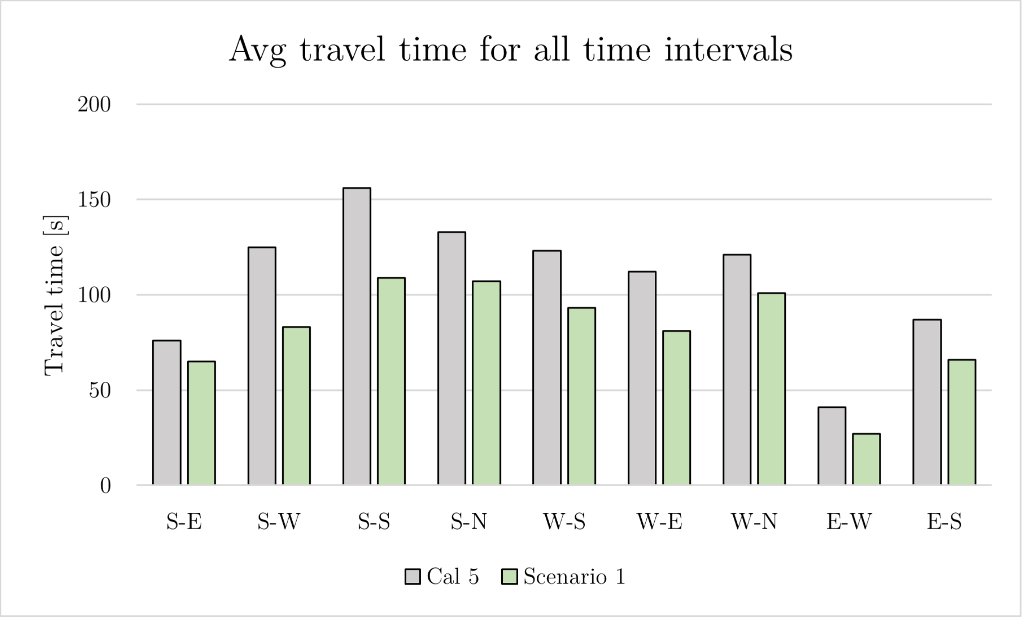

Figure 4.57: The average travel time for the calibrated model and first scenario

As can be seen, the queue length and travel time decreased for all legs and routes in the first scenario. No gridlocks were formed during the time intervals of interest, except for the last time interval in one of the simulation runs for some routes. This gridlock was similar to one formed in calibration 5, which can be seen in Figure 4.47 under section 4.3.5.

4.5.2 Scenario 2: Rebuild

The results from the second scenario with the elongated roundabout and moved pedestrian crossings are presented in this section. The visual interpretation of the simulation was that the roundabout had a higher capacity for buses, as four or even six buses can be present without causing a gridlock. A snapshot from the simulation of two buses in the roundabout while not blocking the tram tracks can be seen in Figure 4.58.

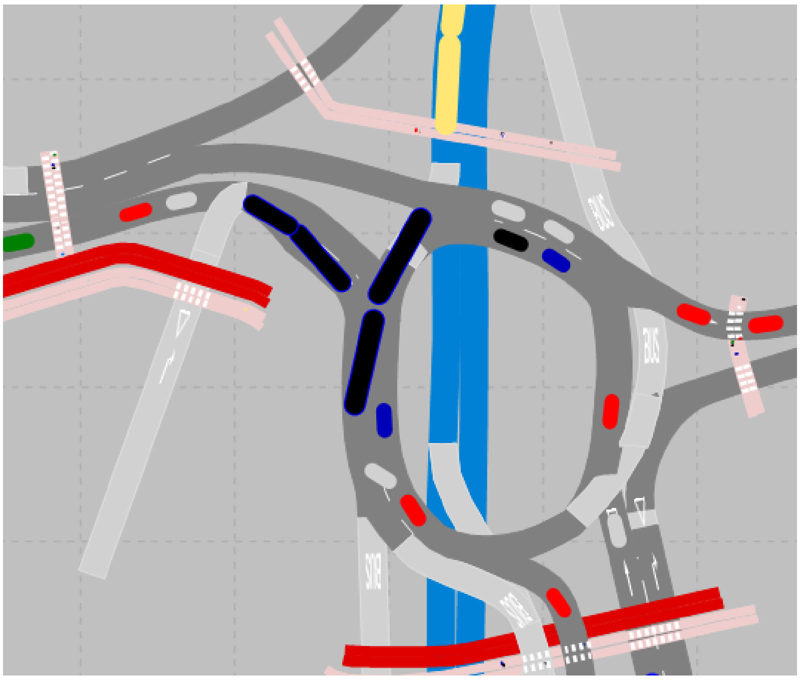

Figure 4.58: Visual representation of the elongated roundabout

A snapshot from the simulation of a tram fitting inside the roundabout can be seen in Figure 4.59.

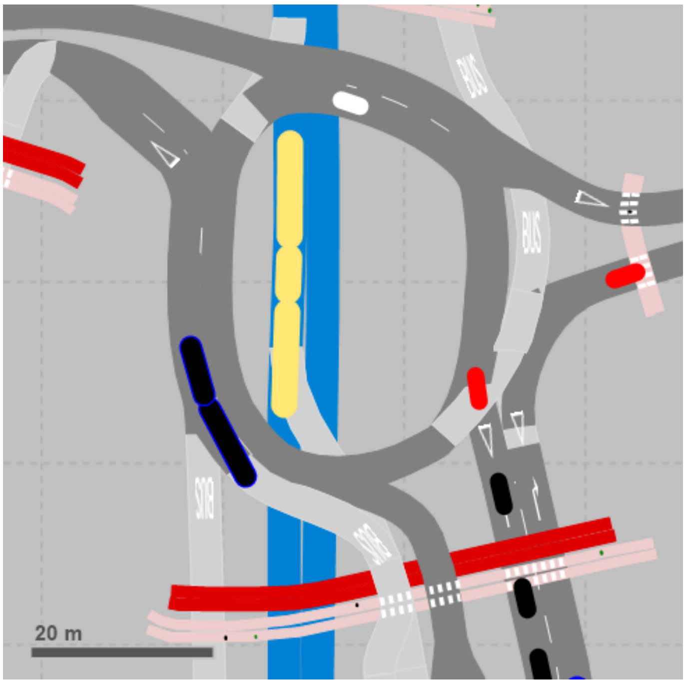

Figure 4.59: Visual representation of a tram inside the elongated roundabout

The average queue lengths and travel times are presented in Figure 4.60 and 4.61.

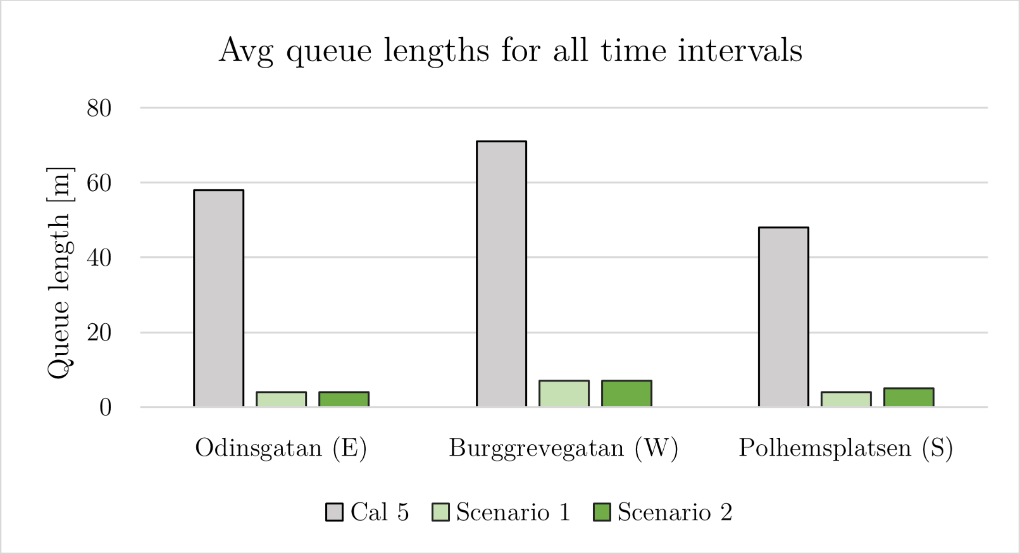

Figure 4.60: The average queue length for the calibrated model and the first and second scenarios

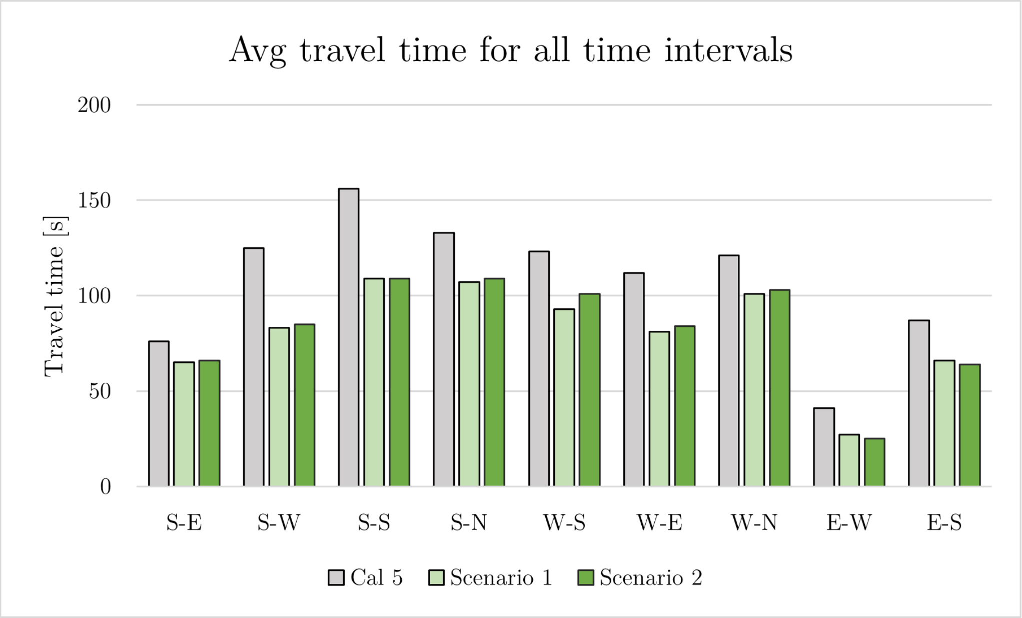

Figure 4.61: The average travel time for the calibrated model and the first and second scenarios

The average queue length and travel time are the same or slightly worse for scenario 2 than for scenario 1, except for the travel time from Odinsgatan (E). Both scenarios are improvements compared to the calibrated model, especially regarding queue lengths, which are almost non-existent.

4.6 Stress test

The public transport frequency was increased from the originally 100 % to 150 % and then 200 % to see to what degree the improved version of Åkareplatsen could manage future needs of public transportation.

Overall, the queues involving buses and trams increased during the stress test, but buses did not seem to be as much of an issue as before the new design. From the simulation of the 150 % load, it was observed that queue spillback at Burggrevegatan reached all the way through the roundabout, partially caused by the relocation of the pedestrian crossing. See 4.62 for a high bus density in the roundabout that did not lead to gridlock.

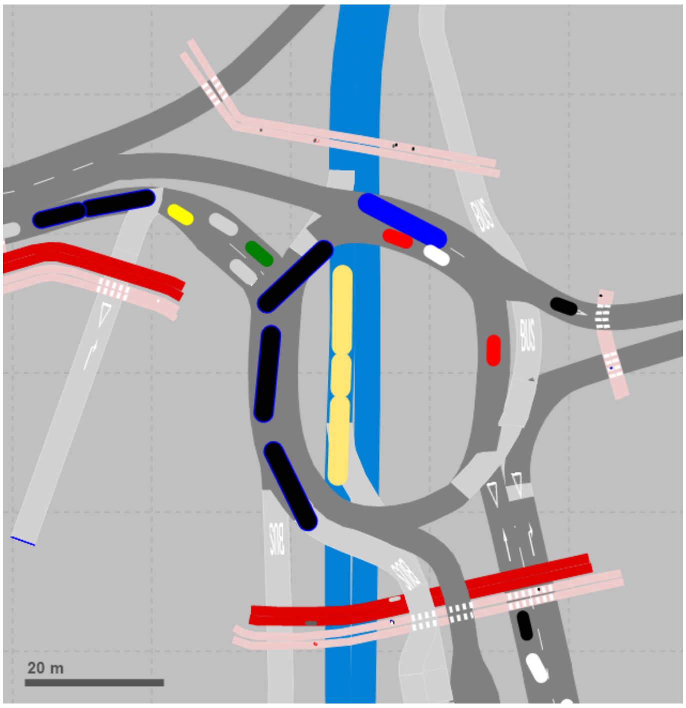

Figure 4.62: Three buses in the left hand side of the roundabout during the stress test of a 150 % load

Gridlocks appeared in 1 out of 10 simulation runs of the 150 % load. In some time intervals and for some routes, the travel time was higher than twice what was previously considered acceptable. However, since no noticeable gridlock could be observed in the entire simulation run, these travel times were assumed to be reasonable. They were thereby included when calculating the mean average and maximum travel times. The results from the stress test indicate that the new design can manage a higher public transportation density without immediate gridlocks.

During the simulation 200 % of the current public transportation load, gridlocks appeared in at least 8 out of the 10 simulation runs. When visually inspecting the traffic conditions, longer red times for tram-crossing traffic at Stampgatan could be observed, causing quicker forming and longer-lasting queue build-ups than at lower densities. Tram queues mainly appear at Stampgatan in the direction of the tram stops at the Central Station, and bus queues at Polhemsplatsen and Central Station bus stops, see Figure 4.63.

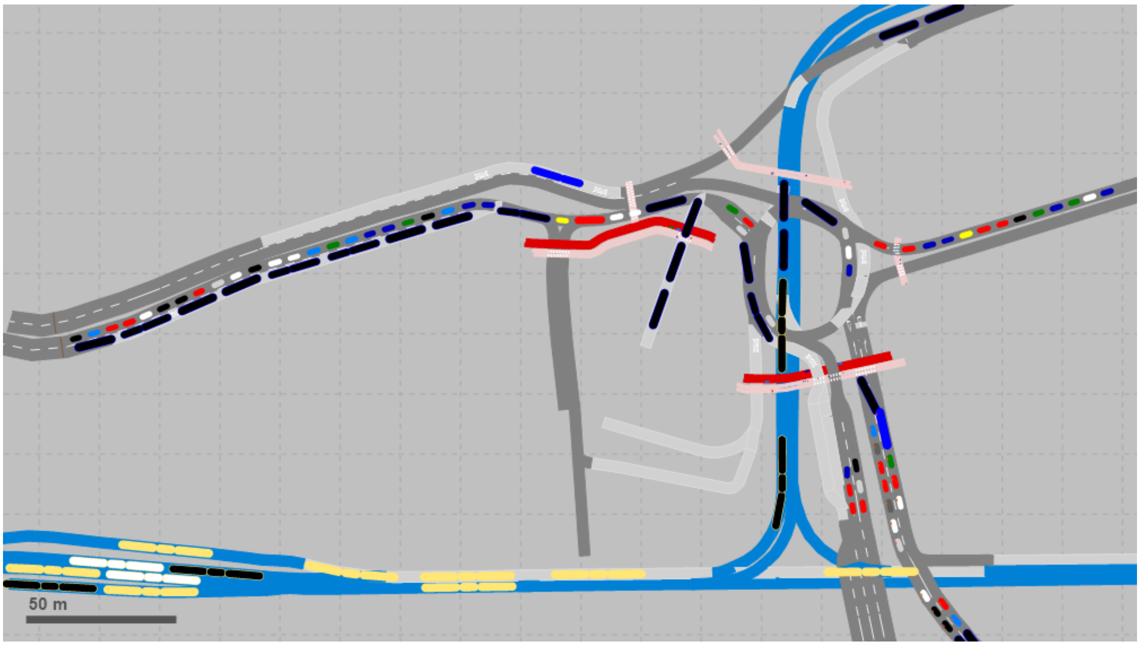

Figure 4.63: Queue formations during the stress test simulation of the 200 % load

A realistic gridlock appeared, as can be seen in Figure 4.64, with the cause of all routes being blocked by a preceding vehicle.

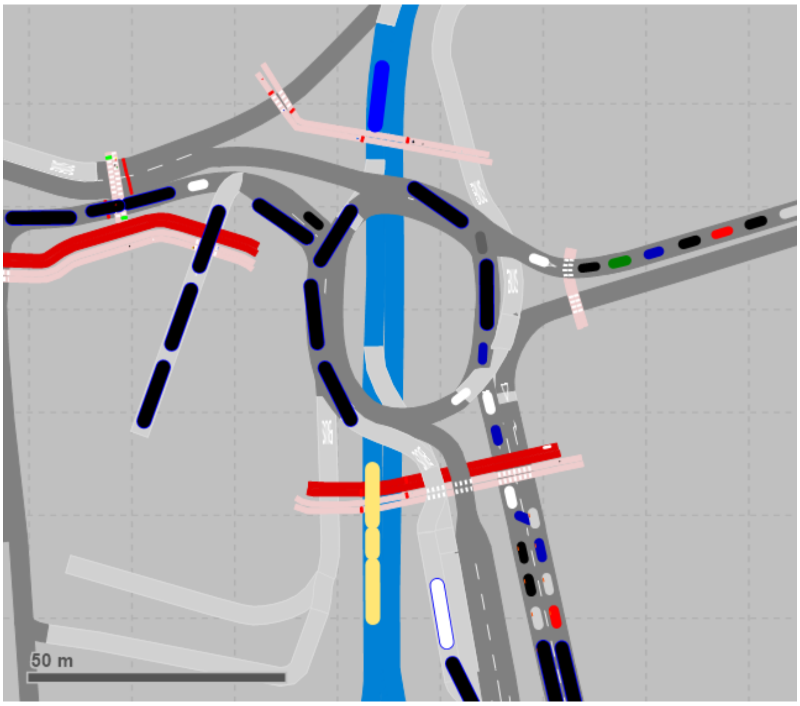

Figure 4.64: Realistic gridlock in the stress test simulation of the 200 % load

See Figures 4.65 and 4.66 for how the average MOEs of queue length and travel times were affected by the incremental increase in public transportation frequency.

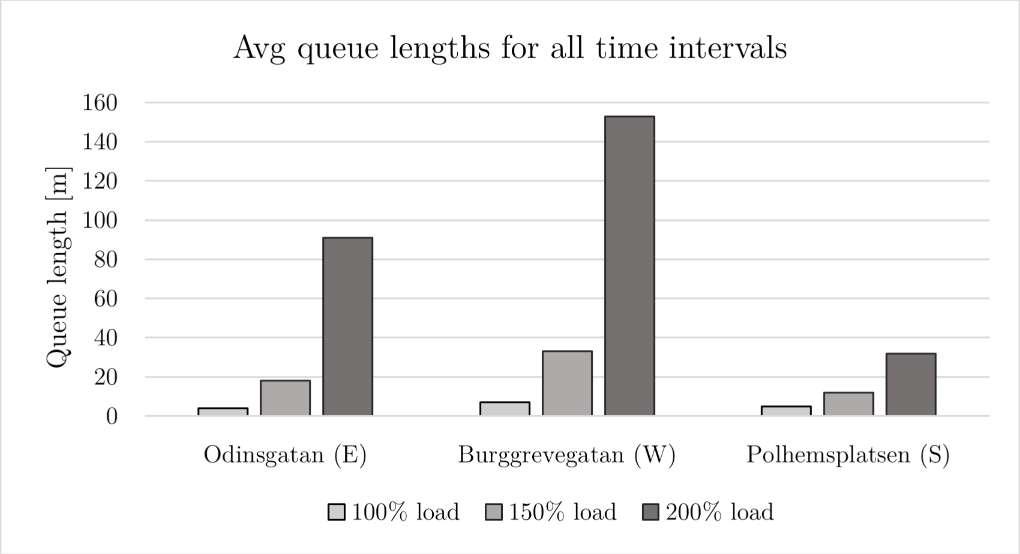

Figure 4.65: Average queue lengths with a 100%, 150%, and 200% load of public transportation

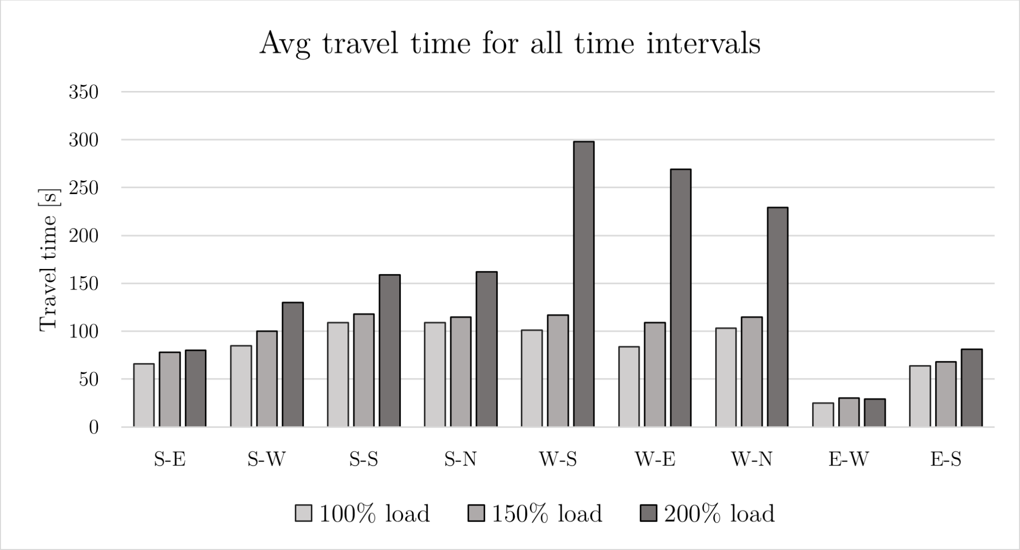

Figure 4.66: Average travel time with a 100%, 150%, and 200% load of public transportation

As can be seen, a 150 % load only marginally affect the queue lengths and the travel times.

5

Discussion

In this section, the findings of the study are reflected upon, explained, and put into context. It includes the initial simulation results and the calibration and validation results, followed by a general discussion regarding how this study can improve Åkareplatsen.

5.1 Initial simulation results

The initial simulation consisted of the original model with 2018 input data and the adjusted model with 2024 input data. Due to the adjusted model being cropped, the vehicle inputs (i.e., where the vehicles are generated from) are placed closer to the data collection points of queue counters and vehicle travel times compared to the original, spatially larger model. This results in a longer travel time from the vehicle inputs to the starting point of the queue counters, for instance. Because of this, queues were expected to form later in the original model than in the adjusted one. Looking at the average queue length at the beginning of the simulation, this was only true for Polhemsplatsen. The unexpected result of queues forming earlier in the original model could be attributed to the model's larger overall vehicle input (1331 cars and trucks compared to 776). On one hand, it was expected that it would take a longer time to travel from the original vehicle inputs. However, due to the high flow of vehicles being generated, they quickly reached the start of the queue counters, leading to the early formation of queues.

For Odinsgatan, the average and maximum queue lengths were longer in the original model than the adjusted at all times. This was expected as the vehicle input for Odinsgatan for the original model was almost twice as high.

The input data for Polhemsplatsen was similar, as the original model had 631 vehicles, and the adjusted model had 344 vehicles. Reasonably, the queue lengths would be longer in the original model compared to the adjusted model, which was not the case. The longer queue lengths in the adjusted model can be due to a higher public transportation line frequency at the location, which participates in the queueing because of the bus stop.

The vehicle input for Burggrevegatan was slightly higher in the adjusted model than the original. Despite this, the original model's average and maximum queue lengths were longer during the entire simulation, except for the last time interval. Again, this could be due to a higher density of public transportation.

As for the vehicle travel times, the results suggest that the original model could not foresee the problems that arise in real traffic situations, such as congestion and gridlocks.

Root mean square error, RMSE, was used to measure the error between the models and field data from 2024. The total RMSE for vehicle travel time for the initial results was lower for both travel time and queue length. In other words, the original model cannot represent reality accurately enough. This was expected since the adjusted model has input data for 2024, and the actual data is from 2024. The vehicle input data to the original model is based on data from 2018, which justifies that the model encounters larger RMSE than the adjusted model.

5.2 Calibration result

Each change of model parameters in the calibration was assessed statistically, using RMSE, and visually, using video-recorded material. Both measurements are of equal importance, even though there is no feasible way to measure the accuracy of the visual findings. Driving behaviour was visually assessed, while the estimation accuracy of the queue lengths and travel times was determined statistically.

The fifth and final calibration, which included all modifications made, was most accurate in replicating actual driving behaviour. It was worse than the first calibration in estimating travel time, but that was faulty as trams got stuck during simulation, which is a behaviour not observed in reality. The fifth calibration was slightly worse than the fourth regarding queue length, but the fifth had a larger sample size and could imitate real traffic situations more accurately. To capture this realistic driving behaviour without causing gridlocks, the most essential model changes were the number of lanes, solving priority and vehicle conflict by using conflict areas and priority rules, and lastly, reduced speed areas.

5.2.1 Driving behaviour

The driving behaviour was successfully captured using the aforementioned changes to model parameters. The most distinctive behaviour to mimic was cars and trucks using one wide lane as two, while buses use them as one due to their size. For this, increasing lanes while blocking vehicle classes in some lanes and using priority rules was a successful method. Unconventional routing was also done so that all buses use the same lane even if they, according to common practice, should be in the same lane as their next turn. This was to capture the turning movement of buses. Several priority rules were used, both in the roundabout and at roundabout entrances. The vehicle classes that were not blocked from any lane should still stand by at a distance if a bus or truck was ahead. This method can be applied to model other multimodal turns or roundabouts.

Some driving behaviours required more work to capture in the model simulations. Åkareplatsens location, between the Central Station, hotels and proximity to large arenas causes many taxis in the area. The taxi drivers were observed to have more risk-taking and aggressive driving behaviour, such as driving faster and in the bus lane. This was not captured as taxis were included in the same vehicle class as private cars and trucks. However, a separate vehicle class for taxis could have solved the issue of them driving faster and more aggressively by implementing smaller gap acceptances and higher speeds in the reduced speed areas.

Some unrealistic behaviours could not be changed with the current knowledge of the software. One of these was lane changes at the shorter two-lane links. The unrealistic lane changes and crashes in the rear could have been prevented by separating the link into two parallel, but by that, missing out on the opportunity to change lanes. These changes were not made as they were judged not to affect the traffic situation, only the visuals.

5.2.2 MOEs

The vehicle input for VISSIM was extracted from the maximum quarter with the highest observed flow. If, for instance, a gridlock had appeared during these 15 minutes, the traffic would have come to a complete temporary standstill, resulting in a non-existent flow. This would, in turn, have led to larger MOEs, such as longer queue lengths and vehicle travel time. The decision of which quarter to base the vehicle flow affected both actual MOEs and simulated MOEs. If the base quarter included actual gridlocks, another take on this study would have been necessary to account for these.

Additionally, the process for extracting values for the actual MOEs might have affected the outcome. For instance, when calculating the average queue length, only 15 values were included, based on the exact queue length 30 seconds into each time interval. Smaller time intervals would have been beneficial since it would have led to a larger sample size and probably a more representative mean value. Also, extracting the actual mean value of each MOE did not capture the natural variation in traffic conditions. However, accounting for the minimum and maximum values resulted in a somewhat reasonable span for comparing the simulated MOEs to the actual ones.

The MOEs of average and maximum queue length and travel time were, to the greatest extent, similarly extracted from the video recordings as in VISSIM. From the video recordings, 15 minutes of data was retrieved. This time period might not allow variations in the traffic system to appear, as it was the quarter with the highest traffic flow. However, the interest lies in capturing the hour with the highest vehicle flow, which is the basis for road designs.

The advantage of a stochastic simulation model is that variations in the traffic system in terms of queue length and travel time can be captured. All simulation runs vary in results; there is no fixed travel time or queue length, just as in reality. Although the simulation result should not be entirely relied upon for environments that are not yet built, MOEs can beneficially be used to compare the outcomes of different changes to the transportation system. Existing environments such as Åkareplatsen can use MOEs to compare changes as a compliment to the visual.

5.2.3 Error

The error was a way of measuring the deviance between the model calibrations and the field-measured MOEs. The error was only calculated for the model versions with a large enough sample size that had not experienced extensive gridlocks.

The final calibration was about 32 minutes off in estimating the travel time and 104 meters in estimating the queue length. Because this is for all streets and routes, these differences between the model and reality can be perceived as marginal. Despite the error, the model was increasingly improved in estimating the travel time. The amount of data to compare queues to were sparse, making travel time a more reliable comparison. As travel time and queues are codependent - long queues lead to higher travel times - these could be interpreted as somewhat interchangeable. Reducing the model error further was not the aim, as the model had already achieved the desired behaviour.

5.2.4 Gridlocks

As for gridlocks, the model simulations created both unrealistic and realistic gridlocks, which were observed in reality. On the one hand, these results were visually appealing, but on the other hand, they were statistically unwanted. This is due to one of VISSIMs drawbacks, that once a gridlock is formed in VISSIM, in most cases, they do not dissolve, as would be the case in reality either by drivers cooperating or by the help of traffic directors. When gridlocks are formed in VISSIM, the queue lengths and travel times are affected; either they are skyrocketing, or no values could be obtained at all, resulting in too low a sample size to base the average on.

5.3 Validation result

Two different data sets, for the minimum and maximum quarter, were used in the validation. The model had about the same error when comparing model results to the field measurements. For the minimum quarter, the model was more accurate in estimating queue length by 8 meters and about two and a half minutes in travel time. From this, the conclusion can be drawn that the model is more accurate in calmer traffic states, even if marginally. It is worth noting that the travel times and queue lengths for Buggrevegatan had to be disregarded due to missing data.

5.4 How to improve Åkareplatsen

During site observations, it was noted that queues form in waves, most likely as the signal heads beside Ullevi (S) and the Central Station (W) let traffic go towards Åkareplatsen. The queues were at their longest when several trams passed, causing a long red time. This could be avoided by minimising red times or removing the signal heads altogether. An excessive amount of buses in the roundabout and their behaviour of blocking tram tracks or other buses were consistently the reason for the formation of complete gridlocks. This could be avoided by re-routing buses, leading to fewer buses in the roundabout simultaneously or by making more space for buses.

From the simulation results of the first scenario, removing signal heads for track-crossing traffic and reducing the number of buses in the roundabout greatly reduced queue lengths and the number of gridlocks. This outcome was expected since those two occurrences were identified as the main culprits for queues and gridlocks. Removing signal heads resulted in a smoother traffic flow. However, the safety risk should be addressed before implementing this measure.

Another occurrence was people jaywalking between Åkareplatsen Travel Centre and Central Station. The pedestrian crossing was moved, causing the travel time for vehicles passing Burggrevegatan to include the time for pedestrians to pass the crossing. This reasonably led to longer travel times. The suggestion could also lead to queue spillbacks into the roundabout, negatively especially affecting public transportation.

No further consequence analysis of how the alternative designs affect nearby streets and junctions has been conducted. One possible effect could be that the congestion problem is relocated elsewhere or that travelling through Åkareplatsen becomes the more attractive route choice, increasing the amount of private-owned vehicles in the area. Additionally, no consideration has been given to already approved and upcoming nearby changes in the traffic state, such as Allélänken. This construction will surely affect the public- and private traffic at Åkareplatsen. Moreover, the suggested design improvements are not supported by existing regulations, and before a possible implementation, further investigations regarding safety and standards are recommended.

The stress test with a higher public density load shows that the new design can manage a higher public transportation density without gridlocks forming, at least to some extent. A 150% load can be managed, but a 200% load causes immediate gridlocks in 8 out of 10 cases. There was expected to be a linear relationship between inputs and outputs, but this was not the case. Instead, a threshold was reached somewhere between 150 % and 200 % load, where the roundabout is at capacity, leading to an exponential increase in travel time and queue length, especially at Bruggrevegatan (W).

From the scenarios and stress test, it is possible to increase the public transit frequency to a certain degree to meet future needs if the roundabout is elongated and the signals over the tram tracks are removed. In doing so, the stops for public transportation should be elongated and the red time over the tram tracks shortened so as not to cause gridlocks.

In addition, some rules need clarification at Åkareplaten. To ensure that no vehicles block other vehicle routes, road markings could be used to signal that vehicles which cannot completely pass the area should not enter it. Simulating this in VISSIM was impossible, so the effects of such measures are unknown.

Another scenario that is thought to improve the situation at Åkareplatsen is to change the entire design into a signalised four-way intersection instead of a roundabout. This was the design before the rebuild into a roundabout, and with the many modes of transportation, it is thought to be less confusing for all road users. In this, it is also suggested that different modes of transportation be separated as much as possible to increase safety and accessibility.

5.5 General

Traffic simulation tools are useful in urban redevelopments, as problems can be predicted, and alternative designs or functions can be tested by simulation beforehand. As was shown in this study, small changes can have a big impact on the traffic situation. VISSIM is a powerful visual tool that facilitates understanding urban traffic flows, and its built-in functions are easily changed with easily interpreted results.

In order to keep public transportation an attractive alternative in the urban transportation system, reducing delays and increasing its reliability are key components. Åkareplatsen is one of the most important public transportation hubs in Gothenburg, visited daily by commuters within and outside of Gothenburg, yet it is still a bottleneck in the system. Relatively small changes to the infrastructure can prevent collisions, gridlocks and queues from reoccurring at the location and thereby increase its capacity to meet today’s and future needs for transportation.

Queue build-ups and gridlocks at Åkareplatsen could have been avoided had microsimulation tools had their place in the investigations beforehand. However, the traffic distribution and the unusual driving behaviour observed at the location would have been more difficult to prevent. Because of Åkaeplatsen’s unusual layout, the exact findings of this study might not apply to other complex urban intersections, but the functions used when calibrating the VISSIM-model can be generalised, such as modelling buses turning movements, resulting in more realistic simulations.

6

Conclusion

This study found that, by using the maximum observed traffic flow as input in VISSIM, the model of Åkareplatsen can be calibrated both visually and statistically. The best visual model version deviates by 33 minutes and 48 seconds for queue length and 104 meters for travel time. The validation shows that the calibrated model performs equally when simulating calmer and more dense traffic states, with a difference of 1 minute, 33 seconds, and 8 meters for travel time and queue length, respectively. The model can also simulate realistic gridlocks, unlike the original model. The calibrated VISSIM model of Åkareplatsen accurately reflects real traffic conditions, deviating by 33 minutes and 48 seconds for travel time and 104 meters for queue length. The model performs consistently across both high and low traffic states and can simulate realistic gridlocks.

The suggestions for improvement at Åkareplatsen show that by using small means, the site can increase in capacity while at the same time allowing for a higher public transit frequency. However, an impact assessment has not been conducted to evaluate whether the traffic problems relocate to other nearby streets or junctions, and it is required before the proposals are implemented. Suggestions for future investigations are to include a larger area in the model or to combine it with a meso- or macro-model. Another suggestion for future studies is to develop a framework for avoiding collision during lane changes in two-laned links, thereby further improving the VISSIM replication of real-world traffic situations.

Meeting the citizens' need for mobility to get to everyday activities is imperative and can advantageously be done by providing reliable public transport. Such an important node as Åkareplatsen, located in the city centre of the second largest city in Sweden, should not have the reoccurring congestion and accidents as there is today, especially between public transport modes.

Creating a simulation model early in the traffic planning process of a central, complex, multi-modal intersection capable of simulating real traffic states facilitates the evaluation of the effectiveness of various designs and the robustness towards different traffic loads. By doing so, resources can be saved by avoiding implementing measures further down the four-step principle of traffic planning. These realistic simulation models are time-consuming to build, require a lot of data, and are not a direct reflection of reality - but in this case, building such a model in the first place would have been beneficial in anticipating the traffic-related problems.

Bibliography

Albalate, D., & Fageda, X. (2021). On the relationship between congestion and road safety in cities. *Transport Policy*, *105*, 145–152. https://doi.org/10.1016/J.TRANPOL.2021.03.011

Andersson, J. (2024, May). Störningar i rusningstrafiken. https://www.gp.se/nyheter/gp-direkt.d4ea89e2-0587-4ff3-bc76-bd25a293050f?access=active&ifr-dir-postId=822c6d67-c161-4a4d-ab74-218207ec0dab&utm_source=ifragasatt&utm_medium=direkt

Andersson, T. (2018). Stopp i kollektivtrafiken på grund av köbildning. *Göteborgs-Posten*. https://www.gp.se/nyheter/goteborg/stopp-i-kollektivtrafiken-pa-grund-av-kobildning.16cd290a-821c-40c8-a113-056d1529e2e4

Barceló, J. (2010). Models, Traffic Models, Simulation, and Traffic Simulation. In J. Barceló (Ed.), *Fundamentals of traffic simulation* (pp. 1–62, Vol. 145). Springer New York. https://doi.org/10.1007/978-1-4419-6142-6

Belin, M.-Å., Johansson, R., Lindberg, J., & Tingvall, C. (1997). The Vision Zero and its Consequences. *Safety and the Environment in the 21st century*.

Berg, J., & Ihlström, J. (2019). The importance of public transport for mobility and everyday activities among rural residents. *Social Sciences*, *8*(2). https://doi.org/10.3390/SOCSCI8020058

City of Gothenburg. (2021, May). *Årsrapport Trafiksäkerhet* (tech. rep.).

Ekström, A. (2023, April). Stopp vid Åkareplatsen efter kollision mellan spårvagn och buss. https://www.gp.se/nyheter/goteborg/stopp-vid-akareplatsen-efter-kollision-mellan-sparvagn-och-buss.cd575ba5-5ca8-4f37-9456-23d8ab094178

Ekström, A., Hallgren, A., & Karlén, M. (2023, September). Stopp i spårvagnstrafiken efter olycka – en till sjukhus. https://www.gp.se/nyheter/goteborg/stopp-i-sparvagnstrafiken-efter-olycka-en-till-sjukhus.b515cc60-9ba7-44dc-ac58-0ebdc17ab851

Elefteriadou, L. (2014). *An Introduction to Traffic Flow Theory* (Vol. 84). Springer New York. https://doi.org/10.1007/978-1-4614-8435-6

Fellendorf, M., & Vortisch, P. (2010). Microscopic Traffic Flow Simulator VISSIM. In J. Barceló (Ed.), *Fundamentals of traffic simulation* (pp. 63–94, Vol. 145). Springer New York. https://doi.org/10.1007/978-1-4419-6142-6

Fernholm, S., & Söderqvist, M. (2024, April). Västtrafikbuss och spårvagn har krockat. https://www.gp.se/nyheter/goteborg/vasttrafikbuss-och-sparvagn-har-krockat.3292b98f-2c38-40de-8d8a-bf83fef4562a

Göteborgs Spårvägar. (n.d.). Våra spårvagnar. https://goteborgssparvagar.se/om-oss/sparvagnar/

Hollander, Y., & Liu, R. (2008). The principles of calibrating traffic microsimulation models. *Transportation*, *35*(May 2008), 347–362. https://doi.org/10.1007/s11116-007-9156-2

Ishaque, M. M., & Noland, R. B. (2009). Pedestrian and Vehicle Flow Calibration in Multimodal Traffic Microsimulation. *Journal of Transportation Engineering*, *135*(6), 338–348. https://doi.org/10.1061/(ASCE)0733-947X(2009)135:6(338)

Jonsson, J. (2023, November). Taxi och spårvagn i krock. https://www.gp.se/nyheter/goteborg/taxi-och-sparvagn-i-krock.c9ae0689-d168-40a0-92a2-eb6d46d8da6e

Karlsson, U. (2023, August). Åkareplatsen byggs om helt. https://www.gp.se/nyheter/goteborg/akareplatsen-byggs-om-helt.2971015a-ea52-45bd-a5d1-b88bd8a266f0

Mahmud, S. M., Ferreira, L., Hoque, M. S., & Tavassoli, A. (2019). Micro-simulation modelling for traffic safety: A review and potential application to heterogeneous traffic environment. *IATSS Research*, *43*(1), 27–36. https://doi.org/10.1016/J.IATSSR.2018.07.002

Majumder, M. (2020, November). *An Approach to Counting Vehicles from Pre-Recorded Video Using Computer Algorithms Using Computer Algorithms* [Doctoral dissertation, Louisiana State University].

Majumder, M., & Wilmot, C. (2023). Accuracy Assessment and Guidelines for Manual Traffic Counts from Pre-Recorded Video Data. *Journal of Transportation Technologies*, *13*(04), 497–523. https://doi.org/10.4236/jtts.2023.134023

Paľo, J., Caban, J., Kiktová, M., & Černický. (2019). The comparison of automatic traffic counting and manual traffic counting. *IOP Conference Series: Materials Science and Engineering*, *710*(1). https://doi.org/10.1088/1757-899X/710/1/012041

Park, B., & Qi, H. (2005). Development and Evaluation of a Procedure for the Calibration of Simulation Models. *Transportation Research Record: Journal of the Transportation Research Board*, *1934*, 208–217. https://doi.org/10.3141/1934-22

Park, B., & Schneeberger, J. D. (2003). Microscopic Simulation Model Calibration and Validation: Case Study of VISSIM Simulation Model for a Coordinated Actuated Signal System. *Transportation Research Record: Journal of the Transportation Research Board*, *1856*(1), 185–192. https://doi.org/10.3141/1856-20

PTV. (2023, December). User manual 2024.

Sävenlund, K. (2023, November). Spårvagnsolycka – flera linjer påverkades. https://www.gp.se/nyheter/goteborg/sparvagnsolycka-flera-linjer-paverkades-.28f5945b-3a26-4305-a6fb-01cb634e9a87

Sjöholm, A., & Kryh, O. (2017, May). *Kollektivtrafiksimulering Åkareplatsen* (tech. rep.). Ramboll. Malmö.

Trafikverket. (2014, April). TRVMB Kapacitet och framkomlighetseffekter.

Trafikverket. (2021, December). Fyrstegsprincipen. https://bransch.trafikverket.se/for-dig-i-branschen/Planera-och-utreda/Planerings--och-analysmetoder/fyrstegsprincipen/

Transportstyrelsen. (2023, October). Största tillåtna längd och bredd. https://www.transportstyrelsen.se/sv/vagtrafik/yrkestrafik/gods-och-buss/matt-och-vikt/langd-och-breddbestammelser/Dimensioner/

United Nations. (2004). *Traffic congestion: the problem and how to deal with it* (A. Bull, Ed.; Vol. 87). www.issuu.com/publicacionescepal/stacks

Wahlstedt, J., Olstam, J., Bång, K.-L., Köhler, J., & Andersson, J. (2014, August). *Handbok för kapacitetsanalys med hjälp av simulering*. Trafikveret.

Wirsenius, P., Remgård, M., Ax, J., Ekman, L., Näswall, L., Andersson, F., Johansson, R., & Linderholm, L. (2022). Vägar och gators utformning.

A

Appendix 1

A.1 Original input data

Table A.1: Original 2018 input data for public transportation lines

Line	Direction	Begin time	LF pm
GRÖN	W-S S-W	120	300
ROSA	W-S S-W	240	300
GUL	N-W W-N	780	900
BLÅ	W-N N-W	60	420
SVART	W-N N-W	360	420
RÖD	N-W W-S	180	450 300
17	W-N N-W	60	240 450
58	W-N N-W	1080	600
121	W-N N-W	300	900
173	N-S S-N	0	1200
503	S-N	0	900
513	N-S S-N	120	900
519	N-S S-N	720	900
100	ÅTC-S S-ÅTC	600	300
101	ÅTC-S S-ÅTC	0	1800 3600

Continued on next page

Table A.1: Continued from previous page

102	ÅTC-S	2100	3600
	S-ÅTC		
120	S-ÅTC	900	1800
300	ÅTC-S	1020	900
	S-ÅTC		
330	ÅTC-S	1200	1800
	S-ÅTC		
GRÅS	N-ÅTC	2940	840
	ÅTC-N		
LERS	N-ÅTC	1080	1800
	ÅTC-N	480	900
1	S-N	0	554
2	Stampgatan-E	300	600
	Stampgatan-W	0	
3	Stampgatan-E	180	554
	Stampgatan-W	420	
4	S-N	480	540
	N-S	600	544
7	Stampgatan-E	420	480
	N-S	240	
9	S-N	120	600
	N-S	240	
11	S-N	600	480
	N-S	540	
13	Stampgatan-E	0	600
	Stampgatan-W	100	

A.2 Initial RMSE for average and maximum queue lengths and vehicle travel times

Table A.2: Initial RMSE for average and maximum queue lengths

Street	**MOE**	**Model**	**RMSE**
Polhemsplatsen (S)	Average	Original	79
		Adjusted	34
	Maximum	Original	13
		Adjusted	10
Burggrevegatan (W)	Average	Ramboll	46
		Adjusted	41
	Maximum	Original	25
		Adjusted	41

Table A.3: Initial RMSE for average and maximum vehicle travel time

Route	MOE	Model	RMSE
S-W	Average	Original	70
		Adjusted	29
	Maximum	Original	210
		Adjusted	121
S-E	Average	Original	177
		Adjusted	193
	Maximum	Original	658
		Adjusted	515
S-S	Average	Original	83
		Adjusted	54
	Maximum	Original	238
		Adjusted	182
W-S	Average	Original	186
		Adjusted	176
	Maximum	Original	250
		Adjusted	239
W-E	Average	Original	147
		Adjusted	119
	Maximum	Original	212
		Adjusted	175
W-N	Average	Original	56
		Adjusted	60
	Maximum	Orignal	187
		Adjusted	192
S-N	Average	Original	70
		Adjusted	77
	Maximum	Original	227
		Adjusted	331
E-W	Average	Original	60
		Adjusted	60
	Maximum	Original	155
		Adjusted	151
E-S	Average	Original	83
		Adjusted	79
	Maximum	Original	208
		Adjusted	201

DEPARTMENT OF SOME SUBJECT OR TECHNOLOGY
CHALMERS UNIVERSITY OF TECHNOLOGY
Gothenburg, Sweden
www.chalmers.se

CHALMERS
UNIVERSITY OF TECHNOLOGY