# Baseline microscopic and macroscopic models

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# 1 Introduction

The AV-ready tools developed within the CoEXist project will be used to test the automation-readiness of eight diverse use cases in four different cities. For five of the use cases a microscopic traffic model is applied and for three use cases a macroscopic traffic modelling approach is used. Applying traffic models for a specific use case commonly follow a process that include the following steps:

1. formulation of the aims and scope of the study,
2. input data collection,
3. construction of the baseline traffic model,
4. model verification,
5. model calibration,
6. model validation,
7. alternatives analysis and
8. documentation.

This process is also used for the CoEXist use cases.

## 1.1 Aim

The aim of this report is to present the development of the baseline traffic models that will be run to investigate each use case. The purposes of the description of baseline microscopic and macroscopic models are:

- To inform the reader of the development of the baseline models, including the study area, the modelling process and the verification, calibration and validation of the models.
- To facilitate information exchange and cooperation between the cities and technical support partners.

## 1.2 Report structure

This report is one of several reports describing the evaluation of the automation-readiness of the eight CoEXist use cases. There are in total seven deliverables related to the evaluation of the use cases:

- D1.3 Use case specifications
- D1.4 Scenario specifications for eight use cases
- D3.1: Completed experimental design templates for eight use cases and AV-ready alternative design
- D4.1 Baseline microscopic and macroscopic models
- D4.2 Technical report on the application of AV-ready modelling tools (incl. input and output data)
- D4.3 Technical report on the application of AV-read hybrid road infrastructure assessment tool
- D4.7 “Guidelines: How to become an AV-ready road authority?”

These reports include documentation at different stages of the specification and evaluation of the use cases. D1.3 and D1.4 presents the use cases and the scenarios at the planning stage. D3.1 describes

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the more formalised experimental designs based on the measures and uncertain factors described in D1.3 and D1.4. This deliverable D4.1 describes the development of the traffic models for the current situation without automated vehicles, while 4.2 describes the inclusions of the automated vehicles in the traffic model applications for the use cases and the simulation results. D4.3 will constitute a final report for the evaluation of the use cases and include updated and revised descriptions of the steps documented in the five earlier deliverables, hence D1.3, D1.4, D3.1, D4.1 and D4.2 can be seen as draft versions of different parts of D4.3 as illustrated in Figure 1. The names of the deliverables in the bullet list are the original names, which are subject to change. For example, D4.3 will probably be renamed to "Traffic modelling and assessment of the introduction of automated vehicles for the 8 CoEXist use cases". The last deliverable in the bullet list (D4.7) will include summaries of the evaluation of the different use cases focusing on the results and not all the technical details with respect to the traffic modelling.

This report starts with a description of the development process of the baseline models (section 2). Section 3 then presents a summary of the baseline models for the eight use cases. Detailed descriptions of the model for each use case are attached to the deliverables in form of 6 Appendixes. Conclusions and lessons learnt are presented in section 4.

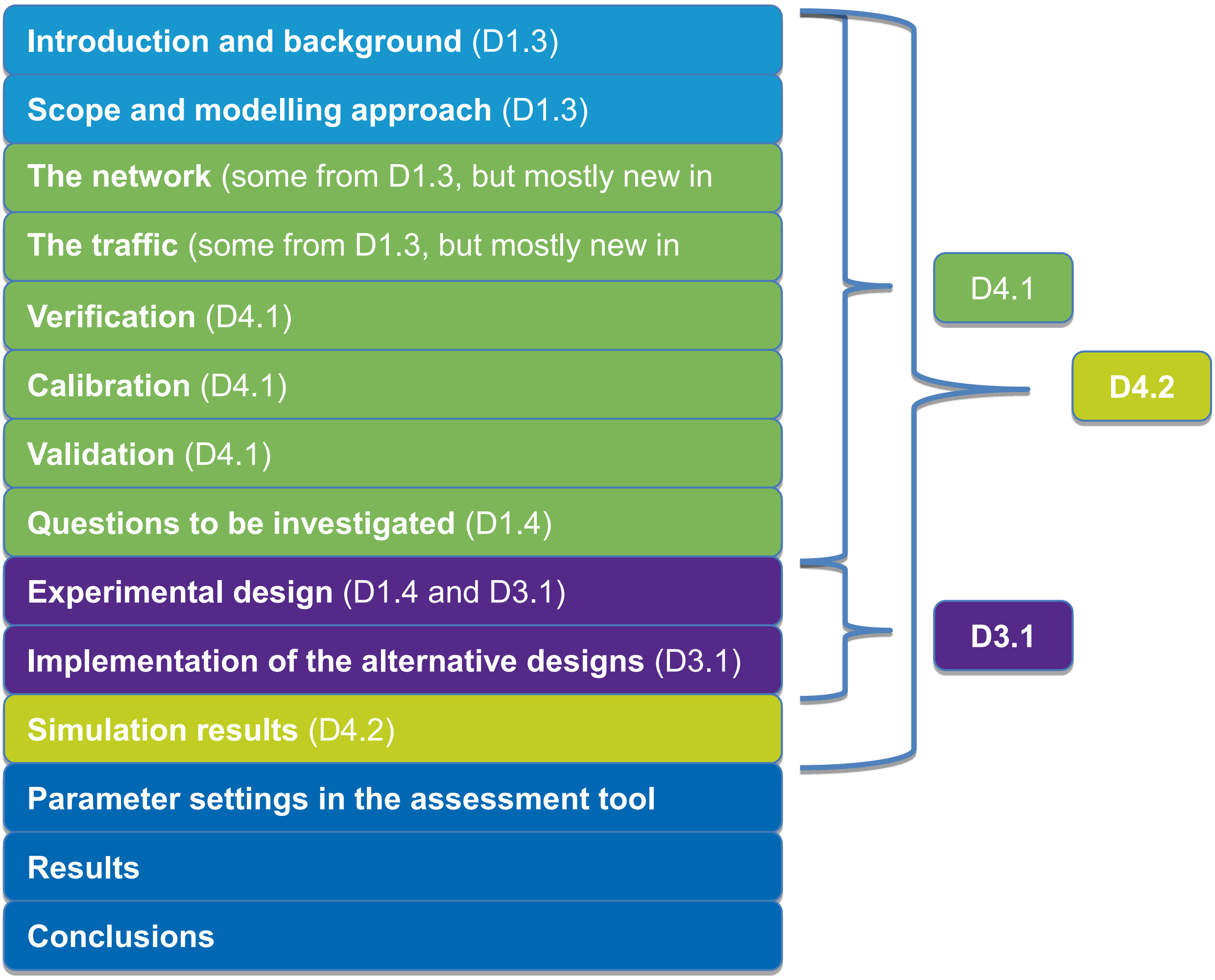


**Figure 1 Structure of deliverable D4.3 and the relation to the other use case related deliverables**

# 2 Development process

The selection of use cases and specification of the scenarios are based on several discussion rounds, among the CoEXist consortium partners and cities, about the practicality and fit with regards to the specific context of each use case. The first drafts of the use cases were presented in the project proposal. The process for further specification of the use cases and the scenarios is described in Figure 2. To allow for more detailed specification of the use cases that fulfil the aims and ensure consistent description, use case and scenario specification templates were developed and circulated among the cities and their support partners.

The development of each baseline model is to a large extent subject to each responsible partner for the method and data used during the verification-calibration-validation process. Some of the baseline models are developed from scratch while some are further developed on existing models. An ‘experimental design workshop’ took take place 15-16th May 2018 in Gothenburg, Sweden, and the plans and progress of the baseline models were presented and discussed. The results from the workshop together with the use case and scenario specifications were then used to guide the development of the baseline model for each use case.

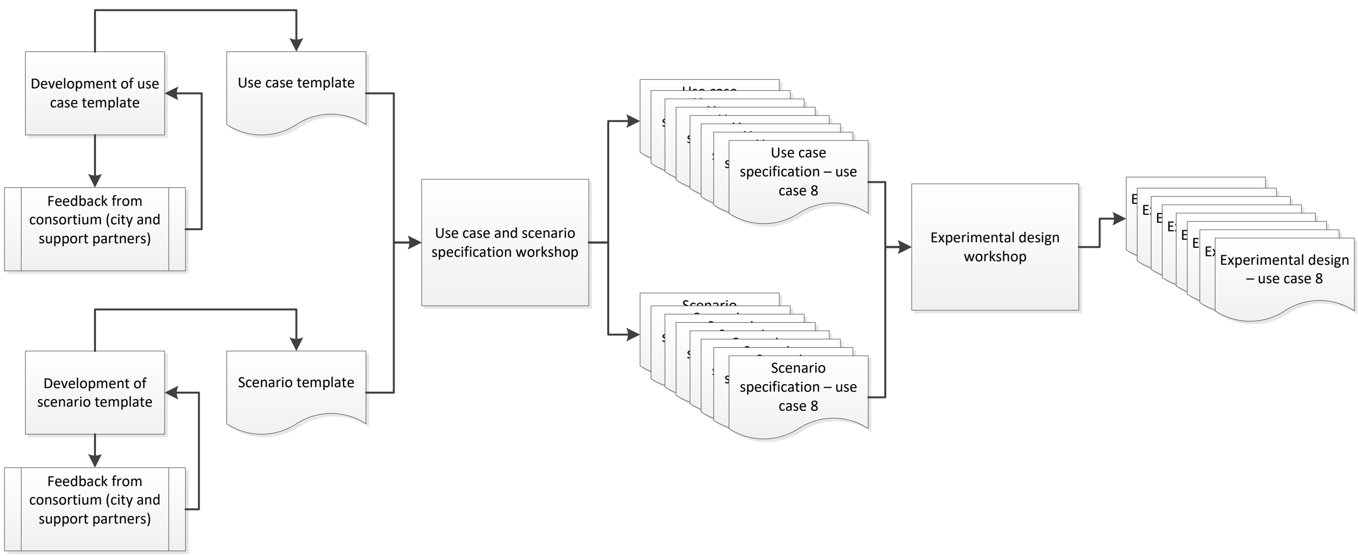


**Figure 2 Flowchart describing the different activities in the development of the use cases, scenarios and experimental designs.**

# 3 Summary of baseline models

This section provides brief summaries of the baseline models that will be used to investigate the impact of CAVs, including the model type, the modelling approach and the questions to be investigated using the baseline model. The detailed descriptions of each baseline model are documented in the Appendixes.

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## 3.1 Gothenburg, Sweden

### 3.1.1 Use case 1: Shared space (microscopic modelling)

Since the pedestrian traffic is central to the use case, the Viswalk[1] extension is used to model pedestrian behaviour by application of the social force model. Since the area under investigation is a shared space where pedestrians move freely and crossing the road segments at any angle, the interaction between pedestrians and vehicles are hard to represent accurately using the standard methods in Vissim[2] and Viswalk. To achieve a more flexible interaction a double representation method is employed which is based on representing vehicles both using the standard driving behaviour models in Vissim and using pedestrians to represent the vehicles in the pedestrian model. In this way the state of the vehicles can be updated using the standard driving behaviour models and the interactions between vehicles follows the usual rules. Also, the reactions of the vehicles to pedestrians is modelled the usual way, while the reactions of pedestrians to vehicles instead consider the additional, pedestrian, representation.

Shared space like environments may be problematic for CAVs to drive without significant delays due to the large volumes of active modes and the lack of traffic control. The questions to be investigated in this use case are related to the effects on the quality of service for all users of the shared space when automated vehicles are introduced.

A detailed description of this baseline model is available in Appendix A.

### 3.1.2 Use case 2: Accessibility during long-term construction works (macroscopic modelling)

A Visum[3] model over the Greater Gothenburg (i.e. the region to be studied) has been developed in the “KomFram” project. This model utilizes the intersection capacity analysis methodology (ICA methodology) and includes a method for signal prioritization and weaving movements at on- and off ramps. The model handles vehicle traffic as a total amount of private passenger cars and heavy good vehicles. In that sense, there is no separation between private car and heavy good vehicles in terms of demand representation. The demand matrix is derived from the Swedish national transport model "Sampers” and calibrated for the peak hour periods using existing traffic counts. On one hand, road construction works and other construction projects have been going on in several places for some time, so a stable “present situation” is difficult to define. On the other hand, a large number of traffic counts are available from recent years, as well as updated travel time information to calibrate and validate the model. The baseline model is calibrated and validated for the year of 2013 and the model for the year of 2018 with all the planned construction works will be used as the baseline for testing effects of CAVs.

Using this baseline model this use case will investigate:

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[1] Viswalk is modelling software developed by PTV to simulate and model the human walking behaviour. For more information, please see: http://vision-traffic.ptvgroup.com/en-us/products/ptv-viswalk/
[2] Vissim is a simulation software developed by PTV. The software is a powerful tool for the evaluation and planning of urban and extra-urban transport infrastructure.
[3] Visum is a modelling software developed by PTV for traffic analyses, forecasts and GIS-based data management.

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- The possible travel time saving, and accessibility improvement from introducing CAVs in a future scenario under the intensive construction period.
- To evaluate the effectiveness of the proposed measures to relieve congestions under the intensive construction period.

A detailed description of this baseline model is available in Appendix B.

## 3.2 Helmond, the Netherlands

### 3.2.1 Use case 3: Signalised intersection including pedestrians and cyclists and use case 4: Transition from interurban highway to arterial (microscopic modelling)

Use case 3 and use case 4 utilise different parts of the same traffic corridor so the description of the baseline models for the two use cases have been merged. Use case 3 focus on the signalised intersection at the end of the corridor while use case 4 focus on the first part, the transition from the highway to the signalised arterial. The microscopic model for use case 3 and 4 was based on the microscopic model developed by the traffic light supplier in Helmond, Dynniq. A Vissim model of the traffic lights at the intersections in Helmond was developed to evaluate traffic light regulations. The infrastructure is accurately reproduced on the digital surface in the model. All lanes, stop lines, detectors are reproduced in the model. In the model the traffic light regulations as used in the reality are implemented. Dynniq has made an extension so that this regulation strategy can be simulated in Vissim. With a connection between Vissim and a simulator of the traffic light controller regulation is established so that the simulation can capture the signal controller in detail. The traffic regulation is dependent on the presence of the traffic on the detectors and the policy settings.

Using this baseline model, the following research questions will be investigated for use case 3:

- Will the introduction of CAVs lead to a more efficient traffic flow?
- Is the performance of the intersection getting better because of a more efficient flow?
- Is the impact dependent on the penetration rate of CAVs?
- Is the impact dependent on the mix of different kinds of CAVs?
- Is automation enough to produce benefits, or is there also a need for connection between vehicles and the infrastructure (V2I)

The following research questions will be investigated for use case 4:

- Will there be less speeding (especially on the westernmost T-junction) due to the presence of CAVs?
- Will the speed become more homogenous due to the presence of CAVs, and will it lead to a more efficient flow?
- Will the travel time become more reliable with the presence of CAVs?
- Will the performance of the traffic get better?
- To what extend are the effects on traffic performance, safety and speeding dependent on the penetration rate of CAVs?
- To what extend are the effects on traffic performance, safety and speeding dependent on the type and mix of CAVs?

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A detailed description of the baseline model for use case 3 and 4 is available in Appendix C.

## 3.3 Milton Keynes, UK

### 3.3.1 Use case 5: Waiting and drop-off areas for passengers (microscopic modelling)

The Central Milton Keynes (MK) study area for the purpose of CoEXist is implemented in Vissim based on real traffic origin-destination (OD) values and signal schemes and timings from 2016 surveyed data. The base scenario road network model corresponds to the current situation, that means all access roads will be open to the city centre and all cars will be manually driven and no AVs introduced. The baseline model is detailed and quite comprehensive covering details of main road networks around the city centre and most feeder points within the area. The baseline central area model will be adapted through the addition of intercept locations, which will make allowance for the approach junction and lane designs. The adapted model will then be exercised to investigate the effectiveness of the measure and how the penetration of AVs will affect the city (i.e. reducing traffic congestion in the city centre area without introducing an unacceptable increase in peripheral road congestion).

Using this baseline model, the following research questions will be investigated:

- What is the effect on the quality of service after vehicle intercept areas are defined?
- Is there a need for operational parameters such as entry and exit capacity requirements for vehicle intercept facilities?
- Quality of service within the city centre affected by restricting access to it. How much road space can be removed within the centre whilst maintaining similar quality of service?
- Impact (capacity) of feeder network into vehicle intercept zones.
- Varying the mix of CAVs and normal cars and analysing congestion.

A detailed description of the baseline model for use case 5 is available in 1.

### 3.3.2 Use case 6: Priority Junction (roundabouts) Operation (microscopic modelling)

For use case 6 a Vissim model of the H3 Monks Way has been created using real traffic OD values and signal schemes and timings from 2016 surveyed data. The base scenario road network model describes the current situation, that means all access roads will be open to the city centre and all cars will be manually driven. The baseline model is comprehensive enough to carry out investigations on intersections and roundabouts. It covers the dual carriage way along the modelled intersection and other parts of dual carriage on opposite end of the roundabouts within H3. It essentially models all four legs of the roundabouts. The adapted model will then be exercised to investigate the effectiveness of the measure and how the penetration of AVs will affect roundabouts using the dual carriage way H3 as a use case. The initial concept is that the intersections improvements will be at a modest scale to respect the environment they are operating/located. Designs and scale of the intersections will be influenced by demand, operational capabilities of the vehicles, safety, mode share and air quality improvements.

Using this baseline model, the following research questions will be investigated:

- What is the effect on congestion on the roundabouts during the different stages of introduction of CAV's?

- How will AVs gap acceptance at intersections affect traffic performance?
- Measures to assist passive CAVs (lane allocation) to pass intersections?

A detailed description of the baseline model for use case 6 is available in Appendix E.

## 3.4 Stuttgart, Germany

### 3.4.1 Use case 7: Impacts of CAV on travel time and mode choice on a network level and Use case 8: Impact of driverless car- and ridesharing services (macroscopic modelling)

Both Stuttgart use cases will utilise an existing macroscopic travel demand model for the Stuttgart Region. The modes included to date in the baseline model are car driver, car passenger, public transport, walking, cycling, Park & Ride and six HGV modes. The travel demand model replicates the trips of the 2.7 million inhabitants of the region split into 1175 zones. The model is calibrated and validated for the year 2010. The model was updated for the year of 2015 with the latest land use data and finalised infrastructure measures. The model describes the demand of an average working day. It is a static 24-hour model without any temporal segmentation. It contains desired departure times for each trip purpose. With this data it is possible to compute hourly demand matrices for each mode. By now the model has been applied successfully for examining more than 200 scenarios in approximately 10 projects for the regional transport plan and various local studies. The large number of successful applications proofed that the model produces reasonable results.

Using this baseline model, the following research questions will be investigated for use case 7:

Stuttgart City requires information to what extend the introduction of CAV will decrease or increase the road capacity, car travel demand and the level of congestion within the Stuttgart City limits and the Stuttgart basin for scenarios with different penetration rates and CAV levels. Use case 7 will investigate the following questions:

- Road capacity: What changes can be expected on motorways, on urban arterials and on urban roads with mixed traffic. Can a capacity increase reduce congestion levels and provide more reliable travel times?
- Route choice: To what extent will changes in travel time and the suitability of certain road types for CAV influence route choice? Can a higher reliability on the motorways surrounding Stuttgart reduce through traffic in the City?
- Mode choice: CAV will only be successful, if they provide a benefit to the car user. CAV promise that drivers can use their in-vehicle time more efficiently and that valet parking makes parking easier. Will more comfortable cars cause a shift in mode choice leading to more car traffic?

The following research questions will be investigated for use case 8:

Developing urban public transport requires long-term planning processes. Stuttgart City and the public transport operator are interested in better understanding the impacts of driverless sharing systems on public transport and on required street parking places:

- What impact will the introduction of car- or ridesharing services have on modal split?

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- What impact will the introduction of car- or ridesharing services have on traffic volumes?
- What are the differences between the impacts of public vs. private ridesharing services?
- How many privately-owned cars can be replaced by a high-performance car- or ridesharing service?
- Which price levels are economically feasible for car- or ridesharing services?

# 4 Conclusions and lessons learnt

This document describes briefly the development process of the baseline microscopic and macroscopic models that will be used to assess the impact of CAVs. These baseline models represent areas with different geographical scales. For instance, the macroscopic models used in use case 7 and 8 covers the whole Stuttgart region including 2.7 million inhabitants while the microscopic model used in use case 6 focuses on the intersections of a motorway H3. Regarding the different modelling approaches used, macroscopic models utilize Deterministic User Equilibrium Assignment or Equilibrium Assignment with Intersection Capacity Analysis whilst the microscopic model simulates the movements of individual vehicles with static and dynamic routing. The verification-calibration-validation process of the baseline microscopic and macroscopic models can be seen as an iterative process. The baseline models that will be used in most use cases currently can produce realistic and desired results to describe the current traffic situations while models for use case 1 and use cases 3, 4 have not been fully developed and validation results will be added in the Deliverable 4.2. Private vehicles, freight transport vehicles, public transport, cyclists and pedestrians are included in one or several baseline microscopic and macroscopic models, providing a comprehensive assessment for investigating the impact of CAVs.

Through the development of the baseline microscopic and macroscopic models, the following experience can be summarized:

- The baseline models were often under development for a long time and used to evaluate various purposes. Therefore, the baseline models are often designed to tackle different challenges with different modelling approaches. For instance, the baseline model for use case 2 was designed to model delays particularly at intersections and therefore detailed description of intersection capacity is adopted in the baseline model but the network size has been controlled into a manageable scale to ensure the model run time is not too long. In that sense, using a specific baseline model for evaluating CAVs means that the impact of CAVs on this specific aspect in transport modelling can be studied in detail (for instance, in the use case 2 the impact of CAVs on delays at intersections can be studied in detail). On the other hand, the uncertainties introduced by the limitation of modelling approach and level of detail of the model can partially be tackled by using sensitivity analysis. This however inevitably increases the number of scenarios and suffers from the curse of dimensionality.
- CAVs will often be tested in a future scenario where infrastructures may change from the data used for the verification-calibration-validation process. In this sense, there is no possible way to validate the model outcome of a future scenario without CAVs but with only future infrastructure since these infrastructures are not present in reality. In that sense, the outcome of the model can be considered more as an assessment of the impact of CAVs rather than prediction of future traffic situation with CAVs.

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- Given that different types of models are used for various use cases, the comparison between results from different use cases can be difficult since different types of models use different metrics as outputs. Furthermore, different models also include different transport modes. This means that the development of these baseline models may need to be coordinated so that comparable metrics can be calculated and be fitted into the same impact assessment tool.

Given that some of the baseline models are still under development, the baseline models described in this deliverable might be revised and the final versions will be included in the final use case deliverable D4.3 “Traffic modelling and assessment of the introduction of automated vehicles for the 8 CoEXist use cases”. Furthermore, intermediate revised versions will be included in D4.2 “Technical report on the application of AV-ready modelling tools (incl. input and output data)”.

# 5 Partners

# Appendix A Use case 1: Shared space

# Scenario specification for use case 1

## Shared space

Version: 1.0
Date: 2018-10-30
Author: Fredrik Johansson and Johan Olstam



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# 1 Introduction and background

Automated last mile services integrated with the public transport system is an interesting solution to increase the accessibility of the city centre without reducing the efficiency of the line based public transport by increasing its stop frequency. However, the city centre of Gothenburg contains several areas with shared space characteristics; both areas that formally are shared spaces and areas with conventional traffic regulations, but dominated by large volumes of pedestrians. The focus of this use case is to determine the traffic effects at shared spaces when automated last mile services are introduced. The last mile service is envisioned to distribute passengers from the main public transport network and consist of automated small buses for six to twelve passengers.

As an example of shared space in the city centre, Kungstorget is selected for detailed simulation in this use case.

## 1.1 Study area characteristics

The study site is the area with shared space characteristics in connection to Kungstorget in central Gothenburg, see Figure 3. The definition of shared space varies between countries. In general, a shared space is an area where pedestrians and vehicles can move freely, but only at walking pace and with caution and there is no clear infrastructure separating the modes. Exact rules differ between countries; in Sweden the formal name is ‘Gångfartsområde’, that is, walking speed area, and all vehicles are limited to walking speed and should give way to pedestrians. Bicycles are included as vehicles in these regulations.

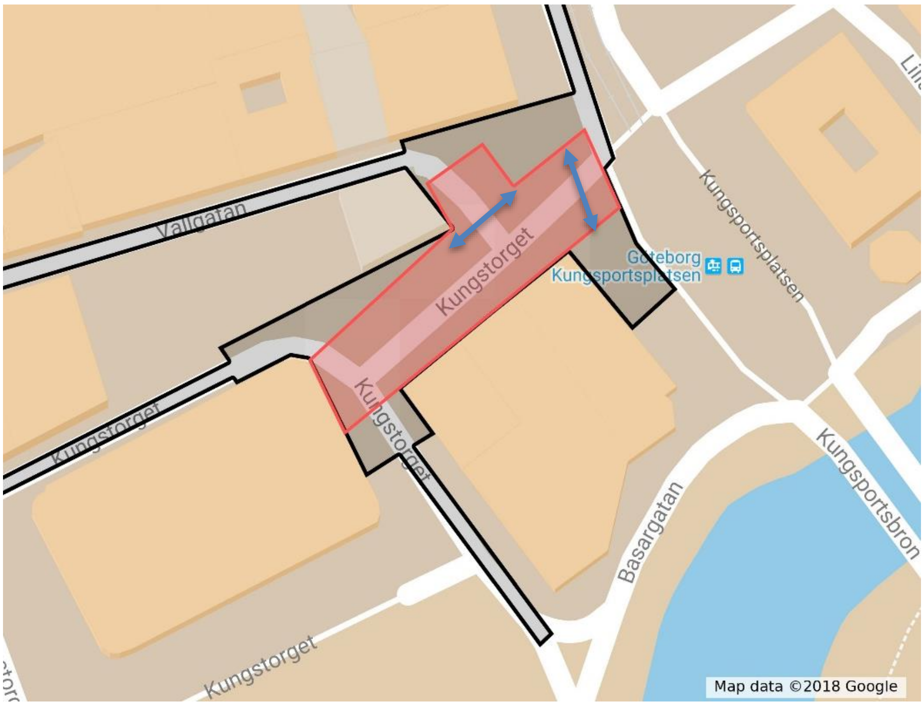


**Figure 3: The proposed study site ‘Kungstorget’ and its surroundings. The blue arrows indicate large pedestrian flows that crosses Vallgatan and Kungstorget. Red indicate the area of interest and black the area included in the model.**

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The area ‘Inom vallgraven’ encircled by canals, see Figure 4, is the historic city centre and is characterized by high pedestrian and public transport flows and narrow low speed streets for motorized vehicles.

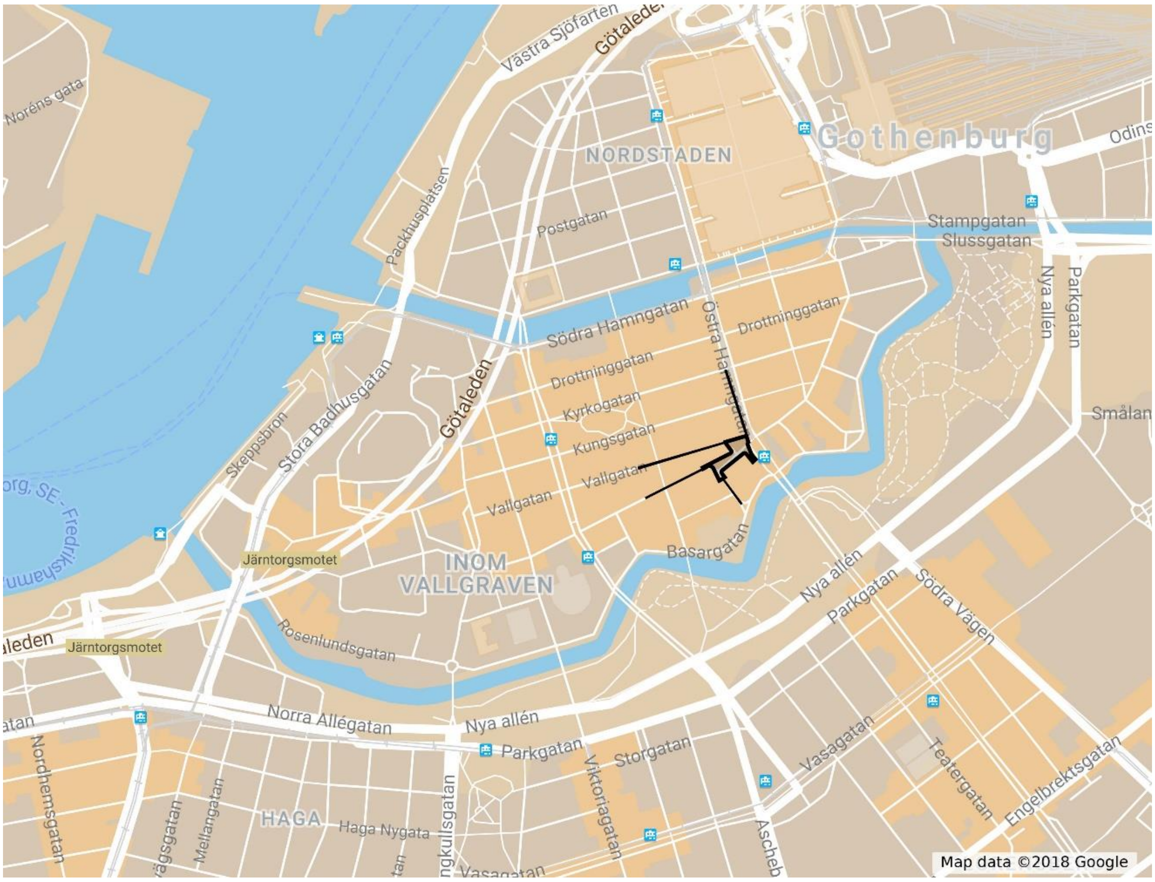


**Figure 4: Gothenburg city center with the study site Kungstorget.**

The area around Kungstorget is a very well-visited place in the heart of the inner city. There is a market hall, a cinema and lots of restaurants and shops. In addition to that, there is a large public transport stop in proximity of the study area. The modes of transport present in the area are mainly cars, taxis, bikes and trucks. In addition to that, large pedestrian flows are crossing Vallgatan and Kungstorget, as indicated in Figure 3. Kungstorget is a narrow local street, that is not formally a shared space area. Taxis are often passing and also tend to park along the street. Vallgatan, on the other hand, is a walking shared space area. Since there are frequent freight deliveries in the area, trucks are often seen parked along Vallgatan in the morning. However, trucks are not allowed to enter Vallgatan and several similar streets in the area after 11 AM. There are low curbs along Kungstorget, while there are no curbs along Vallgatan; the street is at the same level as the surrounding pedestrian surface with bollards marking the recommended path for vehicles.

Pedestrian flows are somewhat structured, but the absence of zebra crossings on Vallgatan or Kungstorget is leading pedestrians to cross the streets anywhere and often diagonally. This contributes to an area with shared space characteristics also at Kungstorget, which formally is not a walking speed area. Close to the intersection Vallgatan/Kungstorget, there are many bike parking facilities offered, mostly well used, these contribute to structuring the pedestrian flows, significantly reducing the route choice possibilities.

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Adjacent to Kungstorget/Vallgatan, there is a larger public transport stop named “Kungsportsplatsen” including both tram and bus stops. Overall, there are 6 tram lines and 6 bus lines that operate in each direction. In total, there are about 40 tram departures and 36 bus departures in each direction during the busiest hours of the day. The stop and the connecting roads are, however, outside of the modelled area, but of course indirectly influence the pedestrian traffic in the area.

## 1.2 Questions to be investigated by applying the modelling approach

Shared space like environments may be problematic for CAVs to drive without significant delays due to the large volumes of active modes and the lack of traffic control. The questions to be investigated in this use case are:

- What is the effect on the quality of service for all users of the shared space from the introduction of automated vehicles?
- Will there be significant queuing for motorized traffic upstream of the shared space due to the interactions between active modes and CAVs?
- How sensitive are the predicted quality of service for each mode to the assumptions on the interaction between active modes and CAVs, and on the assumptions on the behaviour of the CAVs?
- How advanced do CAVs have to be for an efficient traffic flow for both motorized traffic and active modes through the shared space? That is, what assumptions on the behaviour of the CAVs are needed for CAVs to be able to pass the shared space efficiently? This includes assumptions on their ability to communicate their intentions to the pedestrians and cyclists in such a way that they are respected.

# 2 Scope and modelling approach

## 2.1 Type of model

The model of this use case is a microscopic Vissim model that includes motorized vehicles, bicycles, and pedestrians. Since the pedestrian traffic is central to the use case, the Viswalk extension is used to model pedestrian behaviour by application of the social force model (SFM).

Since the area under investigation is a shared space where pedestrians move freely and crossing the road segments at any angle, the interaction between pedestrians and vehicles are hard to represent accurately using the standard methods in Vissim and Viswalk. To achieve a more flexible interaction an improved version of the double representation method proposed by Gibb (2015) is applied, which is based on representing vehicles both using the standard driving behaviour models in Vissim, and using groups of pedestrians to represent the vehicles in the pedestrian model. In this way the state of the vehicles can be updated using the standard driving behaviour models and the interactions between vehicles follows the usual rules. Also, the reactions of the vehicles to pedestrians is modelled the usual way, while the reactions of pedestrians to vehicles instead consider the additional, pedestrian, representation. The details of this setup are described in section 3.

## 2.2 The area and the level of detail of the model for base scenario

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The area of interest for investigation is indicated in red in Figure 3; especially the conflicts between the large pedestrian flows, indicated by blue arrows in the figure, and the motorized traffic on the road segments are of interest. To avoid unwanted effects of the model boundary, the model includes the area indicated in black in Figure 3. Also, the public transport, consisting of buses and trams, at 'Östra Hamngatan' in the east is included, but only for visualisation purposes, so it is not included in this document.

Pedestrians are free to walk anywhere in the modelled area, except for the segment of 'Östra Hamngatan' included in the model, and the initial and final legs of the road network. Formally, the road segments constituting 'Kungstorget' are not shared space, or walking speed area (Gångfartsområde) which is the formal Swedish term in the traffic regulation. However, since the whole area in practice is treated as a shared space by the road users, the whole area is modelled in the same way.

In principle, also vehicles are free to move in any way in a shared space, but in this case, there are clear roads that the vehicles are constrained to by various barriers and markings. This means that pedestrians can move freely in the whole area, while vehicles are constrained to links. However, there are also many barriers in the area for pedestrians, such as bicycle stands, benches, and outdoor seating areas for cafés and restaurants. Such barriers are considered static obstacles for the pedestrians in the model.

The geometric accuracy of features in the area is high; this is achieved by basing the model both on a digital map of the area provided by the city of Gothenburg and on manual measurements on site.

Small obstacles, such as light poles, and the bollards along Vallgatan, are not included in the model since their effects on the flows are deemed negligible.

## 2.3 Included and excluded in the model of base scenario

Cyclists are in principle free to move anywhere in the modelled area, and a small fraction do, but in the model, cyclists are constrained to use the same links as motorized vehicles which significantly simplifies the modelling.

The public transport station Kungsportsplatsen, located directly to the east of the modelled area is not included in the model, but its presence is included through the origin demand matrix of the pedestrians; many go to and from the station which affects both the size and the temporal variation of the flows.

There are many entrances to shops and restaurants and similar at the edge of the simulated area, however, the volumes entering and leaving the simulated area through these seems to be negligible in comparison to other flows, and since these entrances are not close to the interaction with the vehicular traffic they are neglected. At the open edges of the area, origins and destinations are aggregated to five origin and destination areas, as described in section 4.

Figure 5 depicts the network, with individual road segment numbers for each lane, and pedestrian obstacles indicated by red areas. Unnumbered road segments do not affect the simulation but is included in the model for visualization purposes only. On link 6 it is only allowed to drive in one direction, to the south-west, which is why it only has one number.

Along the road segment number 8, see Figure 5, there are almost at all times three or four taxis parked. These are in the model treated statically, that is, they are parked there during the whole simulation

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period, and modeled as pedestrian obstacles, and the link can only be traversed in one direction at a time due to its small width. However, in the baseline scenario this has no effect since the flow is in only one direction.

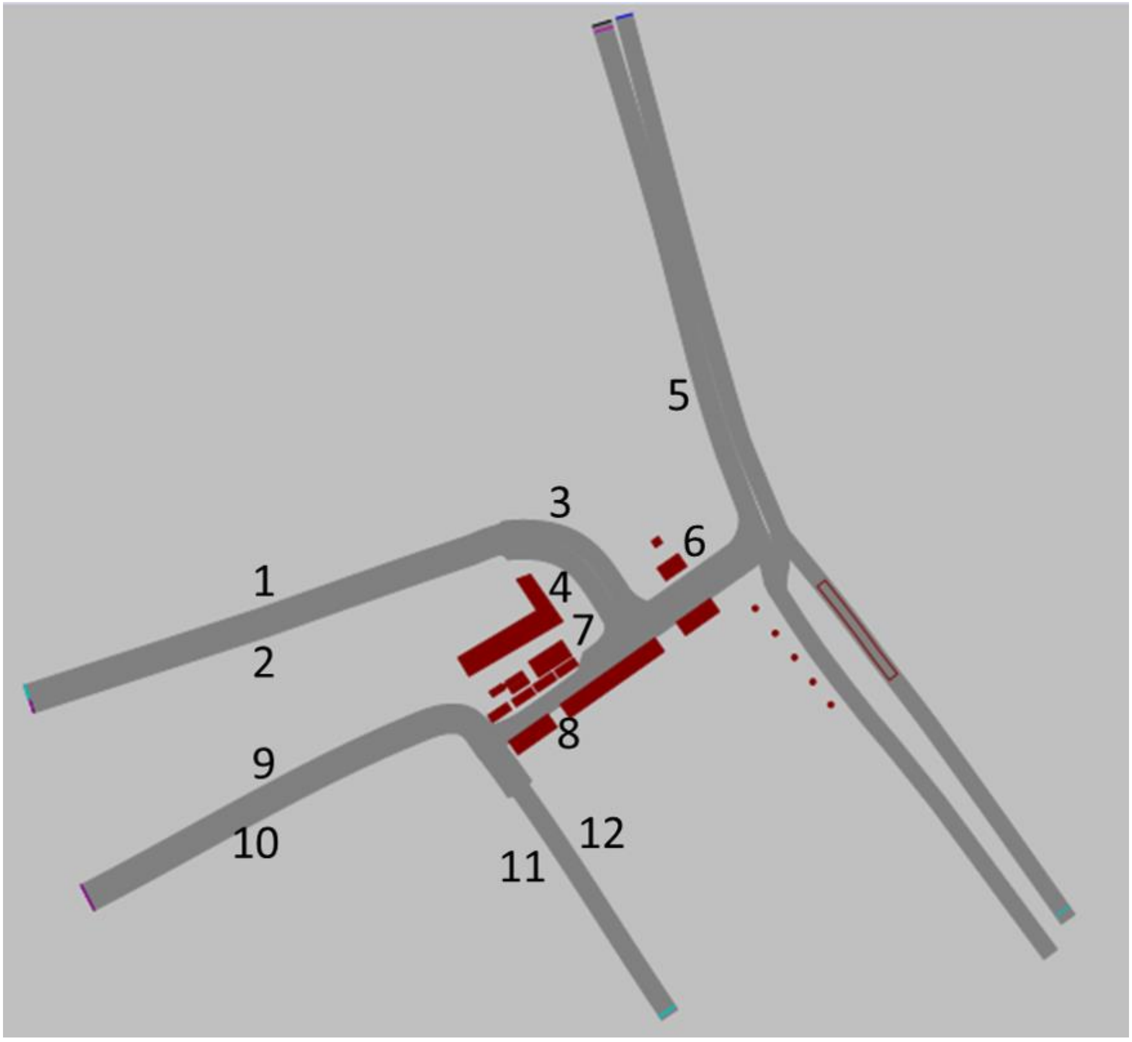


Figure 5: The network with road segment numbers, and pedestrian obstacles in red.

# 3 The network

## 3.1 Detailed description of the network and how it is modelled

In principle, the model of the network can be seen as consisting of two components: a large pedestrian area covering the whole modeled area, and links for vehicles through this area. The idea with the double representation of vehicles is that the vehicle is represented by pedestrians at the pedestrian area at the same position as the vehicle at the road link. However, the details of the implementation are significantly more complex.

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The areas where no vehicles can drive are simply modeled as pedestrian areas. These fill all walkable areas that are not part of the roads. Any obstacle at the pedestrian areas larger than approximately 50 cm are modeled as pedestrian obstacles, see the red areas in Figure 5.

The walkable area on roads are instead represented by pedestrian links that cross the road perpendicular to the direction of the road. These links are placed every 0.5 m and are 0.55 m wide, providing an overlap between the links so that pedestrians can walk in any direction on the links, transferring seamlessly between them. The structure is repeated for each lane of the road to simplify turnings. This peculiar structure is built to enable construction of priority rules for the vehicles, so that they can drive if there are no pedestrians on the closest pedestrian links in front of it, including also some distance on the side of the road. The number of links in front that vehicles consider, and their widths, are model parameters that should be set based on data.

As mentioned before, the vehicles have both a regular vehicle representation and a pedestrian representation, both located at the same position in physical space, but on two different network objects in Vissim. The vehicle representation is located on the regular road links, while the pedestrian representation is located on a pedestrian area with the same shape and location as the road links (or actually two identical pedestrian areas at the same location connected with a static route back and forth between the two, since pedestrian must have a route). The behavior of the vehicle is controlled according to the normal Vissim modeling procedure, that is, the pedestrian representation of the vehicle does not affect the movement of the vehicle. The pedestrian representation exists only to inform the pedestrians that there is an object in their way that they need to avoid. Vehicles interact with other vehicles in the intersections of the model by means of priority rules instead of conflict areas, as is common practice. The reason for this is that the special structure of lots of priority rules needed for the interaction with pedestrians seems to conflict with conflict areas.

In the original implementation by Gibb (2015) each vehicle was represented by a group of tightly packed dummy pedestrians located on a grid of small quadratic pedestrian areas, and the movement of the pedestrian representation of the vehicle was achieved by adding a row of dummy pedestrians in front of the vehicle and removing a row at the back, for each half meter the vehicle moved. In our implementation this has been significantly simplified; instead of using a group of dummy pedestrians on a grid of pedestrian areas, each vehicle is represented by a single dummy pedestrian of the same size as the vehicle on one pedestrian area. This single dummy pedestrian is moved (or actually “destroyed” and created at a new position due to limitations in the COM interface) according to the movement of the vehicle representation in each time step. The main reason for this simplification is that the use case requires that the vehicles are able to make turns and simultaneously interact with pedestrians, which would have been complicated in the original implementation. The downside of our implementation is that the positions of the dummy pedestrians need to be updated in a time-controlled way (each time step), instead of in an event-based way, as was the case in the original implementation. This increases the computational cost of the model. On the other hand, the number of dummy pedestrians has been reduced to one per vehicle, which reduces the computational cost, and the movement of the pedestrian representation of the vehicles has become smoother due since it is updated at each time step in continuous space instead of stepwise on a discrete gird.

To further improve the behavior of pedestrians around vehicles, another modification was made to the original implementation of the double representation. The position of the dummy pedestrian representing a vehicle is slightly shifted in the direction of movement of the vehicle. More exactly, the dummy

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pedestrian is positioned with a constant time headway in front of the real position of the vehicle; in our case set to 0.1 s. There are two reasons for this modification. First, pedestrians should avoid the area in front of vehicles to a greater extent. This is already included in the social force model by the elongation of the isocurves of the force in the direction of motion (or relative motion, depending on version of the SFM), but since it is a vehicle that constitute a significantly more severe danger than another pedestrian, this effect should be stronger for vehicles. The second reason is to encourage pedestrians to walk around moving vehicles behind and not in front of the vehicle. When a pedestrian is blocked by a vehicle moving perpendicular to the desired direction of the pedestrian, the pedestrian will, thanks to the dynamic potential, change the direction of its desired velocity in order to walk around the obstacle. This detour will be chosen such that it becomes as short as possible (given that there are no other pedestrians around that can cause delay). Thus, if the path of the pedestrian is blocked by the front half of a moving vehicle, it will turn to try to walk around the vehicle in front of it, which is likely to fail, and dramatically so if the speed of the vehicle is close to the speed of the vehicle. Shifting the pedestrian representation of the vehicle in the direction of its motion reduces this problem.

## 3.2 Description of the data utilized for the network

The geometry of the area was encoded based on digital maps and additional manual measurements on site of details not accurately represented on the maps. The largest uncertainties in the geometry is the obstacles representing the bicycle stands and the taxi parking. These are modelled as static obstacles with size approximating that of a full bicycle stand and parking, respectively. However, both may also be less than full or overfull, giving a significant variation of the size of the obstacles, which is not represented in the model.

# 4 The traffic

## 4.1 Detailed description of the traffic and its implementation in the model

The OD matrix for vehicles is obtained by manually counting traffic turning proportions in the recorded video. Due to the simplicity of the road network structure, this information is sufficient for OD matrix construction. The origins with corresponding hourly input car traffic volumes for the study period are displayed in Figure 6. All vehicles leave the network on road segment 11, see Figure 5, to the south.

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Figure 6: Vehicle origins and input flows per hour.

For pedestrians, the origin and destination areas were manually constructed based on plots of the first and last points, respectively, of the set of filtered trajectories. These points are aggregated to five origin/destination areas based on their structure and its relation to the infrastructure. The areas from which start and end points of trajectories are aggregated to origins and destination areas are made quite large to capture trajectories that are not detected immediately by the system when the road user enters the area, see the description of the data in subsection 4.2.

A complicating factor for the OD estimation is that there is a gap in the coverage of the detectors a few meters west of Vallgatan, where three cameras were mounted on the same pole, see Figure 7. The system is able to merge some trajectories passing this gap, but most trajectories passing through the gap are identified as two separate trajectories, one ending at one side of the gap and the other starting on the other side. To overcome this problem, two additional origin and destination areas were created at the gap and the OD matrix was estimated on the extended set of seven origin/destination areas, see Figure 8, and then reduced back to the original set of five origins and destinations. The resulting OD matrix for the afternoon peak hour, 17:00-18:00, is presented in Table 1.

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Table 1: OD matrix for pedestrians in the afternoon peak hour.

| | | To | | | | | |
|---|---|---|---|---|---|---|---|
| | | The square | Vallgatan | Ö.Hamngatan | Kungstorget W | Kungstorget S | Total from |
| From | The square | | 274 | 205 | 504 | 116 | 1099 |
| | Vallgatan | 346 | | 171 | 43 | 5 | 564 |
| | Ö.Hamngatan | 204 | 313 | | 533 | 182 | 1232 |
| | Kungstorget W | 642 | 99 | 207 | | 10 | 958 |
| | Kungstorget S | 137 | 87 | 212 | 23 | | 459 |
| | Total to | 1329 | 773 | 795 | 1102 | 313 | 4311 |

The route choice of the pedestrians is governed by a network of static routes to achieve the observed route choice. Between the decision points for the static route choice the desired direction of the pedestrians is determined by the dynamic potential for dynamic approximate quickest path route choice and underlying static shortest path route choice.

## 4.2 Including description of the data utilized

The traffic at the site was observed using computer vision based automatic tracking equipment OTUS3D provided by Viscando Traffic Systems AB. The output of this system is trajectories for all road users at the site; this data set is then used both to estimate the OD matrix and route choice, and to calibrate model parameters.

A total of six data collection systems where used to observe the complete area of interest, see Figure 7. The data from these systems was then merged and the separate trajectory segments from each system joined into global trajectories, in principle enabling direct OD estimation, see Figure 8 for an example of tracked trajectories.

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Figure 7: Coverage of the six detectors. However, some areas were masked in the video recordings due to regulations.

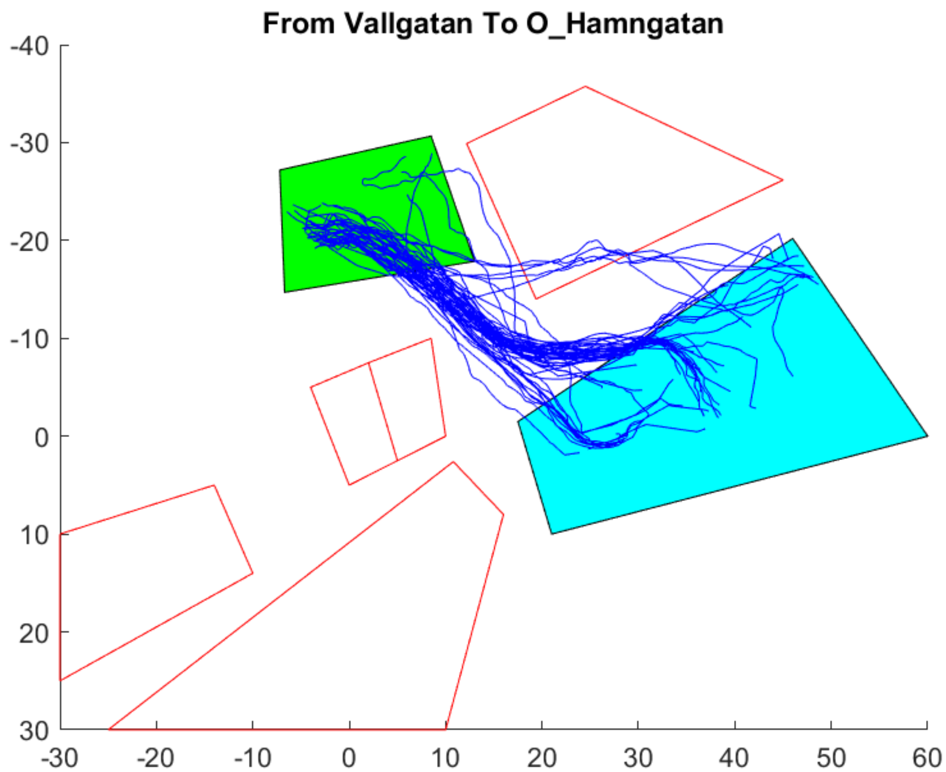


Figure 8: Tracked trajectories from the 'Vallgatan' origin area (green) to the 'O_Hamngatan' destination area (blue). As can be seen, both the OD-flow and route choice may be inferred from the data.

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The automated tracking of road users enables relatively cheap data collection. In this case it enables five days of around the clock data collection within the rather limited data collection budget, which would have been impossible using any manual approach to data collection. However, automatic tracking of traffic in a shared space environment is a challenging task, and as a result the data have large uncertainties. The most common challenges are:

- Misclassification of individual entities: Road users are classified as another type, e.g. a cyclist is classified as a pedestrian.
- Fragmentation and merging: A road user is identified as a group of road users, possibly of another type, or a group of road users are identified as a single road user. For example, it is common that a vehicle is identified as a group of cyclists, or that a group of pedestrians are identified as a vehicle.
- Group size estimation: In dense groups of pedestrians the system is not able to track individuals, but instead try to infer the number of pedestrians in the group from its size. This group size estimation is associated with a significant uncertainty. Also, the individual trajectories of pedestrians in groups are just constructed from the trajectory of the center of the group, so no internal structure or dynamics can be observed.
- Trajectory fragmentation: The system often loses track of a road user and finds it again after some time. This results in the trajectory getting identified as two trajectories, which introduces significant noise.
- Shadow misclassification: Shadows of road users are sometimes identified as road users.
- Short phantom trajectories: The data contains a lot of short trajectories of unknown origin.
- Delayed detection: Road users are not detected as soon as they enter the field of vision of the system, rather it takes a variable amount of time for the system to detect a new road user. This spreads out the starting points of trajectories over an extended area, which complicate origin identification.

To estimate the size of the errors in the data, vehicles were manually counted in six hours video from one of the systems and compared to the automatically extracted data. Similarly, pedestrians were manually counted in one hour of video from each of three of the systems. For each system, the number of pedestrians passing in different directions were counted separately, providing ground truth data for twenty relations. This enabled correcting the automatically collected flow data, and enabled the data supplier to improve the data quality.

The most important result of the validation of the automatic data collection described above is estimations of the failure rates of the detectors. The comparison of detector data and manual counts indicates that the system has problems tracking pedestrians over longer distances, which is in line with the difficulties connected to automatic detection discussed above. This significantly complicates the OD estimation. To overcome this problem the performance of the system as a function of trajectory length was modeled and observations of long trajectories were given a higher weight in the estimation of the OD matrix, in accordance with the model of the performance of the system. That is, each trajectory in the data set was given a weight based on the probability that the system would be able to track a road user during an interval as long as the trajectory.

The data supplier continues working on improving the data and will deliver an improved data set in the beginning of 2019, which will enable a revision and improvement of the OD estimation, calibration, and validation of the model.

# 5 Verification

## 5.1 Verification process

The following steps were taken to ensure an accurately implemented model:

- Verification of input data and coding: Comparisons between the input flows and data, both automatically extracted and video, were made. The geometry was checked by several different persons, both against digital maps and site measurements, and also reviewed by staff familiar with the area.
- Test runs with several different flow levels were performed. Since data was obtained for several days and around the clock, comparison was possible for multiple flow levels. To ensure model stability with respect to perturbations in parameter values, a sensitivity analysis with respect to a set of model parameters was performed.
- The general modelling approach and its implementation was discussed in detail with several experts in the field, including representatives of the developer of the software and researchers specialised in modelling of pedestrian traffic.

## 5.2 Verification results

The verification process resulted in some improvement of the model:

- Verification of the coding of the geometry resulted in an additional site visit for additional measurements and the observation that one of the pedestrian obstacles included in the digital maps was no longer at the site. The coding was updated accordingly.
- Comparison between simulated flows and observations resulted a revision of the route choice, with more decision points added.
- The sensitivity analysis with respect to model parameters confirmed the expected behaviour of the model and constituted an important input for model calibration.
- The discussions of the modelling approach resulted in significant revision of the modelling approach presented by Gibb (2015), to the approach described in section 3.

# 6 Calibration

## 6.1 Description of the calibration process

The general goal for the calibration and validation process of this use case is not mainly to obtain a model with as good fit and predictive power as possible. Instead the main goal is to identify and, to the extent possible, quantify the uncertainties of the model. The reason for this approach is twofold. First, modelling of a shared space environment with an accuracy comparable to standard applications of traffic simulation is not yet possible, or at least not with the limited resources available for model development and data collection within CoEXist. Second, the uncertainties of the future scenarios are very large, so

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spending large amounts of resources on obtaining a model that is much more accurate than the uncertainties related to the future scenarios is not motivated by the results of interest. Thus, the strategy for the calibration and validation in this use case is to identify the parameters most influential on results of interest and adjust these to achieve an acceptable agreement between model predictions and data, and then to focus on quantifying the uncertainty of the model.

Since data from Tuesday to Saturday is available, and the traffic characteristics differ significantly between a Tuesday to Thursday, Friday, and Saturday, the model is calibrated for a regular, i.e. non-Friday, weekday, by calibrating it against the data from Tuesday and validating it against data from Wednesday and Thursday. The time of day considered is the afternoon peak hour 17:00-18:00.

The basis of the calibration process is the sensitivity analysis performed as part of the verification. The sensitivity analysis considers the sensitivity of a small set of system level performance measures to changes in a number of model parameter values. This ensures that the parameters with most effect on the performance metrics are given the most attention in the calibration process. The sensitivity analysis of the SFM performed by Johansson (2016) also contributed to this purpose.

The parameters of the model can be categorized as follows:

- Driving model parameters: these include parameters of the sub-models of driving behaviour, such as car-following and gap acceptance. Important parameters include desired speed, minimum gap, etc. Lane-changing and overtaking is not relevant for the use case and are therefore not considered.
- Parameters controlling vehicle – vehicle interaction at intersections: The interaction between vehicles in intersections are controlled by priority rules, and these are specified by a stop line and time and distance headway to specified conflict markers, which are set in the area where a conflict between vehicles may occur.
- Parameters controlling the reaction of vehicles to pedestrians: The reactions of vehicles to pedestrians are controlled by a large set of priority rules, one for each 50 cm of the road. These rules are specified by a stop line and distance and time headway to a specified number of conflict markers, which are set in the area where a conflict may occur between pedestrian and vehicle.
- Parameters controlling the behaviour of pedestrians: The interactions among pedestrians are controlled by the SFM and the dynamic potential for route choice. Important parameters in this category are the desired speed distribution, the relaxation time, the magnitudes and ranges of the social forces, and the relative impact of the dynamic potential on the desired direction. Since the vehicles are modelled as large pedestrians, at least for the reactions of pedestrians to them, also the reactions of pedestrians to vehicles are included in this category.

## 6.2 Description of calibration result

A selection of results from the initial sensitivity analysis is presented in Table 2. The two flow levels high and low in the table refer to the flow of vehicles, and differ 20% in total flow. As can be seen the table, even a relatively small change in the desired speed of the pedestrians have a large impact on the delay of the vehicles, which indicates that the parameter needs to be calibrated accurately. The sensitivity indicated here is to a shift in the mean of the distribution of the desired speed. However, also the shape of the distribution may be of importance. The other three parameters presented in Table 2 are related to the dynamic potential for pedestrian route choice. The somewhat remarkable in the result is that the

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vehicles are rather strongly affected by changes in these parameters, which emphasises the need to carefully calibrate the model with respect to these parameters. This result is somewhat surprising since the route choice of the pedestrians should not strongly affect the behaviour when they are in front of vehicles.

**Table 2: Sensitivity of performance metrics to changes in selected parameters**

| Parameter | Flow | Relative change in parameter | Relative change in vehicle delay | Relative change in ped. travel time |
|---|---|---|---|---|
| Ped. desired speed, mean | High | 0.13 | 0.5 | 0.16 |
| Ped. desired speed, mean | Low | 0.13 | 0.23 | 0.16 |
| Time step for calculation of the dynamic potential | High | -0.500 | 0.16 | ~0 |
| ‘g’ in the dynamic potential | High | -0.33 | 0.15 | ~0 |
| ‘impact’ of the dynamic potential | High | -0.25 | 0.1 | ~0 |

The calibration of the model with respect to model parameters will be performed base on improved data, soon to be delivered by the data supplier.

# 7 Validation

## 7.1 Description of the validation process

The main purpose of the validation is to estimate the uncertainty of predictions of the model. This is achieved by comparing model results to a data set that was not used to calibrate the model. In this use case the model will be calibrated against data collected on a Tuesday and validated against data from the following Wednesday and Thursday.

In the validation both the estimated OD matrix and the parameter settings obtained in the calibration will be used. An alternative approach, to re-estimate the OD-matrix for each of the days of the validation data set, would have been more accurate in estimating the uncertainty due to the parameter settings. However, the uncertainty in the OD matrix is important to capture the uncertainty of the demand.

## 7.2 Description of validation result

The validation will be performed based on improved data, soon to be delivered by the data supplier.

# 8 Results and conclusions

## 8.1 Conclusions of the verification-calibration-validation process

There are significant uncertainties in the model that will remain when the calibration and validation are completed. There are four main sources of these uncertainties: the complexity of the use case, the variations of the traffic conditions from day to day, the difficulty of collecting accurate data, and that models of pedestrian traffic in general, and the interaction with vehicles in particular, are not as well developed as models of vehicular traffic.

## 8.2 Handling of model uncertainty and/or limitation

The uncertainties will be quantified using the improved data, soon to be delivered by the data supplier.

# 9 Reference

Gibb, S., 2015. Simulating the Streets of Tomorrow: An Innovative Approach to Modeling Shared Space. Technical Report. CH2M Hill Inc.

Johansson, F., 2016. Microscopic Simulation of Pedestrian Traffic (Doctoral dissertation, Linköping University Electronic Press).

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# Appendix B Use case 2: Accessibility during long-term construction works

# Baseline model for use case 2

## Accessibility during long-term construction works

Version: 1.0
Date: 2018-10-30
Author: Chengxi Liu, Johan Olstam, Nina Galligani and Fredrik Johansson



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# 1 Introduction and background

During an upcoming period of long-term construction in Gothenburg, a lot of strain will be put on the existing road infrastructure, which would limit the accessibility to the city centre. Through the application of the Automation-ready macroscopic modelling tool, the aim of this use case is to estimate to what extent the introduction of CAVs (SAE[4] levels 3-5) may improve the traffic conditions during extended construction periods. The effects of the introduction of CAVs on the traffic conditions, e.g. route choice effects of changes in the traffic dynamics on road links and at intersections, will be investigated while the corresponding travel time savings from introducing different count measures with CAVs during the construction period will be evaluated. The measures that are studied in this use case include:

- Introduction of combined bus and CAV lanes
- Allowing bidirectional CAV traffic in tunnels

Each measure will be described in detail together with the experimental design in other deliverables, e.g. D3.1 and D4.3.

## 1.1 Study area characteristics

Gothenburg is the second largest city in Sweden and has around 560,000 inhabitants. It is located on the west coast of Sweden. It is a city with a strategic location in between Oslo and Copenhagen. The Gothenburg region has a population of 1.1 million. Gothenburg is the core and growth engine of Western Sweden and is home to a variety of strong industries including VOLVO, Volvo Cars and SKF.

The area to be modelled is the city of Gothenburg. Currently, Gothenburg is growing dramatically, and the city is preparing to make room for almost 700,000 residents by the year 2035 – that's 150,000 more than today. New houses are being built, and new residential areas and city districts are developed on land previously used for industrial purposes. New infrastructures such as roads, bridges, cycle paths and expanded public transportation will be constructed and to improve the transport system of the city. During a transition period, there are many construction projects that entail some restrictions for traffic and reduce the accessibility in the centre of Gothenburg, Figure 9 illustrates some major roads that are affected by construction projects, marked in green and red.

[4] SAE International, 2016. SAE Standard J3016, Taxonomy and Definitions for Terms Related to Driving Automation Systems for On-Road Motor Vehicles.

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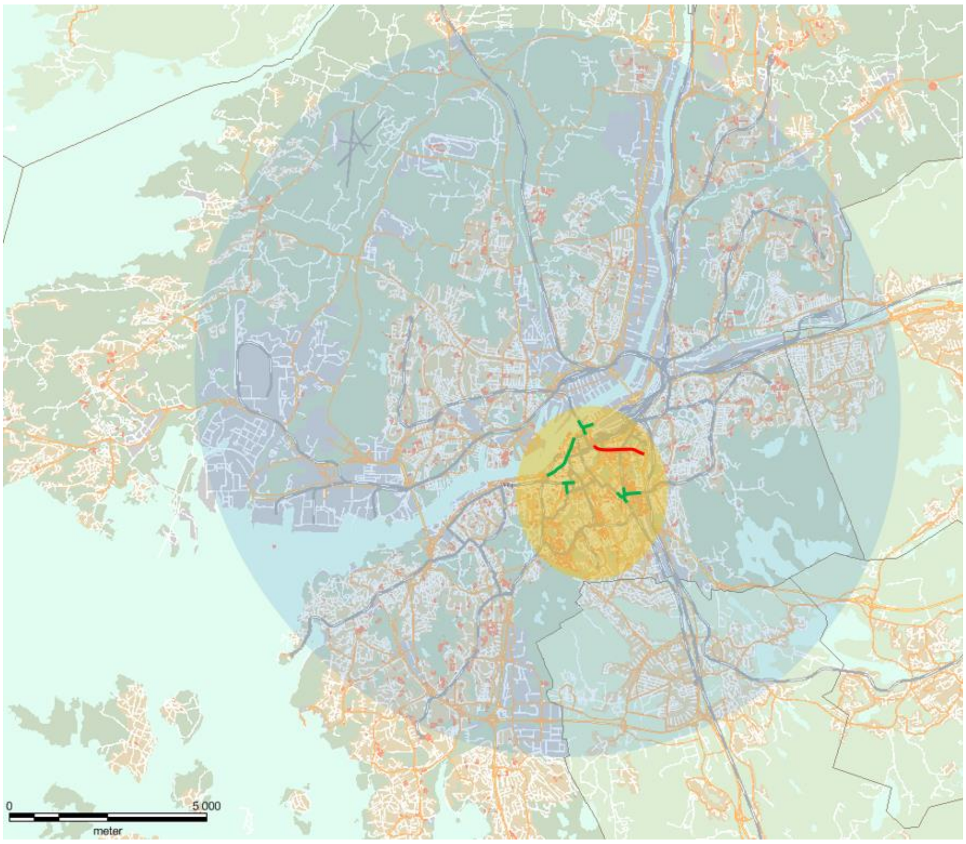


Figure 9 Map of the city of Gothenburg. The yellow circle represents the inner city. Source: Gothenburg municipality.

The yellow circle in Figure 9 represents the city centre of Gothenburg while the blue circle in Figure 9 represents the metropolitan area that are the main area to be modelled. Among all construction projects, there are two roads/routes that are of special interest since they are the two main transport routes into the city, see Figure 10. In the city centre of Gothenburg there are about 100,000 workplaces and a wide range of shopping- and entertainment facilities, which attract visitors from all over the region. Gothenburg's main station is located in the study area. There are also several large parking spaces for passenger cars and a few for bicycles. There is also a well-utilized bicycle sharing system in the area.

**Figure 10 Two roads that are of special interest since they are the two main transport routes into the city centre. On the left: Götatunneln (https://www.google.se/maps/@57.7110474,11.967978,17.66z), on the right Ullevigatan (https://www.google.se/maps/@57.708222,11.9826964,16.32z).**

The present modal split for Gothenburg, considering total personal trips (including through traffic and visitors) in the city and only the trips of the residents of Gothenburg respectively, is presented in Figure 11. Car trips consist of around 40-45% of all trips while the share of public transport is around 28%. Cycling share is around 6-7%.

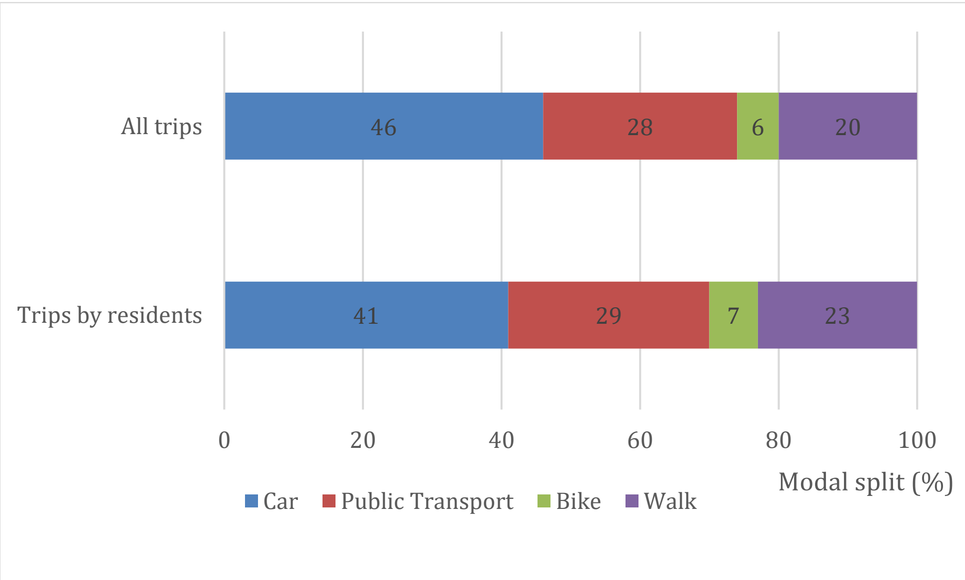

Figure 11 Modal split in Gothenburg.

In this use case, the modes that will be included in the model are cars and heavy goods vehicles. Public transport, pedestrians and bikes will not be included in the model since the focus of the use case is the effect on long-term construction on vehicle traffic performance on the road network level. Such effects can of course lead to modal shifts, but this is currently out of scope of this use case since the city does not have a multimodal traffic model[5].

## 1.2 Questions to be investigated by applying the modelling approach

This use case will investigate the impact of introducing AVs on the accessibility and travel time of private car and heavy goods vehicles on a system level. The city of Gothenburg is going to undertake an intensive construction period in the coming decade. Extensive evaluations of the effects of these construction projects on the accessibility and travel time were conducted within the “KomFram” project (Ramböll, 2017). In this study, the possible travel time saving, and accessibility improvement from introducing CAVs in such a future scenario under the intensive construction period will be investigated.

The second purpose of this use case is to evaluate the effectiveness of the proposed measures to relieve congestions under the intensive construction period. For instance, to what extent can total travel time and accessibility to the city centre be improved by measures such as adding special dedicated CAV lanes or links and at which penetration rates such geometric changes are beneficial?

# 2 Scope and modelling approach

## 2.1 Type of model

The macroscopic model will be developed to tackle the questions discussed in section 1.2. A VISUM model over the area to be studied has been developed in the “KomFram” project. This model is based on intersection capacity analysis methodology (ICA methodology) and includes a method for signal prioritization and weaving movements in on-road and off-road ramps. The model handles vehicle traffic as a total amount of private passenger cars and heavy good vehicles. In that sense, there is no separation between private car and heavy good vehicles in terms of demand representation. The demand matrix is derived from the national transport model "Sampers" (Muriel and Algers, 2002) and calibrated during the peak hours against existing traffic counts. Construction has been going on in several places for some time, so a stable “present situation” can be difficult to define. On the other hand, a large number of traffic counts are available from recent years, as well as updated travel time information.

A scenario for the present situation (2013) and a “construction-time scenario” (2018), when several major construction projects are in progress, are developed as well as ongoing work with a scenario for 2022.

## 2.2 The area and the level of detail of the model for base scenario

5 Development of a multi modal model is ongoing but will not be finished in time for the CoEXist project

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The city of Gothenburg is going to be a construction area in the coming decade. Extensive evaluation of the effects on the traffic system is conducted within the “KomFram” project. The “KomFram”-project is conducted in cooperation between the City of Gothenburg, the Swedish Transport Administration and Västtrafik (the public transport Company). The project includes analyses during the construction period in Gothenburg) to carry out system analyses for the whole of Gothenburg. The analysis within the “KomFram project” has been done using a VISUM model, which in geographical terms encompasses the blue circle in Figure 9. Within the city centre of Gothenburg (the yellow circle), several construction projects will last for many years. The area is used by passenger cars, heavy goods vehicles, pedestrians and cyclists as well as public transport (bus and tram). The red line in the map represents “Ullevigatan”, which has been identified as an entrance street where traffic is at risk to increase due to the limited accessibility on other links to and from the central city. The green lines illustrate examples of roads where capacity will be reduced due to long-term construction works.

### 2.3 Included and excluded in the model of base scenario

The VISUM model contains network representation of car traffic and no representations of public transport, pedestrian and bicycle networks are included. The VISUM model captures the possible route choice change of conventional vehicles as well as AVs due to the improved link capacity and intersection capacity from introducing AV. The year of 2018 is used as the base year in this use case where links, nodes and turns that are affected by the construction projects are represented in the model of base year 2018. The year of 2013 is the base year for the “KomFram” project and the traffic counts data used for calibration and validation were from year of 2013. In that sense, the model for base year 2018 will not be validated in this use case, however, the description of validation for the model of base year 2013 will be presented later on in the section 7. The impact on the link and intersection capacity will depend on different types of AV, e.g. basic, intermediate or advanced AVs.

The model, however, does not consider possible modal shift due to the improved accessibility from introducing AVs, rather the model uses a fixed demand of private car and heavy goods vehicles. On the other hand, demands of cars and heavy goods vehicles are not explicitly separated rather the demand matrix for cars and heavy goods vehicles are handled as an overall matrix which means one does not know the number of cars and heavy goods vehicles for a given origin-destination pair, but one only knows the total.

# 3 The network

### 3.1 Detailed description of the network and how it is modelled

The VISUM model used in the “KomFram project” provides a basis of the model for base scenario in this use case. The car network includes most major arteries and main streets while minor streets are not included in the network. Figure 12 shows the coded model for base scenario in central Gothenburg, where the straight lines represent links and blue dots represent nodes. The capacity and free flow travel time of a link is determined based on number of lanes and speed limit using the Highway Capacity Manual guide (2016) but is adjusted to reflect the Swedish traffic situation.

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In total, there are 45 link types defined representing motorways and streets with different numbers of lane. The model includes 4166 links and 1552 nodes with 12726 turns. Each node represents an intersection where there are four different types of intersections being defined: Uncontrolled, Two-way yield; Signalized; Roundabout. The detailed geometry of each signalized intersection is coded using the junction editor function in VISUM where each turn is defined as well as the priority of the turn according to the type of intersection, number of lanes associated to the turn, etc.

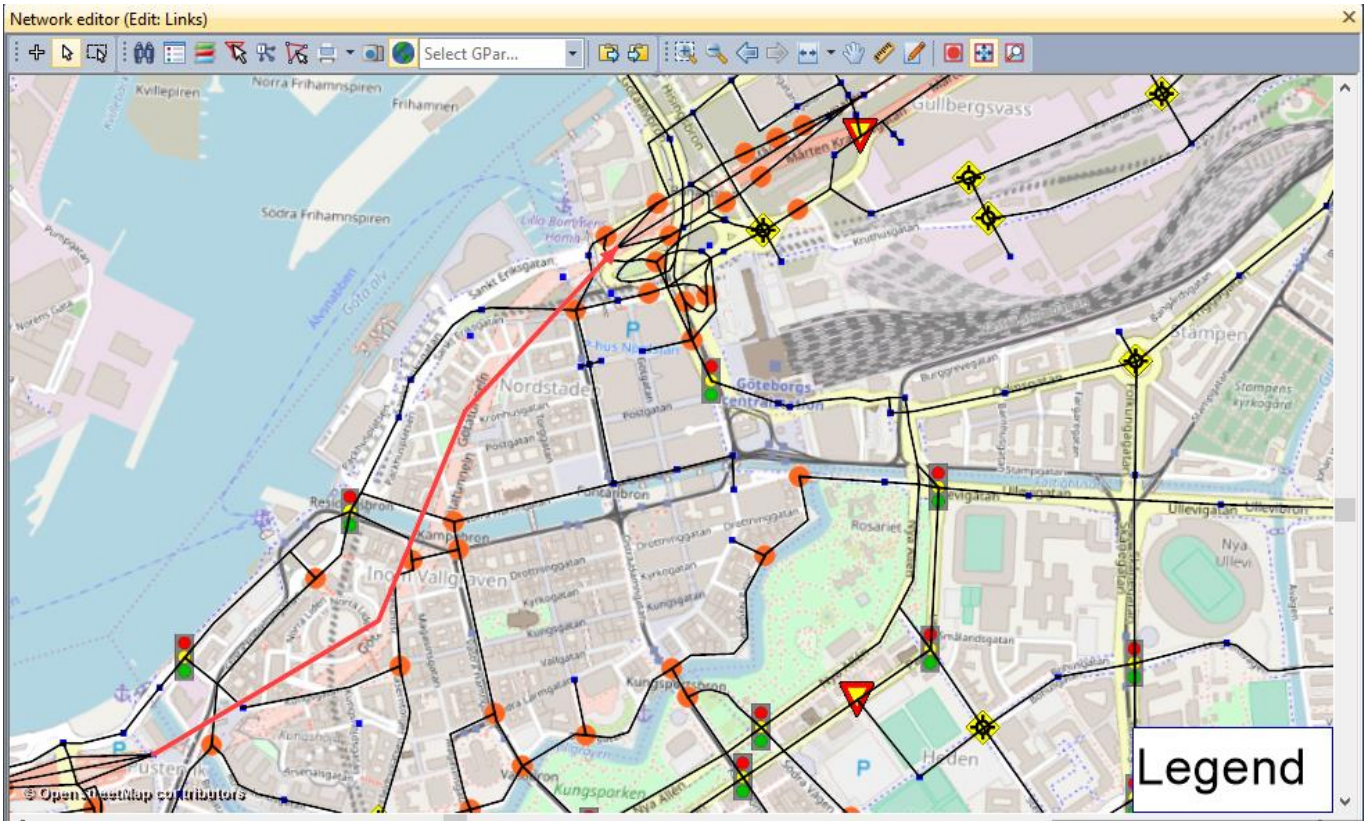


**Figure 12 An example of the VISUM model for base scenario at the central Gothenburg where the links in red represent Göta tunnel.**

The initial demand was defined on the SAMS zone level and was refined through the work in “KomFram project”. Currently, there are 1070 zones defined in the model corresponding to a 1070 × 1070 matrix as the demand matrix. Figure 13 presents the zone system used in this study. It can be seen that the zone classifications within the city centre of Gothenburg is rather detailed while at the suburban and rural areas zones are rather large. At the meantime, the network does not include many secondary roads especially in the rural areas. This is to balance the model run time and the detailed level of the network. Therefore, one may bear in mind that the model result may not represent traffic situations at rural areas.

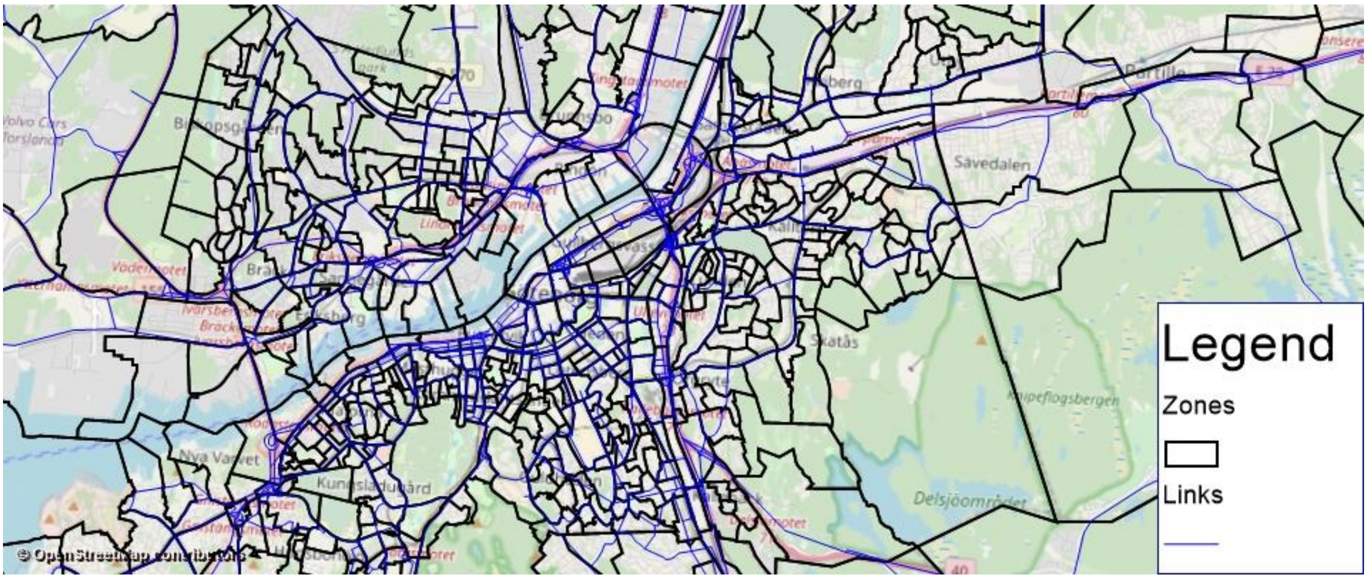


Figure 13 the zone system in the study area

## 3.2 Description of the data utilized for the network

The travel demand matrix used in the model is derived from the national model "Sampers". Travel surveys are from 2011 and 2014, travel survey for the implementation of congestion charge and an ongoing survey 2017, can be used to validate the travel demand.

Beside these data, this use case does not require any additional data collection.

# 4 The traffic

## 4.1 Detailed description of the traffic and its implementation in the model

Figure 14 describes the daily traffic flow levels on the main road network in the Gothenburg region. The E6 motorway passing by Gothenburg in the north-south direction carries large volumes as well as the motorway E20 that enters Gothenburg from the east.

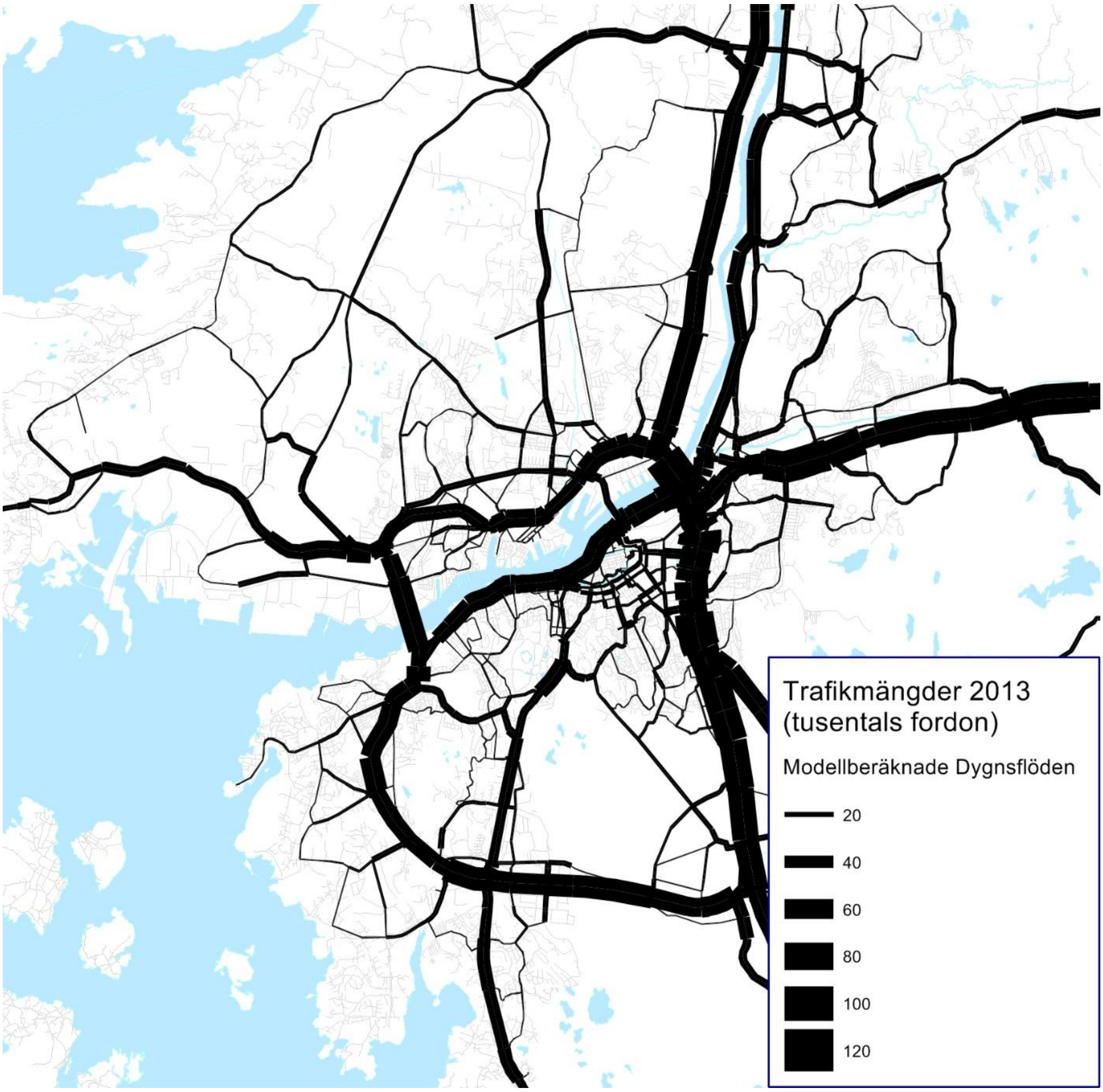


**Figure 14 Daily traffic flow levels (thousands of vehicles) for 2013. Source: Gothenburg municipality.**

The city of Gothenburg has collected traffic data since 1970 and in a longer perspective, much has happened, see Figure 15. Since 1970, traffic at the municipal boarder has almost tripled, with the 28 fixed points it has increased by more than 80 percent and at cross-section “Götaälvsnittet”, that is the connections over and under the river Götaälv, it has increased by almost 70 percent. Despite this, traffic to the city core has decreased more than 75 percent, while traffic at the city center has decreased by more than 30 percent.

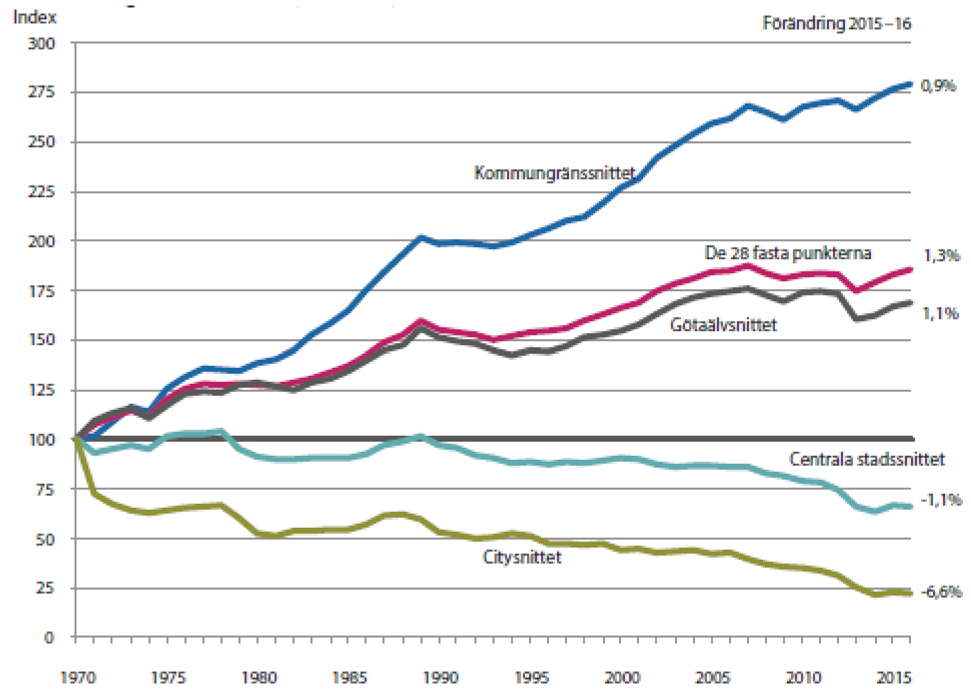


**Figure 15 Historical traffic levels between 1970-2016 for different cross-sections in Gothenburg. Source: Gothenburg municipality.**

The Götaälv cross-section, which is a bottleneck in the city's road network, includes the bridges Götaälvbron, Älvsborgsbron and Angeredsbron as well as the tunnel Tingstadstunneln. There are also some vehicles using the bridge Angeredsbron and ferries. In total, 222,300 vehicles passed the Götaälv cross-section on a weekday during 2016. Figure 16 illustrates how this flow is divided on the different paths.

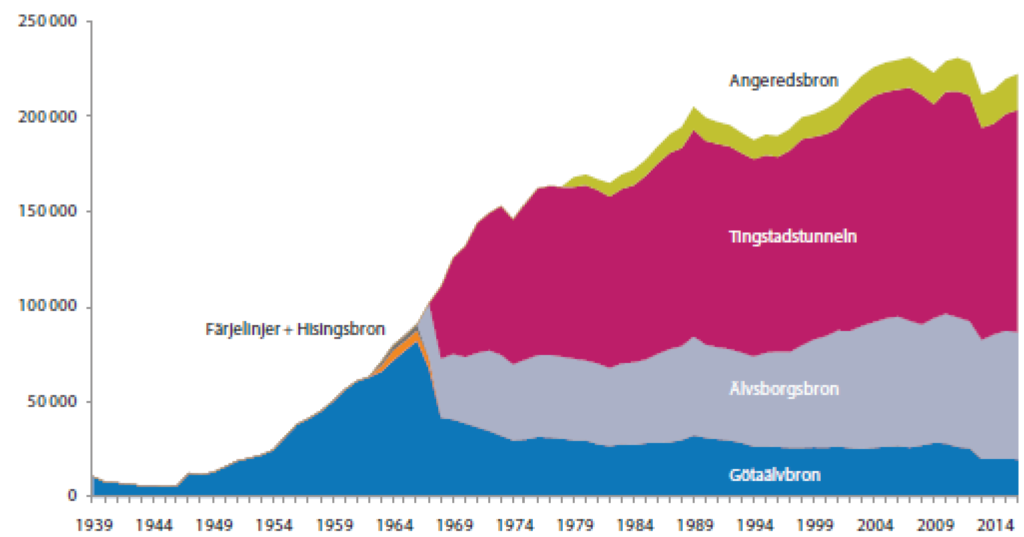


**Figure 16 Average weekday daily traffic passages over and under the river Götaälv using the bridges Götaälvbron, Älvsborgsbron and Angeredsbron and the tunnel Tingstadstunneln. Source: Gothenburg municipality.**

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## 4.2 Description of the data utilized

Traffic counts on approximately 200 roads in Gothenburg is used for calibration. Data can also be retrieved from the congestion charging system, in addition to the traffic counts, in approximately 30 congestion charging stations. All traffic data can be obtained on a 15-minute level including direction for the total number of vehicles, for some roads number of trucks can be displayed.

The validation was conducted using 700 traffic count stations to and from the city centre area, passages through the congestion charging stations and passages over and under the river Göta Älv. The validation is conducted for the year of 2013.

# 5 Verification

## 5.1 Verification process

The model for base scenario was developed in the “KomFram” project where internal verifications of model were conducted. The base scenario model was tested in the “KomFram” project by 6 different scenarios representing traffic at morning and afternoon peak hours in different years. In this project, the models for year 2013 and 2018 are further verified by checking 1. Whether coding of links/nodes/turns are correct. 2. Run the base scenario and compare the result with the result obtained in “KomFram” project. 3. Consult PTV to discuss the possible solutions for the problem identified.

**Table 3 the summary of scenarios in the model**

| Scenario | Description |
|---|---|
| Afternoon rush hour in the year of 2013 | Base scenario of the “KomFram” project |
| Morning rush hour in the year of 2013 | The demand matrix is replaced to the one representing demand in morning rush hour |
| Afternoon rush hour in the year of 2014 | Compared to afternoon rush hour in the year of 2013, the congestion charge stations are adjusted. |
| Morning rush hour in the year of 2014 | The same as afternoon rush hour in the year of 2014 but with demand matrix representing demand in morning rush hour |
| Afternoon rush hour in the year of 2018 | The scenario representing the construction period where all the construction projects listed in Table 4 are included in the model. |

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| | |
|---|---|
| Morning rush hour in the year of 2018 | The same as afternoon rush hour in the year of 2018 but with demand matrix representing demand in morning rush hour. This scenario is used as the base scenario of this use case. |

**Table 4 the list of construction projects that are presented in the model.**

| **Construction projects** | **description** |
|---|---|
| Åkareplatsen | New bus station that leads to re redesign of lanes for car traffic at Åkareplatsen. |
| Svingeln Part 1 | Redesign of Friggagatan |
| Söderleden and Sisjömotet | Additional lanes between Sisjömotet and Åbromotet and redesign of Sijömotet |
| Svingeln Part 2 | Redesign of Olskroken roundabout |
| E45 Götaleden | Redesign of E45 Götaleden |
| Delsjövägen | Delsjövägen is closed for both directions |
| Västlänken Station Haga | Rosenlund bridge and the downstream Sprängkullsgatan are closed for both directions |
| Västlänken Station Korsvägen | Links from/to north and south connecting Korsvägen are reduced to one lane. |
| Marieholmstunneln | Redesign of Tingstadsmotet |
| Nordre Älv | Speed limit on Nordre älv bridge is reduced to 70 km/h |
| Älvsborgsbron | Älvsborg bridge is no longer considered as arterial road and number of lanes are reduced from 3 to 2. |
| Marieholmsgatan | Marieholmsgatan and on- and off-ramps towards E45 towards Marieholmsgatan are closed |

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The model was run in VISUM 14 in the “KomFram” project while in this project the model will be further tested and developed in VISUM 17. Since the “ICA methodology” which is the core of the model is under constant update from VISUM 14 to VISUM 17, the verification focuses on presenting the different results obtained from model runs on VISUM 14 and VISUM 17.

## 5.2 Verification results

The internal check of the model for base scenario shows that no coding error is identified.

The model for base scenario was tested using VISUM 17.01-11. the scenario “Morning rush hour in the year of 2013” is used as the base scenario for verification and validation since the result of scenario for morning rush hour is more stable than that of afternoon rush hour. This decision was made after consulting Ramböll and Gothenburg city.

The queue length and traffic flow at the equilibrium stage obtained from the model run are then compared with the corresponding results in in “KomFram” project which was run on VISUM 14. Clear differences are identified and shown in Figure 17 and Figure 18. For the traffic volume, the difference can be up to 383 vehicles in the morning peak while for queue length, it can be up to 66 vehicles. However, within the city centre, the difference is much smaller where the maximum difference for volume is 240 vehicles while for queue length it is 16 vehicles. The model results from VISUM 17 run are further validated against traffic counts and the results are presented in section 7.

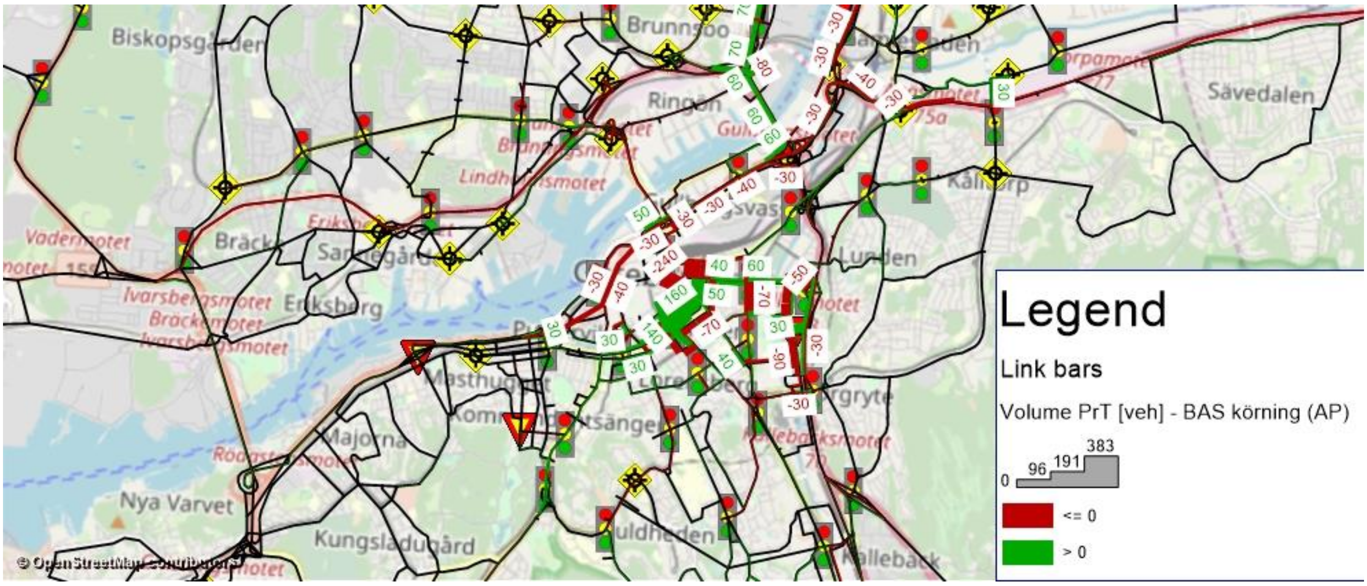


Figure 17 Traffic flow differences between results obtained in VISUM 17 and VISUM 14

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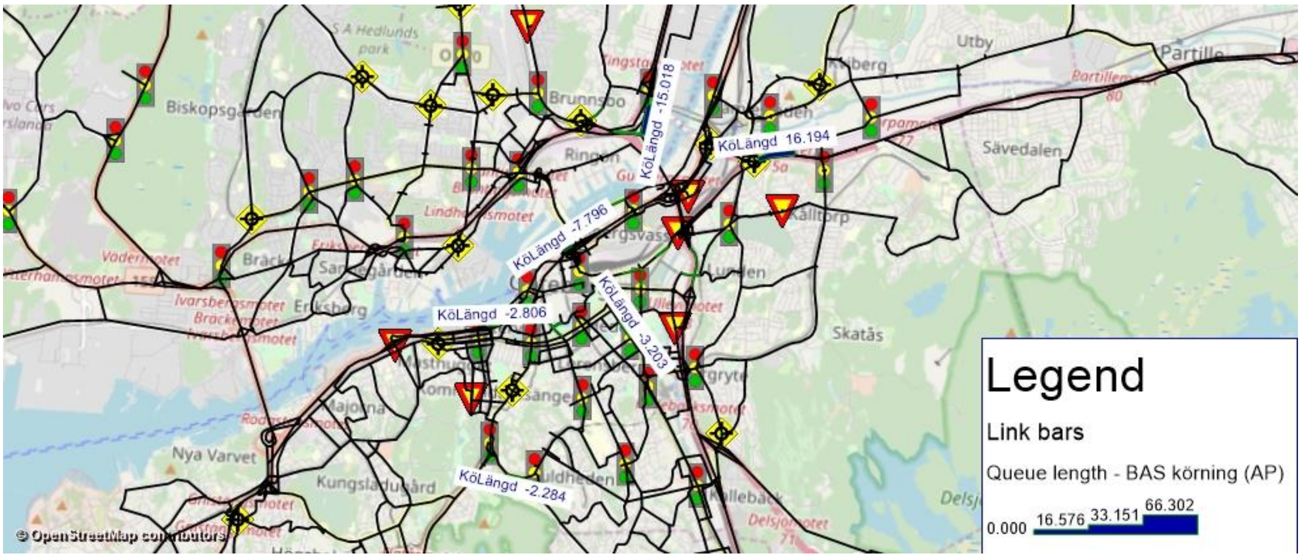


Figure 18 Queue length differences between results obtained in VISUM 17 and VISUM 14

The total link queue length is used as an index to illustrate the differences in terms of convergence between VISUM 14 and VISUM 17 runs and the results are presented in Figure 19. In total 50 iterations were run during the ICA process. It can be seen that at the last iteration, both model runs reach similar total link queue length but not exactly the same number, which is around 2250 meters. These results indicate that there are clear differences between model runs on VISUM 14 and VISUM 17 but the deviation is within the acceptable range. Further comparison against traffic counts will be discussed in the section Validation

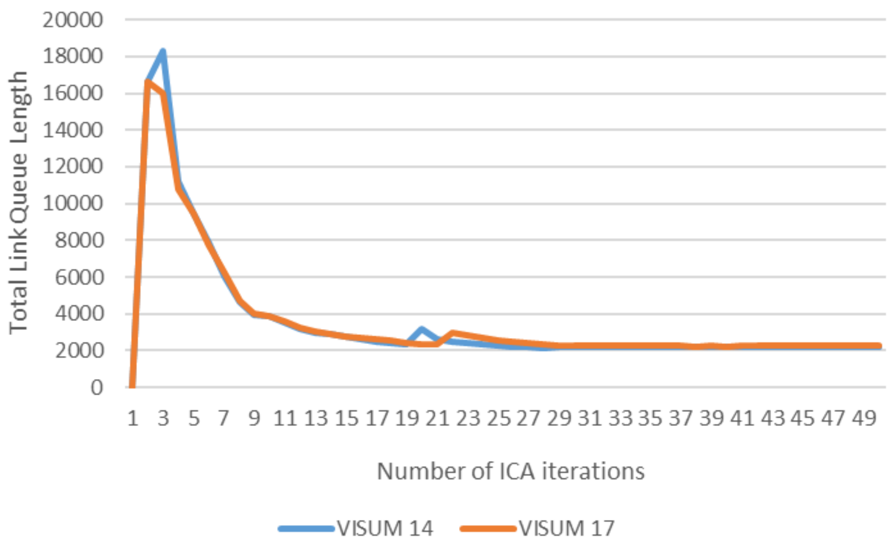


Figure 19 the difference in total link queue length between VISUM 14 and VISUM 17.

# 6 Calibration

## 6.1 Description of the calibration process

The model for base scenario is already calibrated for the case without CAV in the “KomFram” project. For this model, the important parameter settings include:

- Input demand matrix.

Demand matrix is taken from the SAMPERs regional model results and are further split and/or aggregated to smaller zones. Given that SAMPERS model is a national model the demand matrix is calibrated for the whole Väst Götland region. Therefore, the demand matrix may not reflect the actual demand for Gothenburg city which is a much smaller or local geographic unit than Väst Götland region. The calibration is done mainly by adjusting the demand matrix so that the link flow at the equilibrium stage can best match the traffic counts at some specification count stations. The detailed process of demand matrix adjustment is described in the technique report of “KomFram” project. In general, a gradient adjustment method is implemented using the “Tflow Fuzzy” function in VISUM, and the following general procedure is conducted:

1. Demand of each OD pair is adjusted and assigned to the network and the new equilibrium stage will be calculated.

2. The new equilibrium stage results in new link flows which are then used to compare with the traffic counts.

3. The result of the comparison provide new information about how the demand of each OD pair needs to be further adjusted.

4. Procedure continued until it reaches an equilibrium.

- Volume-delay function settings for both links and nodes

The Volume-delay function (VDF) of each link and node are specified following the HCM guidelines and then are further adjusted to the Swedish context. Detailed description of how VDF is adjusted can be found at Ramböll (2017).

- Convergence criterion of the assignment with Intersection capacity analysis (ICA)

The convergence criterion of ICA in VISUM 17 differs from that from VISUM 14 which was used in the “KomFram” project. Two extra parameters need to be specified in VISUM 17, shown in Figure 20. The settings are specified by consulting PTV.

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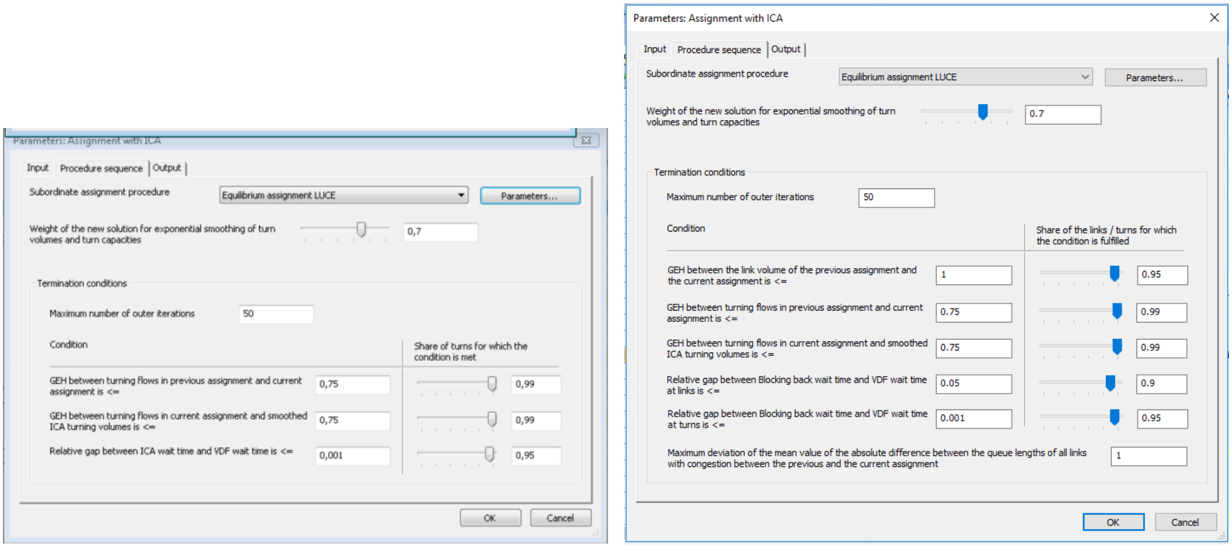


**Figure 20 the convergence criterion of ICA in VISUM 14 (left) and VISUM 17 (right).**

## 6.2 Description of calibration result

The calibration process requires traffic count data. Traffic count data in the year of 2013 are derived from 52 traffic count stations to and from the centre area, passages through the congestion charging stations and passages over and under the river Göta Älv. The geographical locations of these links are presented in Figure 21. Detailed calibration result can be found in Ramböll (2017), where the calibrated (adjusted) demand matrix results in the traffic flow which better matches up with the traffic count data in the year of 2013. The calibrated demand matrix is then used as the input matrix for this use case.

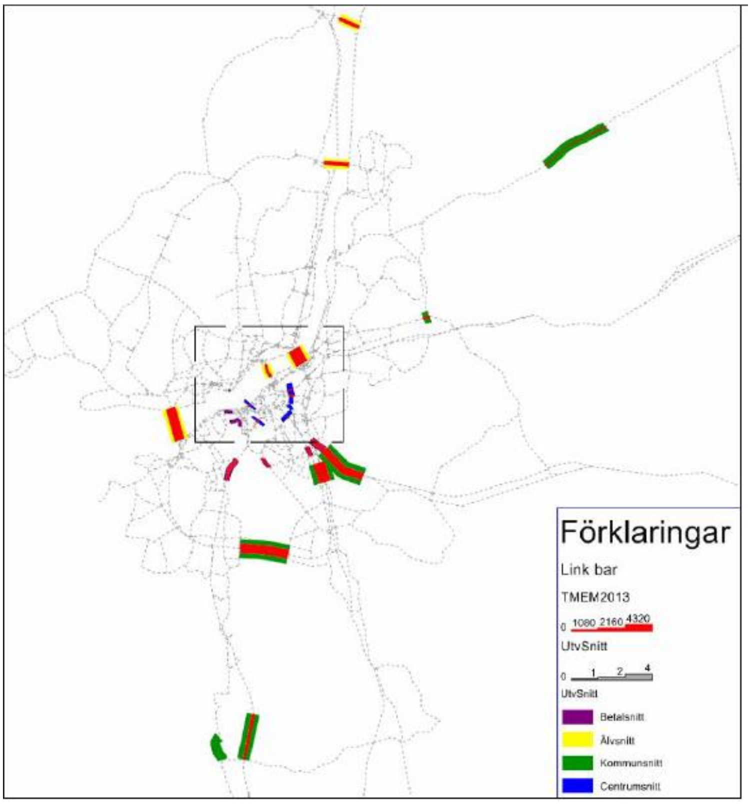


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Figure 21 Links with count stations (Ramböll, 2017)

# 7 Validation

## 7.1 Description of the validation process

The validation work was also done in the “KomFram” project for scenarios of morning and afternoon rush hour in the year of 2013. The validation was conducted using 700 traffic count stations to and from the centre area, passages through the congestion charging stations and passages over and under the river Göta Älv. It is important to note that these traffic count stations are different from the ones used for calibration. The traffic flow calculated from the scenarios are compared with the traffic counts. In that sense, traffic flow is the only measure used for validation in this use case.

For validation, validation results for both morning and afternoon rush hour are presented. The model results on VISUM 17 in the year of 2013 are validated against traffic counts for both morning and afternoon rush hour. It is worth noting that the base scenario in this use case will be the model representing infrastructure in the year of 2018, see Table 3. However, the traffic count data is only available for the year of 2013, therefore further validation for the model representing infrastructure in the year of 2018 will not be included in this use case.

## 7.2 Description of validation result

The traffic counts with predicted volume passing through a certain area are first investigated. Four areas/borders are defined and visualised in Figure 22. The red line represents Älv and traffic passing through the bridges over Älv will be counted. The blue ring represents the congestion charge area and traffic traversing links on the border will be counted. The yellow ring represents the core city centre area. The municipality border is not shown in the picture. Table 5 presents the results. The difference between VISUM 17 and VISUM 14 is marginal in both morning and afternoon rush hour scenarios. The only exception is the municipality border where VISUM 17 underestimates volume by 9% in the afternoon rush hour scenario while VISUM 14 matches the traffic counts quite well.

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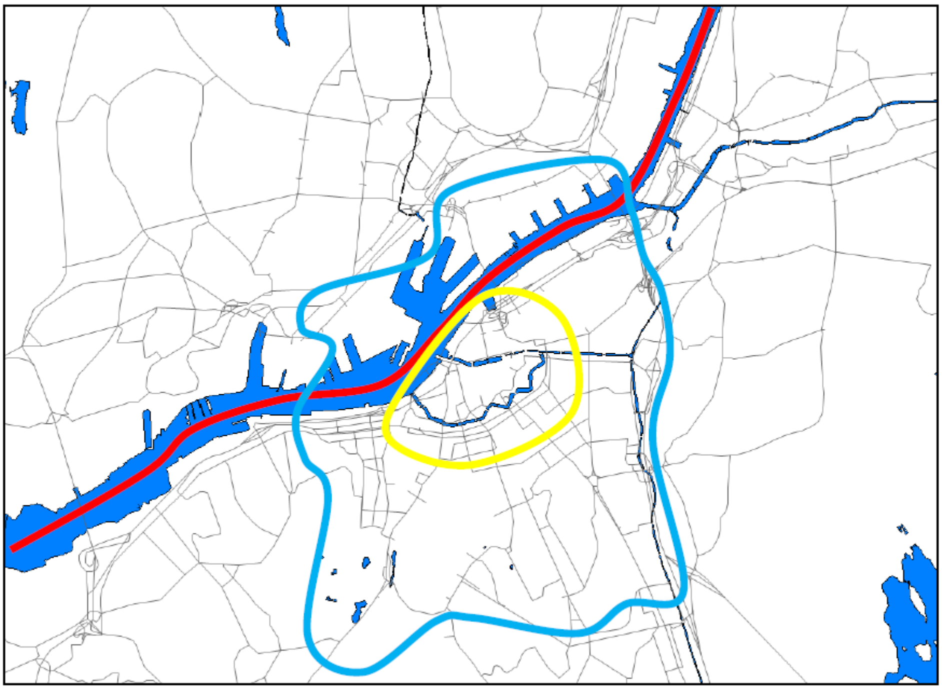

Figure 22 Areas for validation (the municipality border is out of the picture)

Table 5 Comparison of predicted traffic volume from VISUM 17/VISUM 14 and the traffic counts.

| Defined area/ring | Morning peak hour | | | | Afternoon peak hour | | | |
|---|---|---|---|---|---|---|---|---|
| | VISUM 14 | VISUM 17 | Counts | Diff | VISUM 14 | VISUM 17 | Counts | Diff |
| Älv | 17597 | 17538 | 18060 | -3%/-3% | 21340 | 20423 | 21370 | -0%/-4% |
| Centrum | 14037 | 14087 | 12910 | -8%/-9% | 17196 | 16958 | 16130 | +7%/+5% |
| Congestion charge | 1746 | 1723 | 1530 | -14%/-13% | 19123 | 18745 | 19750 | -3%/-5% |
| Municipality border | 8311 | 8335 | 7670 | -8%/-9% | 24941 | 23271 | 24890 | +0%/-9% |

When taking all the links where there are traffic counts, linear regression models were run between predicted volume and traffic counts to evaluate the model results. The results are shown in Figure 23 and Figure 24 for morning rush hour and afternoon rush hour respectively. For morning rush hour, VISUM 17 and VISUM 14 runs provide very similar results as the linear regression coefficients are very similar as well as the $R^2$. For the afternoon scenario, the deviation between VISUM 17 and VISUM 14 runs is slightly larger where VISUM 14 run provides a better model fit against traffic counts.

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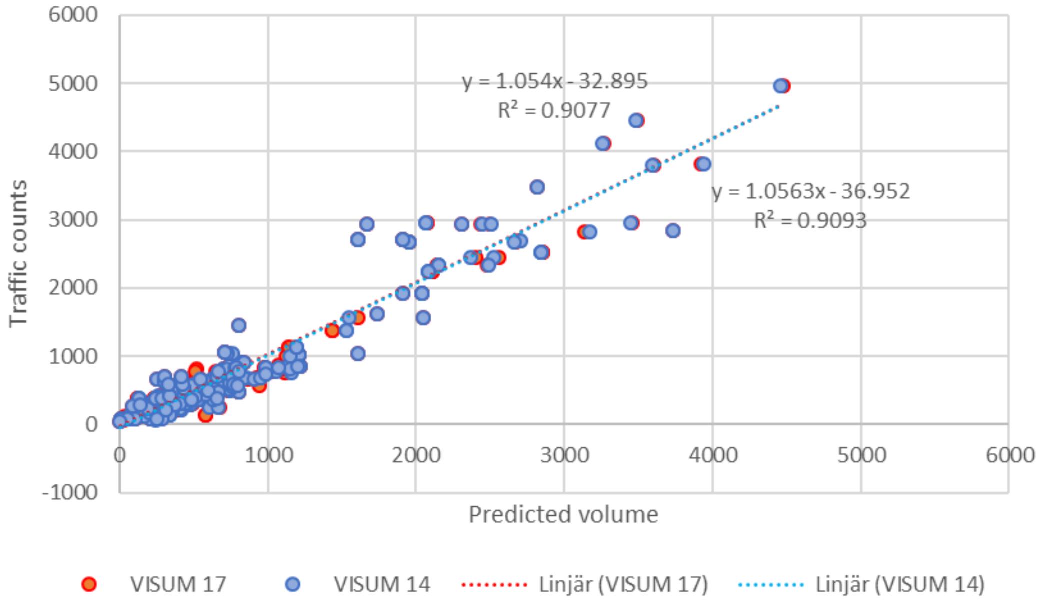


Figure 23 Linear regression models between predicted volume and traffic counts, morning rush hour

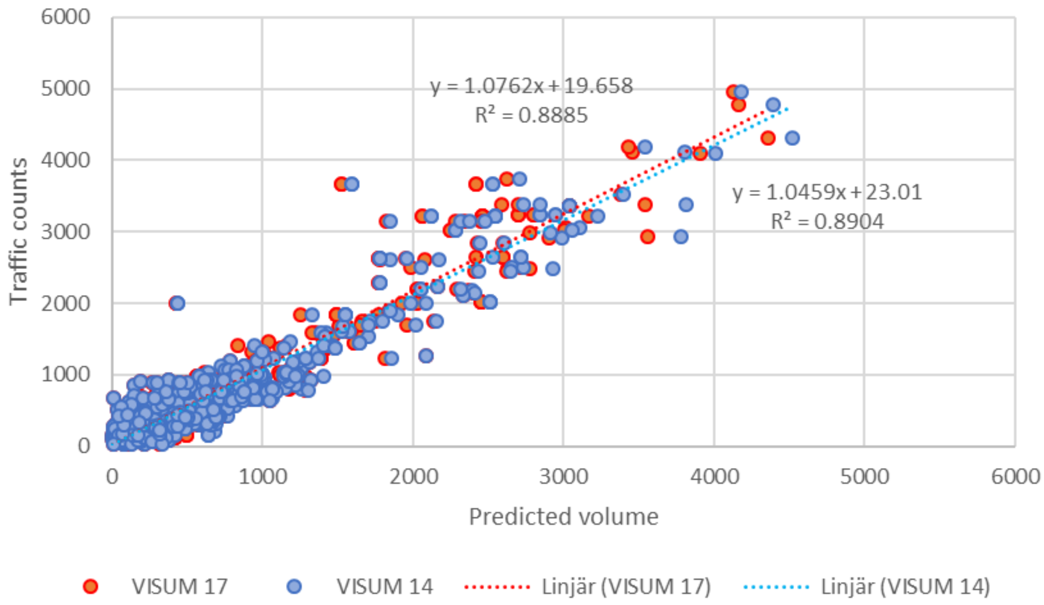


Figure 24 Linear regression models between predicted volume and traffic counts, afternoon rush hour

# 8 Results and conclusions

## 8.1 Conclusions of the verification-calibration-validation process

The model for base scenario in this use case was developed in the “KomFram” project, and within that project the verification-calibration-validation process was completed. In this project, further possible coding

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errors in the base scenario were checked while identifying the possible inconsistencies in the results caused by runs on different VISUM versions (VISUM 14 used in “KomFram” project and VISUM 17 used in this use case). The calibration and validation were done both by comparing predicted traffic flow with the observed traffic counts. The difference is that the calibration process focuses on using the comparison to guide the adjustment for the input demand matrix, while validation process uses the comparison to evaluate the model results. It is important to note that the traffic counts used in calibration and validation are from different sources.

The result of verification-calibration-validation process shows that model runs on VISUM 17 and VISUM 14 can lead to different results which can be caused by the different convergence criterion in ICA module in VISUM 17 and VISUM 14. On the other hand, ICA module also was improved from VISUM 14 to VISUM 17. Further settings of convergence criterion in ICA module is consulted with PTV. The calibration process further adjusted the input demand matrix and will be used in this use case. The validation result shows a satisfying result when the predicted traffic flow was compared with traffic counts from 700 traffic count stations. The deviation between VISUM 17 and VISUM 14 runs is smaller in the morning rush hour scenario than the afternoon rush hour scenario. Therefore, morning rush hour will be used for the year of 2018 as the base scenario of this use case.

## 8.2 Handling of model uncertainty and/or limitation

It is important to note that the model for base scenario has several limitations and many uncertainties are not handled. Many are due to the nature limitations of the macroscopic model and the method used while some are due to the lack of data. The limitations and uncertainties are summarised below:

- Since the model is a macroscopic static traffic assignment, no time dimensions are included in the analysis which means the temporal congestion patterns are not reflected in the model.
- The model assumes a fixed travel demand which indicates that the possible modal shift, changes in destination caused by improvement in accessibility is not included. The demand of private car and heavy goods vehicles are not separated also, and therefore possible uncertainties due to the shift between private and freight transport could not be captured.
- Although the ICA module considers the capacity and delays at each intersection and possible congestion propagation to the upstream links, uncertainties from delays caused by pedestrians and bicycles crossing the intersection are not modelled.
- The base scenario of this use case will be morning rush hour of the year of 2018. However, this base scenario is not validated due to the availability of data. Instead, the morning rush hour of the year of 2013 is validated against the traffic counts.

# 9 Reference

Muriel, B. and Algers, S. 2002. “SAMPERS—The New Swedish National Travel Demand Forecasting Tool.” In *National Transport Models*, 101–118. Springer. http://link.springer.com/10.1007/978-3-662-04853-5_9.

Ramböll, (2017). Teknisk PM – Uppdatering av Centrum modell. Malmö (in Swedish)

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Highway Capacity Manual, Sixth Edition: A Guide for Multimodal Mobility Analysis. (2016) Transportation Research Board, national research council.

# Appendix C Use case 3: Signalised intersection including pedestrians and cyclists; and Use case 4: Transition from interurban highway to arterial

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# Baseline model for use case 3 and 4

## Use case 3: Signalised intersection including pedestrians and cyclists

## Use case 4: Transition from interurban highway to arterial

Version: 1.0
Date: 2018-10-30
Author: Frank van den Bosch



This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No. 723201-2

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# 1 Introduction and background

In Helmond Verbonden - The Mobility Vision 2016-2025 (2016), Helmond points out that the city wants to provide a sustainable and safe traffic system, including Smart Mobility, and that the city tries to become a leader in innovation in mobility. As the hometown of the Automotive Campus, Helmond is fully committed to maintain its pioneering role in the field of Smart Mobility. Smart Mobility solutions will change the face of mobility considerably and Helmond would like to take the leading role. Therefore, Helmond tries to investigate if introducing CAVs could contribute to these goals.

Use case 3 and 4 focus on the evaluation of the impact of automated driving on a transition section from the inter-urban highway between Helmond and Eindhoven to the arterial that enters Helmond. AVs or connected AVs (CAVs) may also provide a more homogeneous speed which contributes to a more reliable travel time and shorter delays for the traffic in total.

## 1.1 Study area characteristics

This use case focuses on a part of the A270 between Eindhoven and Helmond. The provincial road 270 (N270/A270) is partly a 44 km long provincial road and partly a motorway between N271 at Well and Eindhoven, as shown in Figure 25.

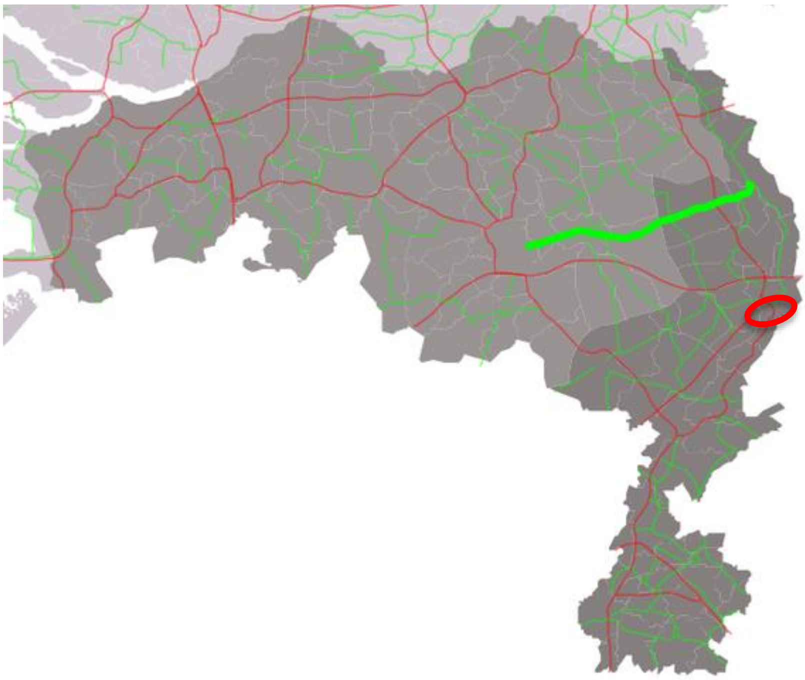

Figure 25 The geographical location of the provincial road 270.

The section that belongs to motorway is 3.4 kilometre long between Helmond and Eindhoven and in the rest of this document it will be referred to "the Helmondweg". This is because the road is an important passage for commuting between Helmond and Eindhoven. "the Helmondweg" was constructed in the 1970s as a motorway with a length of 7.8 kilometres. after that, the length of the motorway has been

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reduced to 3.4 kilometres. The construction of the Helmond district of Brandevoort resulted in two ground-level crossings and the construction of a bus lane near Eindhoven resulted in a speed restriction.

The A270, shown in Figure 26, is equipped with advanced systems for carrying out traffic experiments. Over a length of 5 kilometres, cameras have been installed to track the exact positions of all cars at a frequency of ten times per second. A communication network has also been set up so that exchange messages directly between cars equipped with special equipment are possible.

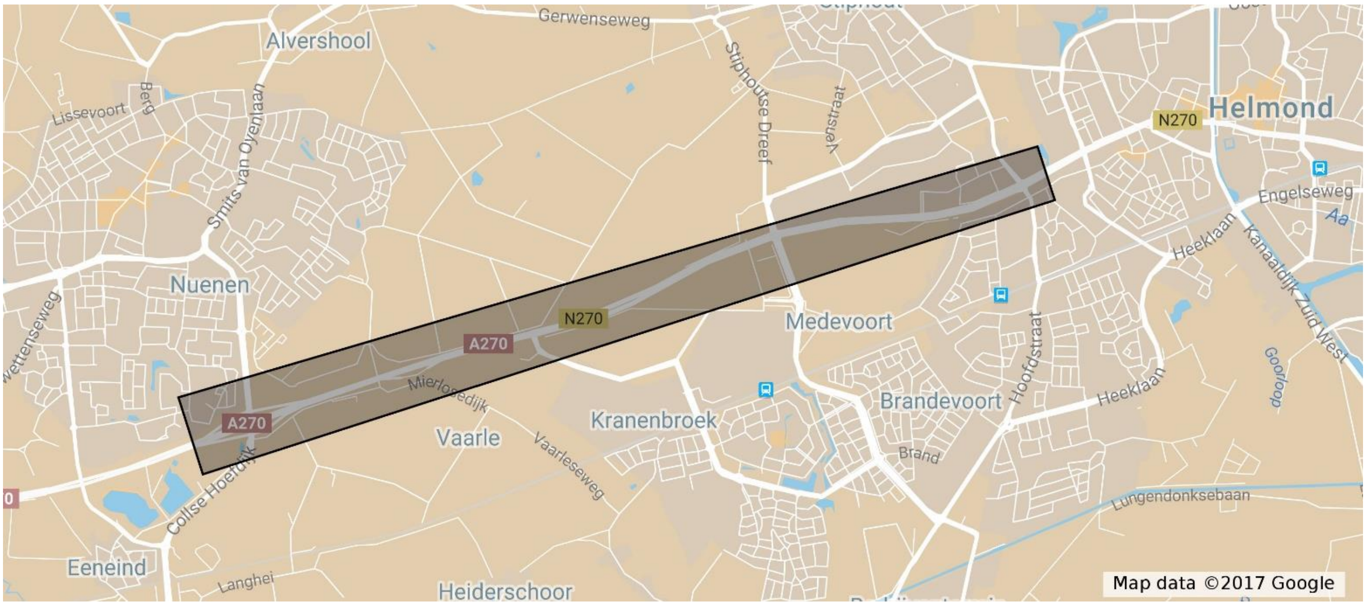


Figure 26 The detailed location of A270.

The track of interest in this use case is A270/N270/Europaweg and it is the main connection between Eindhoven and Helmond. Every day about 35,000 vehicles are on this track. This track has a variable speed limit as illustrated in Figure 27.

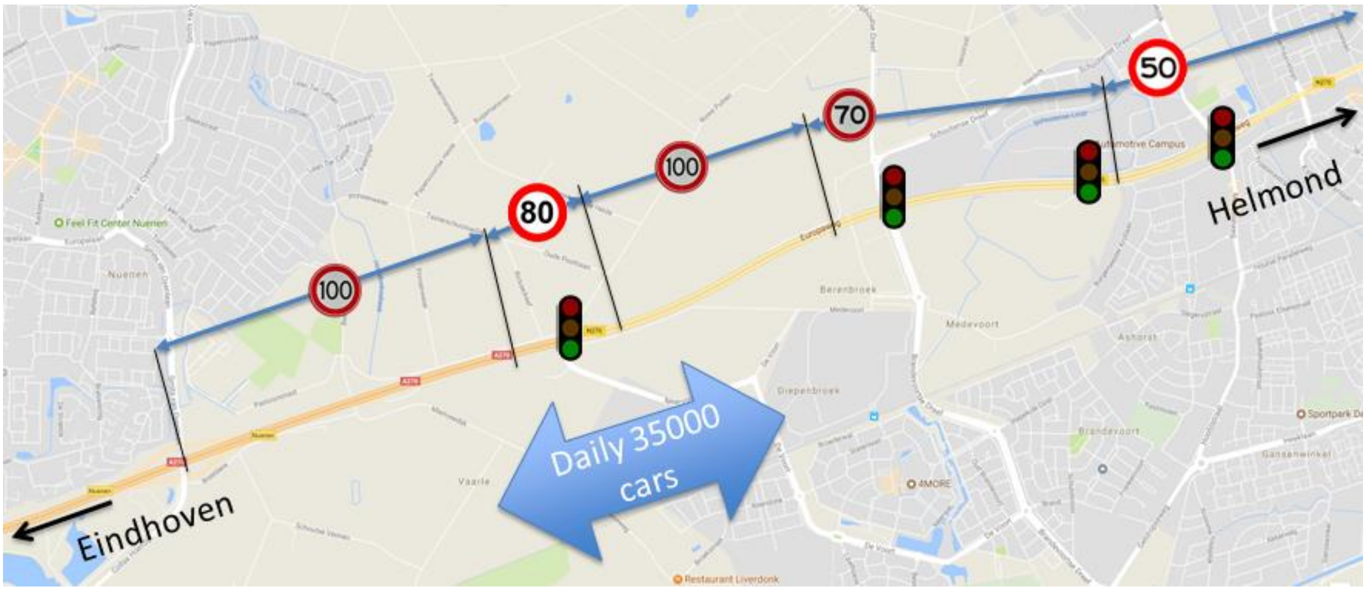


Figure 27 the variable speed limit on A270/N270/Europaweg.

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For use case 3, only one intersection will be investigated in detail, see Figure 28 and Figure 29. For use case 4, the whole track is of interest.

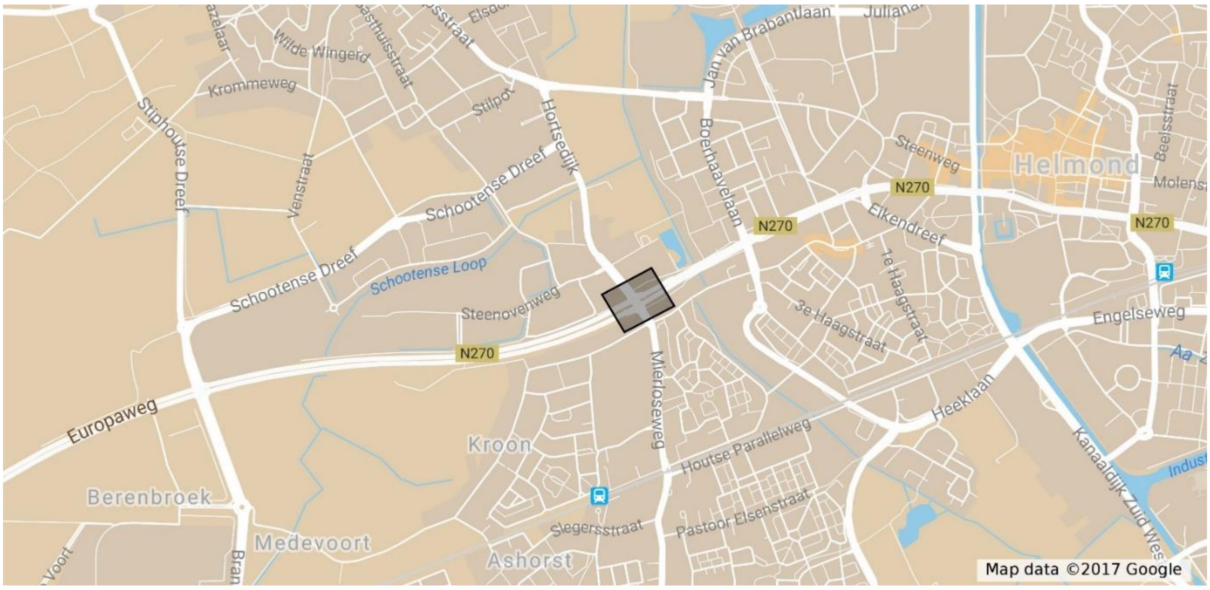


Figure 28: The site of use case 3.


Figure 29: The intersection to be studied in use case 3.

## 1.2 Questions to be investigated by applying the modelling approach

The following research questions will be investigated for use case 3:

- Can introducing CAVs lead to a more efficient traffic flow?

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- Is the performance of the intersection getting better because of a more efficient traffic flow?
- Is the impact dependent on the penetration rate of CAVs?
- Is it dependent on the kind of CAVs?
- Is automation enough to produce benefits, or is there also a need to be connected to the infrastructure (V2I)

The following research questions will be investigated for use case 4:

- Will there be less speeding (especially on the westernmost T-junction) due to the presence of CAVs?
- Will the speed become more homogenous due to the presence of CAVs, and will it lead to a more efficient flow?
- Will the travel time become more reliable with the presence of CAVs?
- Will the performance of the traffic in terms of travel time and delay get better?
- To what extend are the effects on traffic situation, safety and speed dependent on the penetration rate of CAVs?
- To what extend are the effects on traffic situation, safety and speed dependent on the type of CAVs?

# 2 Scope and modelling approach

## 2.1 Type of model

The microscopic model for use case 3 and 4 was based on the microscopic model developed by the traffic light supplier in Helmond, Dynniq. A Vissim models of traffic lights at intersections in Helmond was developed to evaluate traffic light regulations, shown in Figure 30 for use case 4.


**Figure 30 The Vissim model for A270/N270/Europaweg.**

For use case 3, only one intersection will be focused, see Figure 31.

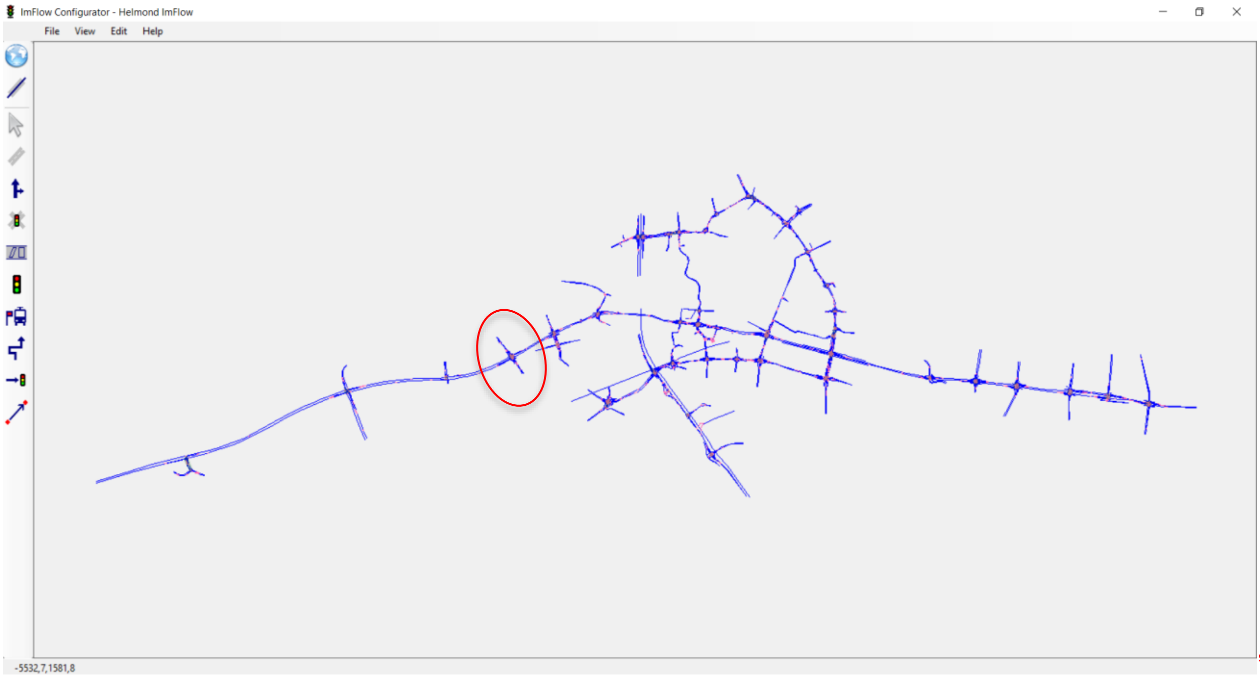


Figure 31 The Vissim model for A270/N270/Europaweg and the intersection of interest in this use case.

For use case 3 and 4, the model was extended to the west by PTV with a part of the highway with the on- and off- ramps by the village of Nuenen. PTV used this extended model for extracting data from AVs from TASS to create a AV-ready Vissim extension (see D2.4). Therefore, there is a large track with road section where the transition from the interurban highway between Helmond and Eindhoven to the arterial that enters Helmond take place.

## 2.2 The area and the level of detail of the model for base scenario

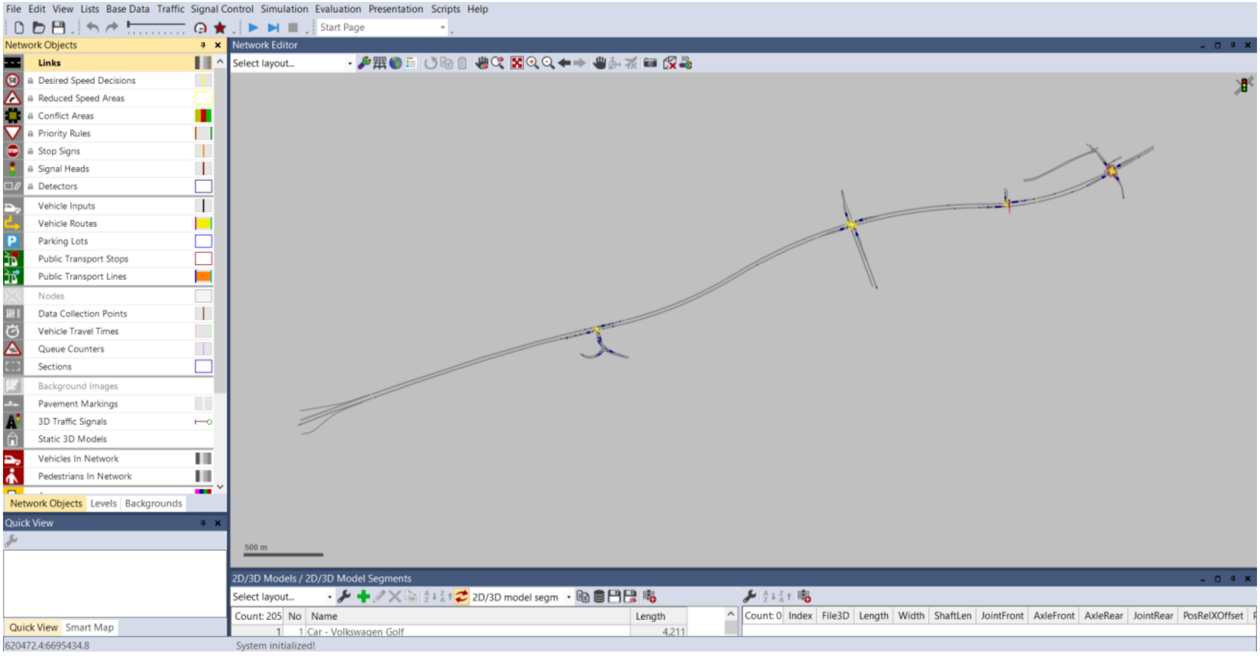

Figure 32 the screenshot of the model in Vissim

The model (Figure 32) starts in the west with the on- and off-ramps near the city of Nuenen. It has 4 signalised intersections:

- Intersection A270-Neervoortsedreef (KP805)
- Intersection N270-Brandevoortsedreef-Schootensedreef-Europaweg (KP804)
- Intersection Europaweg N270 - Automotive Campus (KP806)
- Intersection Europaweg N270 – Hortsedijk (KP701=)

The infrastructure is accurately reproduced on the digital surface in the model. All lanes, stop lines, detectors are reproduced in the model (Figure 9).

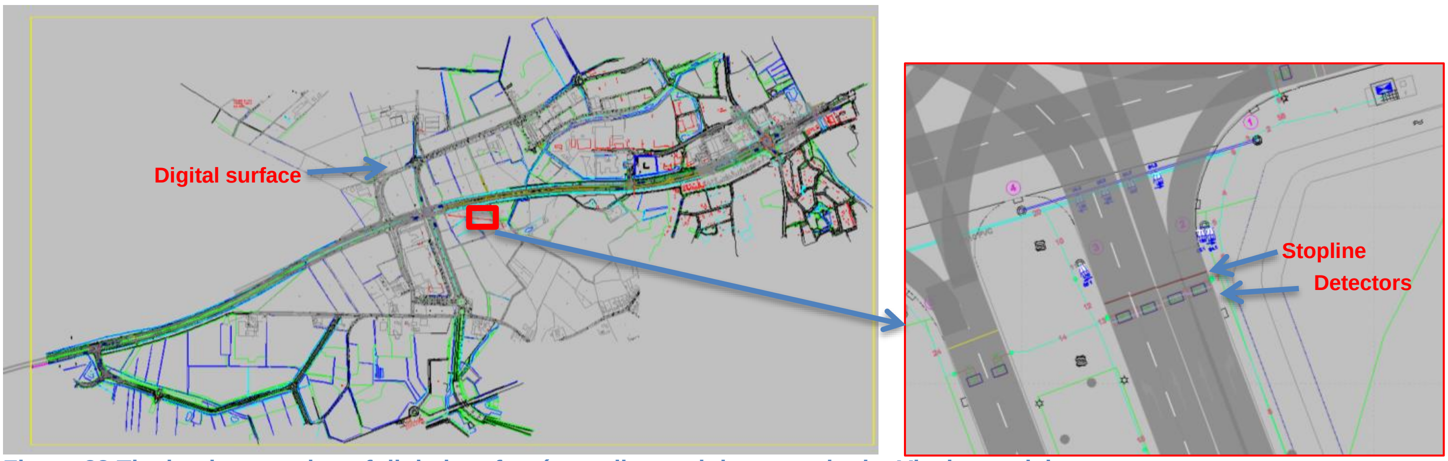


Figure 33 The implementation of digital surface´, stopline and detectors in the Vissim model

## 2.3 Included and excluded in the model of base scenario

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No. 723201

In the model the traffic light regulations as used in the reality are implemented. In Helmond “ImFlow” is name for the adaptive traffic control system that is used to regulate the traffic. ImFlow is an adaptive network system. The uniqueness of ImFlow is that traffic is regulated on the basis of the traffic volume, rather than on the basis of the presence of traffic as with traditional traffic control systems.

ImFlow applies the smart algorithm to get information on to what extent the available road capacity is used and optimizes the use of the road on that basis. In addition, ImFlow adopts a unique concept for regulating the traffic to achieve the government policy objectives. One can define traffic flow objectives within ImFlow, for instance, to shorten waiting times for crossing slow traffic and give priority to public transport. In Helmond the policy is set to facilitate the traffic flow in east-west direction (The A270/N270) and minimise the delay in that directions.

Dynniq has made an extension so that this regulation strategy can be simulated in Vissim. With the Imflow Simulator a connection between Vissim and the Imflow regulation is being made so that the simulation is close to the real world. The traffic regulation is dependent on the presence of the traffic on the detectors and the policy settings in Imflow. The user interface of Dynniq is shown in Figure 34.

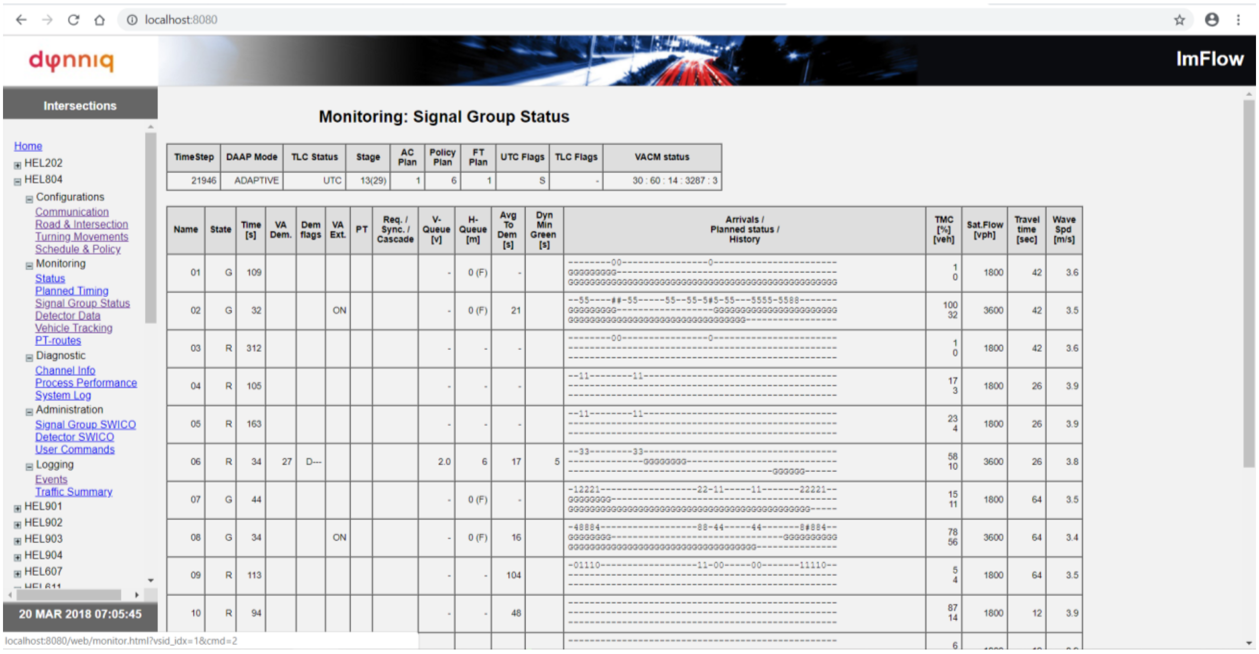


**Figure 34 the user interface of Dynniq.**

The parking lots along the A270 and the on and off-ramps near Nuenen along the A270 are not included. The parking lots and the on- and off-ramp are not important for this use case since they will not affect the measures of interest. However, the effect of merging in and merging out is a different use case but not relevant and maybe even disturbing other results when putting it in this use case.

# 3 The network

## 3.1 Detailed description of the network and how it is modelled

This project has received funding from the European Union’s Horizon 2020 research and innovation programme under grant agreement No. 723201

The Vissim model is based on Dynniq (the traffic light supplier) used to implement and evaluate traffic light regulations. The network is extended with a part of the highway by PTV. The model is accurately adjusted to the background where there is an accurate drawing of all the infrastructure, roadsides, stop lines, detectors, traffic lights

The model has 158 links, 27 speed decisions, 76 signal heads, 280 detectors, 25 vehicle inputs and 14 Static Vehicle route decisions. The model uses demand from traffic detectors that is built on 11 time intervals from 15 minutes (900 seconds).

## 3.2 Description of the data utilized for the network

The data used is traffic counts from the detectors of the traffic light installation, see Figure 35, and manually counted pedestrians and cyclists. Data input is provided by time intervals from 15 minutes (900 seconds). With this data provided per 15 minutes and even per turn direction (because every turn has its own lane) the turn percentages per 15 minutes can also be provided and are implemented in the model.

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https://helmond.it-t.nl/Display.aspx?v=3&b=11-10-2017&e=11-10-2017&f=Intensities

wo 11

Grafiek

Tabel

*Gefilterde intensiteiten in MVT van 11-10-2017 van alle geselecteerde richtingen per kwartier*

| 11-10-2017 | 01 | 02 | 03 | 04 | 05 | 06 | 07 | 08 | 09 | 10 | 11 | 12 | Totaal |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 00:00 - 00:15 | 1 | 24 | 4 | 7 | 0 | 3 | 7 | 52 | 4 | 2 | 2 | 0 | 106 |
| 00:15 - 00:30 | 0 | 25 | 5 | 4 | 1 | 1 | 6 | 46 | 8 | 1 | 3 | 0 | 100 |
| 00:30 - 00:45 | 0 | 14 | 1 | 0 | 1 | 1 | 10 | 38 | 2 | 1 | 7 | 0 | 75 |
| 00:45 - 01:00 | 0 | 7 | 0 | 0 | 0 | 5 | 1 | 16 | 1 | 5 | 0 | 0 | 35 |
| 01:00 - 01:15 | 0 | 12 | 2 | 0 | 0 | 3 | 0 | 29 | 3 | 0 | 0 | 0 | 49 |
| 01:15 - 01:30 | 0 | 12 | 0 | 0 | 0 | 1 | 3 | 29 | 4 | 2 | 1 | 0 | 52 |
| 01:30 - 01:45 | 0 | 13 | 3 | 0 | 1 | 0 | 1 | 12 | 0 | 1 | 0 | 0 | 31 |
| 01:45 - 02:00 | 0 | 4 | 1 | 0 | 0 | 1 | 0 | 17 | 0 | 1 | 2 | 1 | 27 |
| 02:00 - 02:15 | 0 | 7 | 1 | 2 | 0 | 2 | 0 | 11 | 1 | 0 | 0 | 0 | 24 |
| 02:15 - 02:30 | 0 | 6 | 1 | 1 | 0 | 0 | 1 | 16 | 0 | 0 | 0 | 2 | 27 |
| 02:30 - 02:45 | 0 | 8 | 0 | 0 | 1 | 0 | 0 | 7 | 0 | 0 | 1 | 0 | 17 |
| 02:45 - 03:00 | 0 | 2 | 0 | 0 | 0 | 1 | 3 | 9 | 1 | 0 | 0 | 0 | 16 |
| 03:00 - 03:15 | 0 | 6 | 1 | 0 | 0 | 2 | 1 | 9 | 0 | 2 | 0 | 0 | 21 |
| 03:15 - 03:30 | 0 | 2 | 0 | 0 | 0 | 1 | 1 | 6 | 0 | 0 | 1 | 0 | 11 |
| 03:30 - 03:45 | 0 | 11 | 0 | 0 | 2 | 1 | 1 | 10 | 1 | 3 | 0 | 0 | 29 |
| 03:45 - 04:00 | 0 | 6 | 0 | 1 | 0 | 3 | 1 | 7 | 0 | 0 | 0 | 0 | 18 |
| 04:00 - 04:15 | 0 | 15 | 0 | 0 | 0 | 3 | 2 | 6 | 0 | 0 | 0 | 0 | 26 |
| 04:15 - 04:30 | 0 | 16 | 1 | 2 | 0 | 3 | 1 | 9 | 3 | 2 | 0 | 0 | 37 |
| 04:30 - 04:45 | 0 | 27 | 1 | 0 | 1 | 6 | 1 | 21 | 1 | 4 | 1 | 0 | 63 |
| 04:45 - 05:00 | 0 | 28 | 1 | 1 | 0 | 4 | 2 | 12 | 0 | 2 | 0 | 0 | 50 |
| 05:00 - 05:15 | 1 | 51 | 0 | 2 | 0 | 7 | 3 | 20 | 1 | 6 | 0 | 1 | 92 |
| 05:15 - 05:30 | 0 | 103 | 2 | 1 | 2 | 19 | 10 | 38 | 1 | 4 | 2 | 1 | 183 |
| 05:30 - 05:45 | 2 | 116 | 0 | 6 | 1 | 28 | 7 | 34 | 2 | 15 | 2 | 0 | 213 |
| 05:45 - 06:00 | 1 | 82 | 2 | 2 | 3 | 29 | 4 | 25 | 5 | 12 | 3 | 0 | 168 |
| 06:00 - 06:15 | 1 | 158 | 2 | 4 | 4 | 41 | 3 | 37 | 2 | 22 | 2 | 3 | 279 |
| 06:15 - 06:30 | 2 | 249 | 1 | 1 | 5 | 47 | 16 | 63 | 8 | 31 | 9 | 4 | 436 |
| 06:30 - 06:45 | 6 | 327 | 10 | 6 | 12 | 75 | 17 | 102 | 7 | 50 | 15 | 4 | 631 |
| 06:45 - 07:00 | 1 | 281 | 15 | 12 | 14 | 113 | 29 | 105 | 16 | 52 | 19 | 3 | 660 |
| 07:00 - 07:15 | 3 | 394 | 10 | 13 | 22 | 137 | 43 | 145 | 17 | 54 | 19 | 3 | 860 |
| 07:15 - 07:30 | 4 | 379 | 15 | 22 | 39 | 149 | 36 | 197 | 32 | 67 | 41 | 5 | 986 |
| 07:30 - 07:45 | 7 | 365 | 19 | 32 | 63 | 138 | 38 | 242 | 25 | 90 | 44 | 10 | 1073 |
| 07:45 - 08:00 | 9 | 318 | 21 | 40 | 62 | 158 | 40 | 291 | 59 | 89 | 43 | 12 | 1142 |
| 08:00 - 08:15 | 5 | 317 | 31 | 57 | 79 | 125 | 32 | 296 | 49 | 80 | 46 | 16 | 1133 |
| 08:15 - 08:30 | 6 | 299 | 33 | 50 | 43 | 128 | 38 | 241 | 55 | 65 | 40 | 8 | 1006 |
| 08:30 - 08:45 | 13 | 277 | 27 | 53 | 50 | 92 | 38 | 205 | 37 | 72 | 41 | 11 | 916 |
| 08:45 - 09:00 | 13 | 232 | 26 | 34 | 56 | 91 | 43 | 222 | 44 | 39 | 42 | 9 | 851 |
| 09:00 - 09:15 | 11 | 213 | 21 | 24 | 30 | 66 | 42 | 168 | 34 | 44 | 43 | 10 | 706 |
| 09:15 - 09:30 | 6 | 227 | 15 | 32 | 21 | 51 | 29 | 137 | 12 | 41 | 37 | 8 | 616 |
| 09:30 - 09:45 | 4 | 190 | 17 | 23 | 21 | 61 | 27 | 159 | 31 | 42 | 20 | 7 | 602 |
| 09:45 - 10:00 | 7 | 180 | 21 | 29 | 21 | 61 | 32 | 150 | 20 | 36 | 24 | 4 | 585 |

Figure 35 The traffic data that is available from traffic lights.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No. 723201

# 4 The traffic

## 4.1 Detailed description of the traffic and its implementation in the model

Figure 36 presents the current traffic situation from google maps at A270/N270. Despite the large amount of traffic and the N270e traffic lights, no severe congestion is observed. Google maps traffic also shows that there is some delay at the traffic lights but that in general car traffic is 'normal'. Same conclusions can be drawn from running the Vissim simulation model. However, one can observe that there is a certain delay for the links close to the intersections with traffic lights.

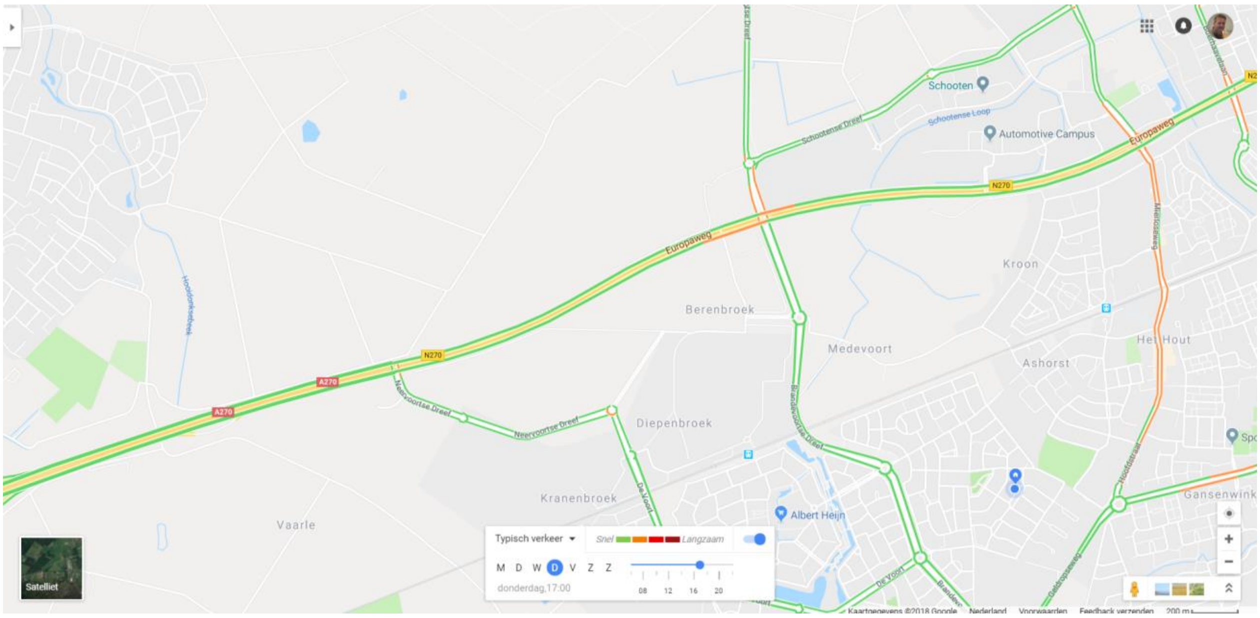


Figure 36 the current traffic situation (travel time) on A270/N270

## 4.2 Including description of the data utilized

In use case 3 and 4, the data from a specific day, Thursday 8 September 2016, was used. The chosen date represents a normal work day. The traffic control device logs and stores all events of the traffic light application such as duration of green and red light, the detector occupation and many more.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No. 723201

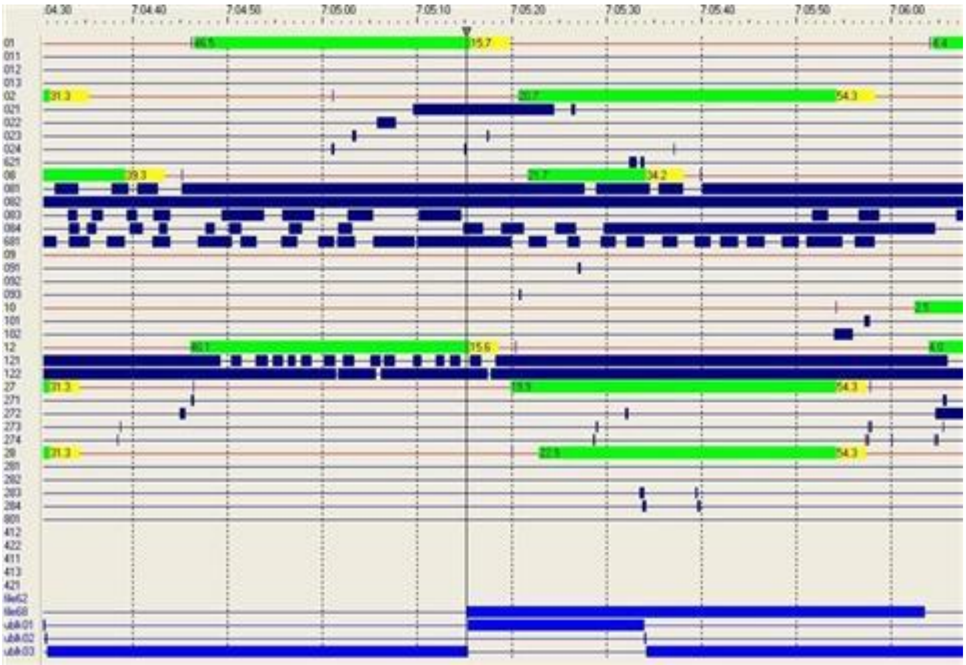

Figure 37 A view of a log-file from a traffic light application

In Figure 37 every line indicates a detector or traffic light. The green/yellow bar indicates the status of the light. Underneath are the corresponding detectors. When blue in this view it indicates the detector is occupied. This logging file can also be used to extract more information such as intensities, delay.

Helmond has the opportunity to use an application called "Webstats" to extract information, such as intensities, delays, queues for every intersection with a traffic light. In Webstats there is the opportunity to filter on days, directions, time and many more, see Figure 39.

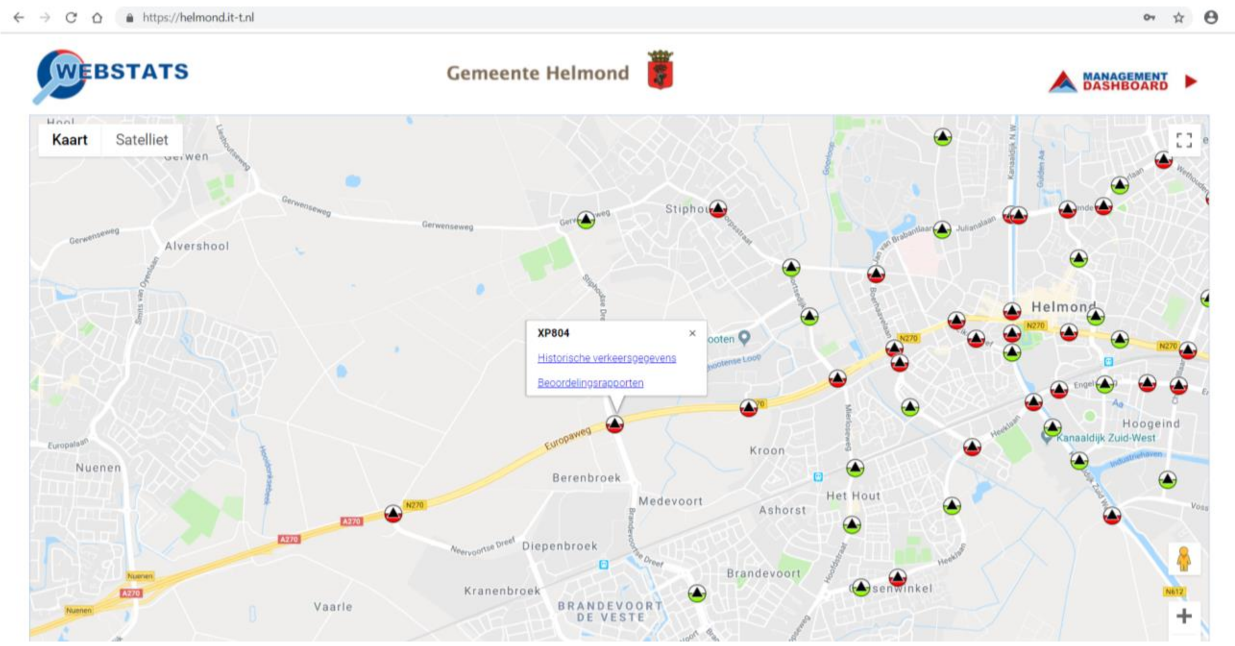


Figure 38 the user interface of the application "Webstats".

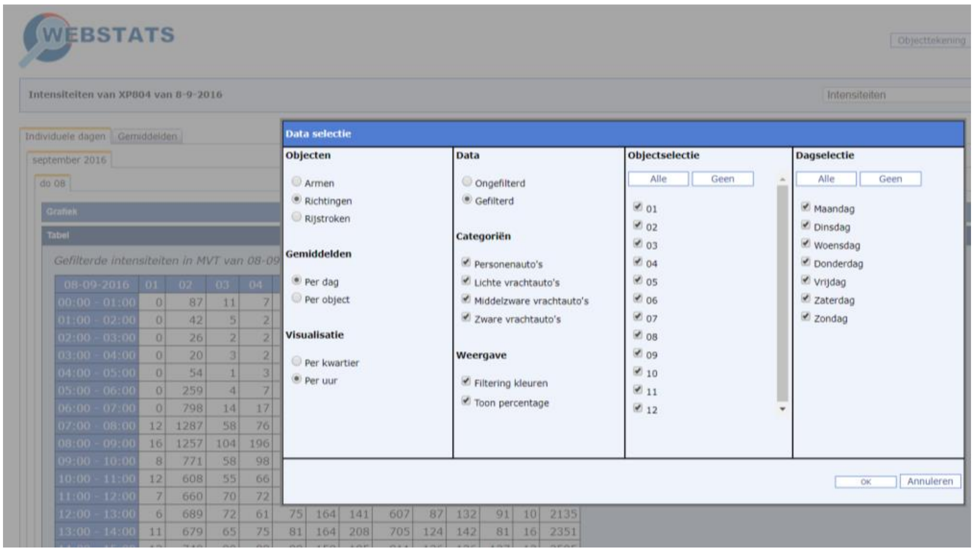


**Figure 39 Attribute selection in the application "Webstats".**

# 5 Verification

## 5.1 Verification process

The verification process includes both the verification of signal controller and the verification of Vissim model. The verification of signal controller ensures all the signal plans are specified correctly and can control the traffic lights as planned. Through the verification process, some signal plans on some intersections were found not working properly in Vissim. Traffic on several lanes in Vissim did not react on the traffic lights and just pass the intersection not responding on the traffic lights. There were some problems with the external traffic light controller. After contacting the traffic light supplier, the problem was solved and some detectors had to be renamed.

The second part of the verification process checks whether the Vissim model includes all the necessary components and can model the intersections properly. After the verification process, no coding error were found in the Vissim model.

Through running some test simulations, two errors were identified and fixed. Trucks in the model often used to appear on the left lane on both directions while in reality lorry traffic is usually on the right lane and only use on the left lane when overtaking or pre-sorting for the right direction. The traffic was found to change lanes when they are close to the intersection in the right direction. Vehicles in the Vissim model stop on the road and wait to get a gap for the lane changing. Therefore, all the traffic behind were slowed down dramatically, some extreme cases maybe far from the reality. Figure 40 provides an example of such lane changing behaviour in the Vissim model, the red car on the right lane wants to turn left (see the arrow) at the upcoming intersection, because of a lot of traffic on the left lane the car couldn't find a right gap to merge to the left. It slows down and even stops on the right lane. The cars on the left lane anticipate and also coming to a stop to let the car merge.

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Figure 40 The example of extreme cases of lane changing behaviour

## 5.2 Verification results

The problems with the external traffic light controller and traffic not responding were fixed by contacting the traffic light supplier. The problem was solved by renaming some detectors. After that the traffic in the model responded well on the traffic light signals.

Because Vissim generates the traffic randomly on the 2 lane sections, sometimes also trucks will be generated on the left lane. To prevent Vissim from generating trucks on the left lane, a small new (input) link was created where the left lane is prohibited for trucks. As a result, Vissim does not generate trucks on the left lane and trucks will use the left lane in the network only if they want to overtake or pre-sort.

The problem of stopping and lane changing just before an intersection when they want to pre-sort was caused by the fact that the turn directions (vehicle routes) in the beginning started just in front of a crossing. So, vehicles in the model get there turn directions very late and couldn’t anticipate even if the lane changing parameter in Vissim was set very large. The problem was solved by starting the vehicle routes just after the junction where traffic was coming from. Figure 41 illustrates the modifications in Vissim where the turn directions were adjusted from the place close to the downstream intersection to the upstream intersection.

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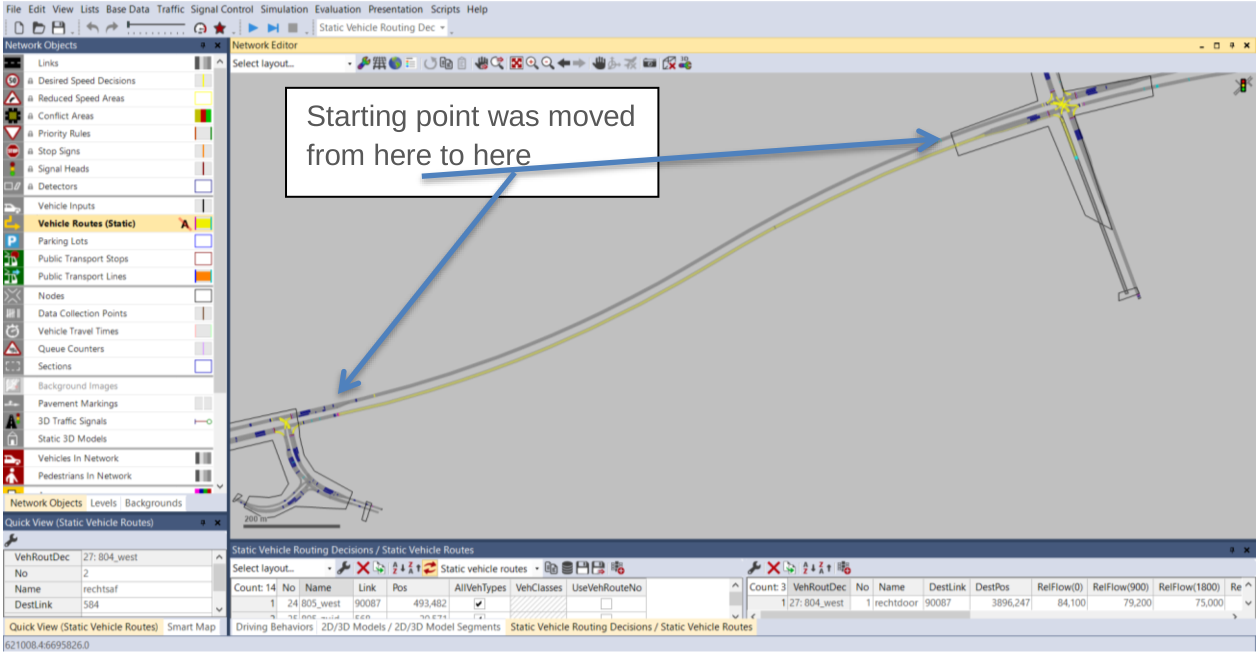



Figure 41 the adjustment of Vehicle routes in the Vissim model

# 6 Calibration

## 6.1 Description of the calibration process

Because of the exact data provided by the traffic lights the counts and turns on every section are just like the day the data was collected. No further demand and route calibration is necessary.

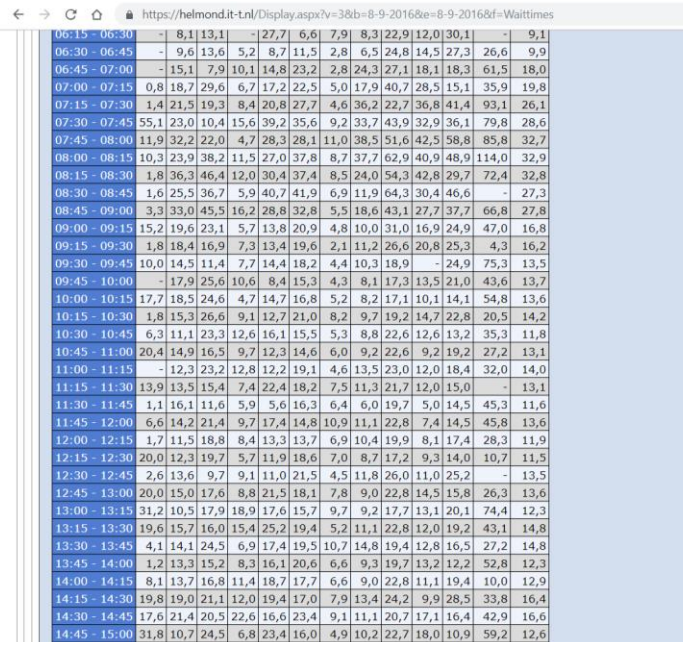
## 6.2 Description of calibration result

Figure 42 presents the average waiting time at each time interval for the average delay per vehicle from webstats which is calculated from the log files and Figure 43 presents the queue length of each lane at each time interval from webstats.

In use case 3, delay from turn on junctions can be extracted from Vissim and can be compared with the calculated delay from webstats.

In use case 4, the average delay and queue lengths from webstats will be compared with the delays and queue lengths in Vissim, if parameter adjustments will be implemented if the simulation results of delay and queue lengths differ from the observed values.

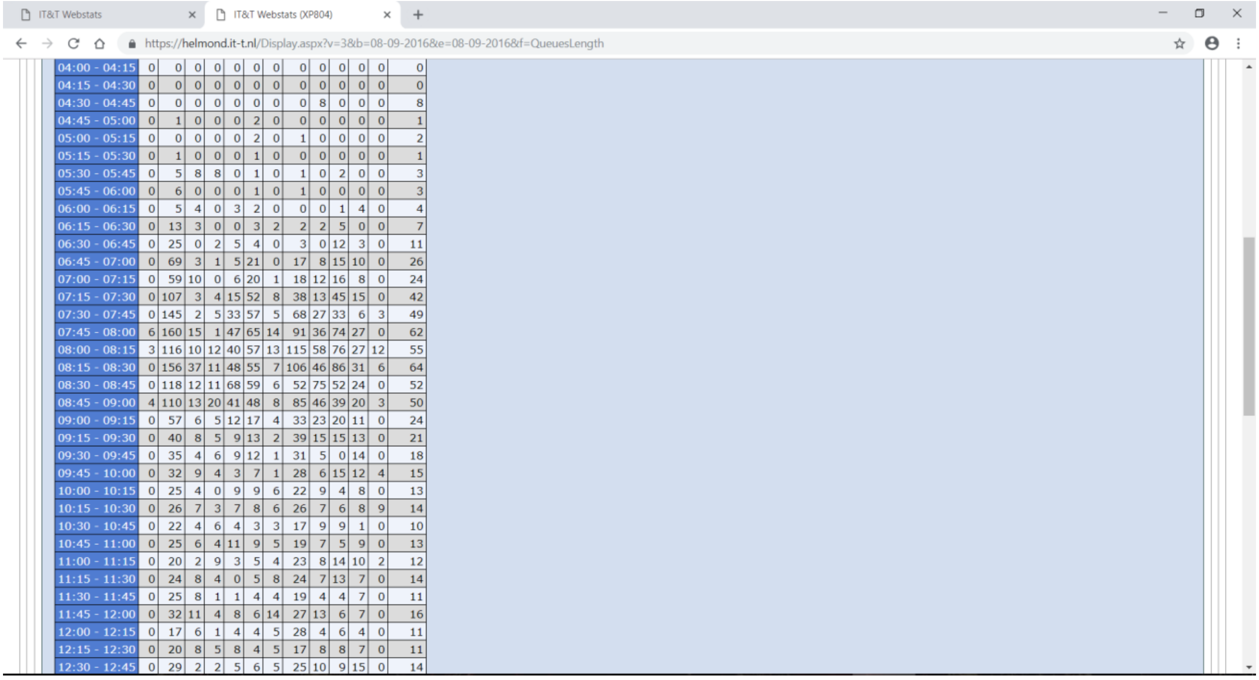
This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No. 723201



https://helmond.it-t.nl/Display.aspx?v=3&b=8-9-2016&e=8-9-2016&f=Waittimes

| | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 06:15 - 06:30 | - | 8,1 | 13,1 | - | 27,7 | 6,6 | 7,9 | 8,3 | 22,9 | 12,0 | 30,1 | - | 9,1 |
| 06:30 - 06:45 | - | 9,6 | 13,6 | 5,2 | 8,7 | 11,5 | 2,8 | 6,5 | 24,8 | 14,5 | 27,3 | 26,6 | 9,9 |
| 06:45 - 07:00 | - | 15,1 | 7,9 | 10,1 | 14,8 | 23,2 | 2,8 | 24,3 | 27,1 | 18,1 | 18,3 | 61,5 | 18,0 |
| 07:00 - 07:15 | 0,8 | 18,7 | 29,6 | 6,7 | 17,2 | 22,5 | 5,0 | 17,9 | 40,7 | 28,5 | 15,1 | 35,9 | 19,8 |
| 07:15 - 07:30 | 1,4 | 21,5 | 19,3 | 8,4 | 20,8 | 27,7 | 4,6 | 36,2 | 22,7 | 36,8 | 41,4 | 93,1 | 26,1 |
| 07:30 - 07:45 | 55,1 | 23,0 | 10,4 | 15,6 | 39,2 | 35,6 | 9,2 | 33,7 | 43,9 | 32,9 | 36,1 | 79,8 | 28,6 |
| 07:45 - 08:00 | 11,9 | 32,2 | 22,0 | 4,7 | 28,3 | 28,1 | 11,0 | 38,5 | 51,6 | 42,5 | 58,8 | 85,8 | 32,7 |
| 08:00 - 08:15 | 10,3 | 23,9 | 38,2 | 11,5 | 27,0 | 37,8 | 8,7 | 37,7 | 62,9 | 40,9 | 48,9 | 114,0 | 32,9 |
| 08:15 - 08:30 | 1,8 | 36,3 | 46,4 | 12,0 | 30,4 | 37,4 | 8,5 | 24,0 | 54,3 | 42,8 | 29,7 | 72,4 | 32,8 |
| 08:30 - 08:45 | 1,6 | 25,5 | 36,7 | 5,9 | 40,7 | 41,9 | 6,9 | 11,9 | 64,3 | 30,4 | 46,6 | - | 27,3 |
| 08:45 - 09:00 | 3,3 | 33,0 | 45,5 | 16,2 | 28,8 | 32,8 | 5,5 | 18,6 | 43,1 | 27,7 | 37,7 | 66,8 | 27,8 |
| 09:00 - 09:15 | 15,2 | 19,6 | 23,1 | 5,7 | 13,8 | 20,9 | 4,8 | 10,0 | 31,0 | 16,9 | 24,9 | 47,0 | 16,8 |
| 09:15 - 09:30 | 1,8 | 18,4 | 16,9 | 7,3 | 13,4 | 19,6 | 2,1 | 11,2 | 26,6 | 20,8 | 25,3 | 4,3 | 16,2 |
| 09:30 - 09:45 | 10,0 | 14,5 | 11,4 | 7,7 | 14,4 | 18,2 | 4,4 | 10,3 | 18,9 | - | 24,9 | 75,3 | 13,5 |
| 09:45 - 10:00 | - | 17,9 | 25,6 | 10,6 | 8,4 | 15,3 | 4,3 | 8,1 | 17,3 | 13,5 | 21,0 | 43,6 | 13,7 |
| 10:00 - 10:15 | 17,7 | 18,5 | 24,6 | 4,7 | 14,7 | 16,8 | 5,2 | 8,2 | 17,1 | 10,1 | 14,1 | 54,8 | 13,6 |
| 10:15 - 10:30 | 1,8 | 15,3 | 26,6 | 9,1 | 12,7 | 21,0 | 8,2 | 9,7 | 19,2 | 14,7 | 22,8 | 20,5 | 14,2 |
| 10:30 - 10:45 | 6,3 | 11,1 | 23,3 | 12,6 | 16,1 | 15,5 | 5,3 | 8,8 | 22,6 | 12,6 | 13,2 | 35,3 | 11,8 |
| 10:45 - 11:00 | 20,4 | 14,9 | 16,5 | 9,7 | 12,3 | 14,6 | 6,0 | 9,2 | 22,6 | 9,2 | 19,2 | 27,2 | 13,1 |
| 11:00 - 11:15 | - | 12,3 | 23,2 | 12,8 | 12,2 | 19,1 | 4,6 | 13,5 | 23,0 | 12,0 | 18,4 | 32,0 | 14,0 |
| 11:15 - 11:30 | 13,9 | 13,5 | 15,4 | 7,4 | 22,4 | 18,2 | 7,5 | 11,3 | 21,7 | 12,0 | 15,0 | - | 13,1 |
| 11:30 - 11:45 | 1,1 | 16,1 | 11,6 | 5,9 | 5,6 | 16,3 | 6,4 | 6,0 | 19,7 | 5,0 | 14,5 | 45,3 | 11,6 |
| 11:45 - 12:00 | 6,6 | 14,2 | 21,4 | 9,7 | 17,4 | 14,8 | 10,9 | 11,1 | 22,8 | 7,4 | 14,5 | 45,8 | 13,6 |
| 12:00 - 12:15 | 1,7 | 11,5 | 18,8 | 8,4 | 13,3 | 13,7 | 6,9 | 10,4 | 19,9 | 8,1 | 17,4 | 28,3 | 11,9 |
| 12:15 - 12:30 | 20,0 | 12,3 | 19,7 | 5,7 | 11,9 | 18,6 | 7,0 | 8,7 | 17,2 | 9,3 | 14,0 | 10,7 | 11,5 |
| 12:30 - 12:45 | 2,6 | 13,6 | 9,7 | 9,1 | 11,0 | 21,5 | 4,5 | 11,8 | 26,0 | 11,0 | 25,2 | - | 13,5 |
| 12:45 - 13:00 | 20,0 | 15,0 | 17,6 | 8,8 | 21,5 | 18,1 | 7,8 | 9,0 | 22,8 | 14,5 | 15,8 | 26,3 | 13,6 |
| 13:00 - 13:15 | 31,2 | 10,5 | 17,9 | 18,9 | 17,6 | 15,7 | 9,7 | 9,2 | 17,7 | 13,1 | 20,1 | 74,4 | 12,3 |
| 13:15 - 13:30 | 19,6 | 15,7 | 16,0 | 15,4 | 25,2 | 19,4 | 5,2 | 11,1 | 22,8 | 12,0 | 19,2 | 43,1 | 14,8 |
| 13:30 - 13:45 | 4,1 | 14,1 | 24,5 | 6,9 | 17,4 | 19,5 | 10,7 | 14,8 | 19,4 | 12,8 | 16,5 | 27,2 | 14,8 |
| 13:45 - 14:00 | 1,2 | 13,3 | 15,2 | 8,3 | 16,1 | 20,6 | 6,6 | 9,3 | 19,7 | 13,2 | 12,2 | 52,8 | 12,3 |
| 14:00 - 14:15 | 8,1 | 13,7 | 16,8 | 11,4 | 18,7 | 17,7 | 6,6 | 9,0 | 22,8 | 11,1 | 19,4 | 10,0 | 12,9 |
| 14:15 - 14:30 | 19,8 | 19,0 | 21,1 | 12,0 | 19,4 | 17,0 | 7,9 | 13,4 | 24,2 | 9,9 | 28,5 | 33,8 | 16,4 |
| 14:30 - 14:45 | 17,6 | 21,4 | 20,5 | 22,6 | 16,6 | 23,4 | 9,1 | 11,1 | 20,7 | 17,1 | 16,4 | 42,9 | 16,6 |
| 14:45 - 15:00 | 31,8 | 10,7 | 24,5 | 6,8 | 23,4 | 16,0 | 4,9 | 10,2 | 22,7 | 18,0 | 10,9 | 59,2 | 12,6 |

Figure 42 Waitting time (delay) extracted from webstats



IT&T Webstats

IT&T Webstats (XP804)

https://helmond.it-t.nl/Display.aspx?v=3&b=08-09-2016&e=08-09-2016&f=QueuesLength

| | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 04:00 - 04:15 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 04:15 - 04:30 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 04:30 - 04:45 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 8 | 0 | 0 | 0 | 8 |
| 04:45 - 05:00 | 0 | 1 | 0 | 0 | 0 | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 1 |
| 05:00 - 05:15 | 0 | 0 | 0 | 0 | 0 | 2 | 0 | 1 | 0 | 0 | 0 | 0 | 2 |
| 05:15 - 05:30 | 0 | 1 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 1 |
| 05:30 - 05:45 | 0 | 5 | 8 | 8 | 0 | 1 | 0 | 1 | 0 | 2 | 0 | 0 | 3 |
| 05:45 - 06:00 | 0 | 6 | 0 | 0 | 0 | 1 | 0 | 1 | 0 | 0 | 0 | 0 | 3 |
| 06:00 - 06:15 | 0 | 5 | 4 | 0 | 3 | 2 | 0 | 0 | 0 | 1 | 4 | 0 | 4 |
| 06:15 - 06:30 | 0 | 13 | 3 | 0 | 0 | 3 | 2 | 2 | 2 | 5 | 0 | 0 | 7 |
| 06:30 - 06:45 | 0 | 25 | 0 | 2 | 5 | 4 | 0 | 3 | 0 | 12 | 3 | 0 | 11 |
| 06:45 - 07:00 | 0 | 69 | 3 | 1 | 5 | 21 | 0 | 17 | 8 | 15 | 10 | 0 | 26 |
| 07:00 - 07:15 | 0 | 59 | 10 | 0 | 6 | 20 | 1 | 18 | 12 | 16 | 8 | 0 | 24 |
| 07:15 - 07:30 | 0 | 107 | 3 | 4 | 15 | 52 | 8 | 38 | 13 | 45 | 15 | 0 | 42 |
| 07:30 - 07:45 | 0 | 145 | 2 | 5 | 33 | 57 | 5 | 68 | 27 | 33 | 6 | 3 | 49 |
| 07:45 - 08:00 | 6 | 160 | 15 | 1 | 47 | 65 | 14 | 91 | 36 | 74 | 27 | 0 | 62 |
| 08:00 - 08:15 | 3 | 116 | 10 | 12 | 40 | 57 | 13 | 115 | 58 | 76 | 27 | 12 | 55 |
| 08:15 - 08:30 | 0 | 156 | 37 | 11 | 48 | 55 | 7 | 106 | 46 | 86 | 31 | 6 | 64 |
| 08:30 - 08:45 | 0 | 118 | 12 | 11 | 68 | 59 | 6 | 52 | 75 | 52 | 24 | 0 | 52 |
| 08:45 - 09:00 | 4 | 110 | 13 | 20 | 41 | 48 | 8 | 85 | 46 | 39 | 20 | 3 | 50 |
| 09:00 - 09:15 | 0 | 57 | 6 | 5 | 12 | 17 | 4 | 33 | 23 | 20 | 11 | 0 | 24 |
| 09:15 - 09:30 | 0 | 40 | 8 | 5 | 9 | 13 | 2 | 39 | 15 | 15 | 13 | 0 | 21 |
| 09:30 - 09:45 | 0 | 35 | 4 | 6 | 9 | 12 | 1 | 31 | 5 | 0 | 14 | 0 | 18 |
| 09:45 - 10:00 | 0 | 32 | 9 | 4 | 3 | 7 | 1 | 28 | 6 | 15 | 12 | 4 | 15 |
| 10:00 - 10:15 | 0 | 25 | 4 | 0 | 9 | 9 | 6 | 22 | 9 | 4 | 8 | 0 | 13 |
| 10:15 - 10:30 | 0 | 26 | 7 | 3 | 7 | 8 | 6 | 26 | 7 | 6 | 8 | 9 | 14 |
| 10:30 - 10:45 | 0 | 22 | 4 | 6 | 4 | 3 | 3 | 17 | 9 | 9 | 1 | 0 | 10 |
| 10:45 - 11:00 | 0 | 25 | 6 | 4 | 11 | 9 | 5 | 19 | 7 | 5 | 9 | 0 | 13 |
| 11:00 - 11:15 | 0 | 20 | 2 | 9 | 3 | 5 | 4 | 23 | 8 | 14 | 10 | 2 | 12 |
| 11:15 - 11:30 | 0 | 24 | 8 | 4 | 0 | 5 | 8 | 24 | 7 | 13 | 7 | 0 | 14 |
| 11:30 - 11:45 | 0 | 25 | 8 | 1 | 1 | 4 | 4 | 19 | 4 | 4 | 7 | 0 | 11 |
| 11:45 - 12:00 | 0 | 32 | 11 | 4 | 8 | 6 | 14 | 27 | 13 | 6 | 7 | 0 | 16 |
| 12:00 - 12:15 | 0 | 17 | 6 | 1 | 4 | 4 | 5 | 28 | 4 | 6 | 4 | 0 | 11 |
| 12:15 - 12:30 | 0 | 20 | 8 | 5 | 8 | 4 | 5 | 17 | 8 | 8 | 7 | 0 | 11 |
| 12:30 - 12:45 | 0 | 29 | 2 | 2 | 5 | 6 | 5 | 25 | 10 | 9 | 15 | 0 | 14 |

Figure 43 Queue length from Webstats

# 7 Validation

The validation process and results for use case 3 and use case 4 will be updated in Deliverable 4.2.

## 7.1 Description of the validation process

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No. 723201

## 7.2 Description of validation result

# 8 Results and conclusions

The results and conclusions for use case 3 and use case 4 will be updated after the validation results are added in Deliverable 4.2.

## 8.1 Conclusions of the verification-calibration-validation process

## 8.2 Handling of model uncertainty and/or limitation

# 9 Reference

None

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No. 723201

# Appendix D Use case 5: Waiting and drop-off areas for passengers

# Baseline model for use case 5

## Waiting and drop-off areas for passengers

Version: 1.0
Date: 2018-10-30
Authors: Brian Matthews, Ammar Anwar and Prof John Miles



This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No. 723201-2

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This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No. 723201

# 1 Introduction and background

## 1.1 Study area characteristics

The Central Milton Keynes (CMK) (city centre) is an area approximately 3km by 1.5km covering central business, retail and leisure area, generic UK post code MK9 3EQ. The area of interest is displayed in Figure 1 below.

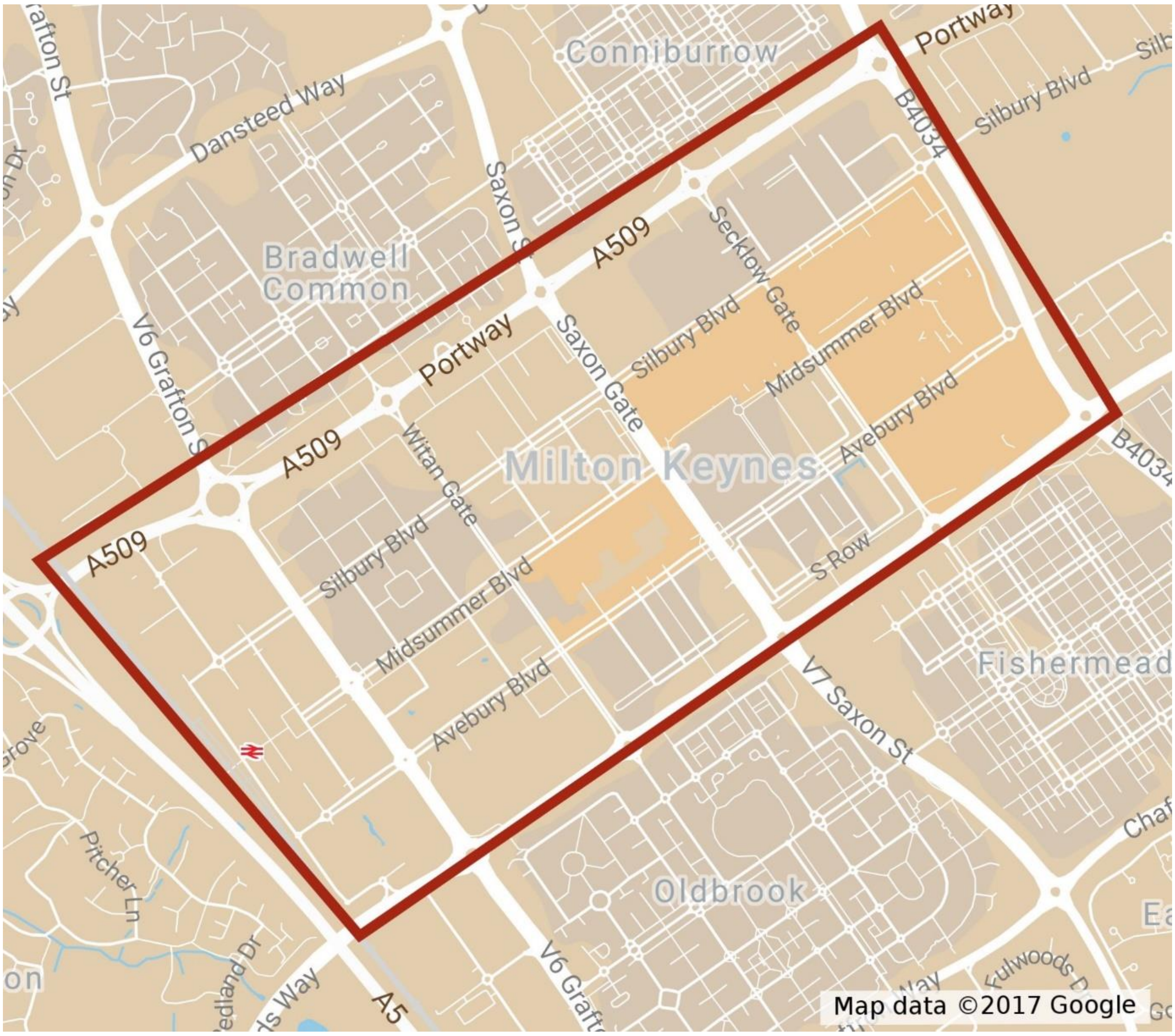


Figure 44 The city area of interest

To assess the impact of CAVs on the Milton Keynes centre area of interest the highlighted area in Figure 45 would be modelled in microsimulation. The road types are mostly arterial in nature external to the city centre and within the centre the roads tend to be urban.

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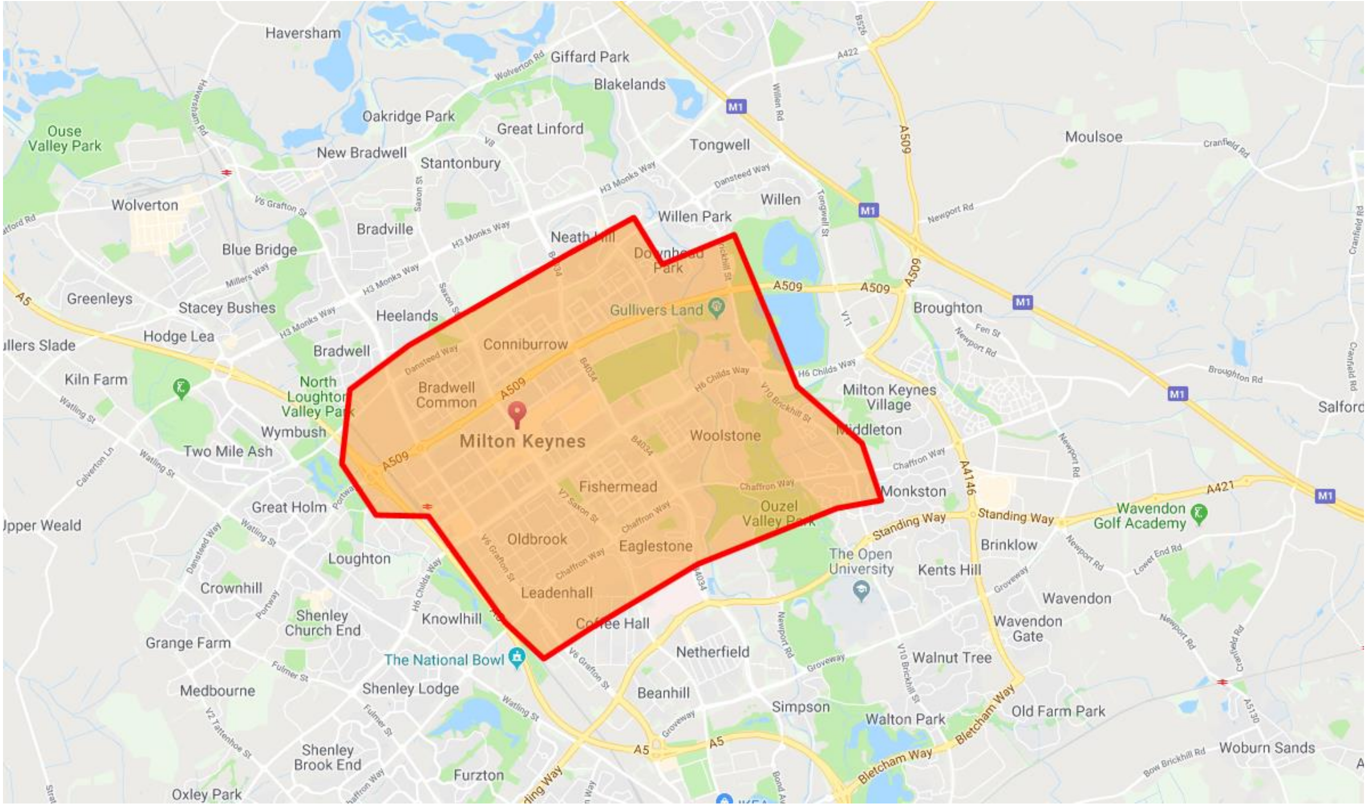


Figure 45 Area to be modelled for the use case

Milton Keynes (MK) is a city located in Buckinghamshire, England. The Milton Keynes administrative area includes the city of Milton Keynes and surrounding boroughs displayed in Figure 46 by the red boundary line.

The city centre (Figure 44) provides the economic hub with 30,000 employees, regional retail facilities and leisure activity. The city is served by the national rail network with services from London, Birmingham, North of England, and Scotland. There are a relatively low number of residential properties areas within the centre area.

There is a focus of public transport operation through the central spine route – Midsummer Boulevard. The centre has around 25,000 parking spaces. The Highway typically has a speed limit of 30mph (48kph) having mainly four lane carriageways with some bus priority. There is limited bicycle infrastructure within the city centre.

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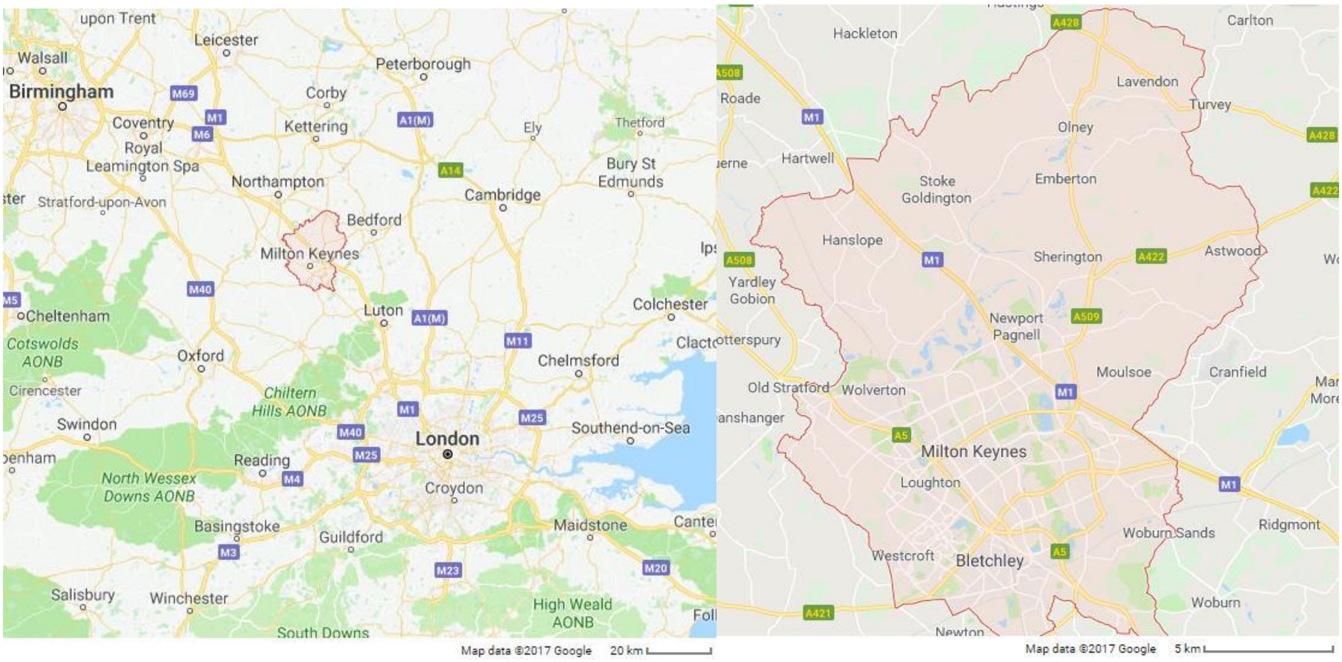


**Figure 46 Milton Keynes administrative area**

The city has an autonomous Pod (automated last mile service) network defined in anticipation of services starting in 2018. A Pod is a low speed autonomous vehicle generally designed to work in road and off-road spaces and with a high degree of interaction between pedestrians and the built environment. See link for further information: https://ts.catapult.org.uk/innovation-centre/cav/cav-projects-at-the-tsc/self-driving-pods/. Private car is the main mode of transport. The current modal split from surveyed data of 2017 is presented in Figure 4. Modes to be modelled for the purpose of this use case are cars and heavy goods vehicles (HGVs).

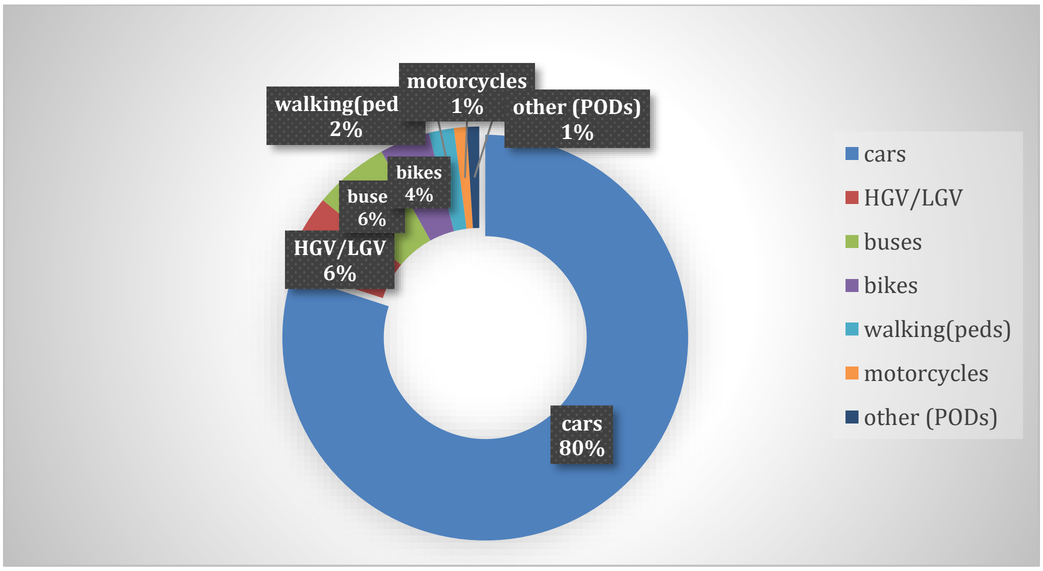


**Figure 47 Modes of transport prevalent within the city**

## 1.2 Questions to be investigated by applying the modelling approach

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No. 723201

Questions to investigate in this use case are:

- What is the effect on the quality of service after vehicle intercept areas are defined?
- Is there a need for operational parameters such as entry and exit capacity requirements for vehicle intercept facilities?
- Quality of service within the city centre affected by restricting access to it. How much road space can be removed within the centre whilst maintaining similar service quality?
- Impact (capacity) of feeder network into vehicle intercept zones.
- Varying the mix of CAVs and normal cars and analysing congestion.

# 2 Scope and modelling approach

## 2.1 Type of model

The Central MK study area for the purpose of CoEXist is being built within Vissim software using real traffic OD values and signal times from 2016 surveyed data. Base scenario road network to be modelled will be the current situation that means all access will be open to the city centre and all cars will have normal non-AV behaviours. The exact road network that will be modelled is highlighted below.


**Figure 48 Road network built in Vissim for modelling the use case**

## 2.2 The area and the level of detail of the model for base scenario

The city centre has a mix of roundabouts, traffic signals and side road junctions based on a grid network. City centre traffic signals are fixed time controlled with timings set to allow movements in all directions with no blocked turns. Edge of city has vehicle actuated traffic signals using the MOVA control strategy on the main approach routes from west. The signal times and settings are reviewed annually.

There are no congestion charges, but variable levels of charging for parking are in operation based on proximity and busyness of the parking spot location. The road functions are a mix of distributor and access roads, built to modern standards. Main access roads to access edge of city are 4-lane high speed carriageways with roundabout intersections with some side road accesses. Within the city centre, routes are 4 lanes with a lower speed limit with high number of access points into on-street car parks. Main city centre junctions are fixed time signals allowing all movements on single phases. The central boulevard includes bus priority lanes. These lanes are operational during peak hours only. There are a very low number of dedicated cycle paths across the city.

All pedestrian routes are segregated with underpasses available at all highway junctions. Segregated pedestrian and cycle routes combined are available for surrounding residential areas. These combined provide 19 access points from surrounding residential areas to the Central Milton Keynes area. The city has 20,000 on-street highway parking spaces managed by Milton Keynes Council (MKC), 5000 private spaces operated by developments (see map in Figure 49). For taxis there is a key rank at station and the retail core area.

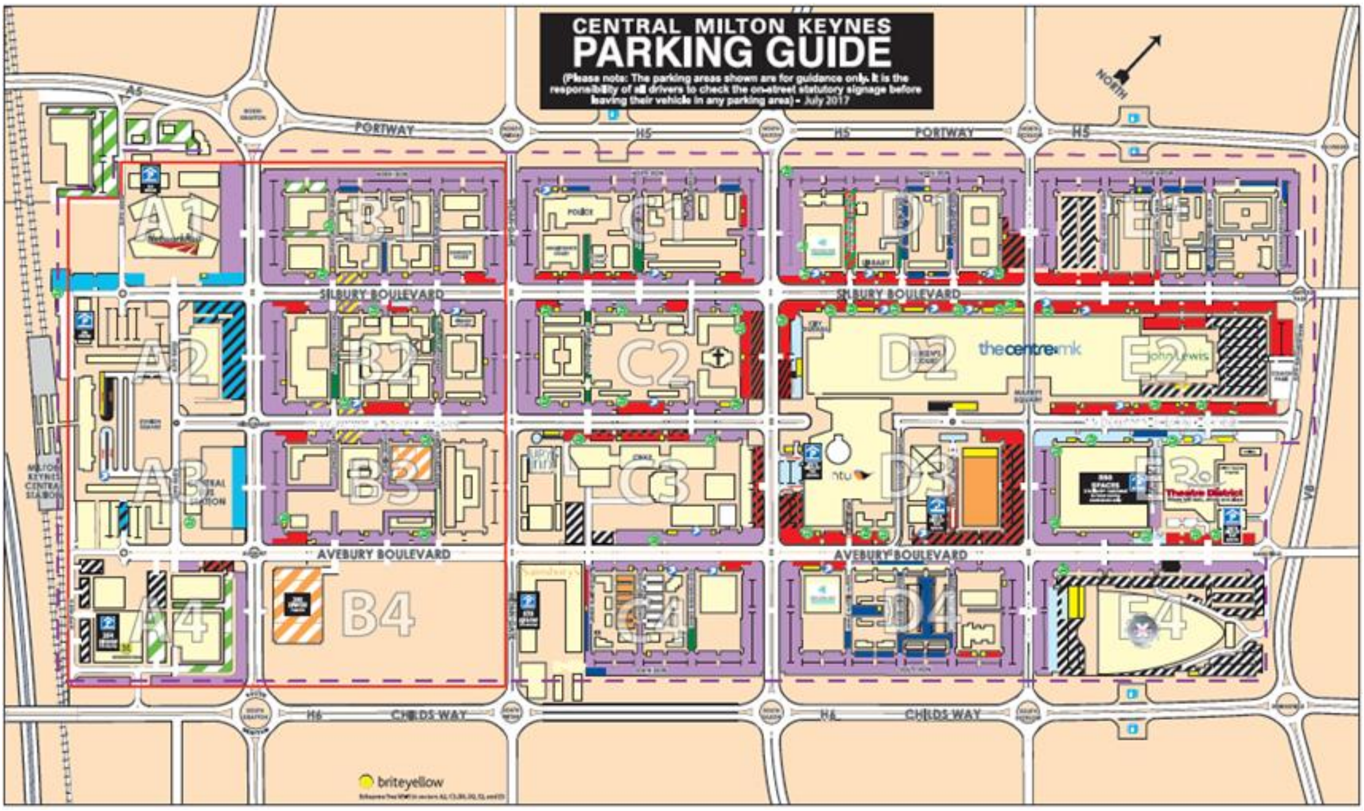


Figure 49 Map of the milton keynes central area including parking

Analog and digital maps are available for city area and can be accessed via Milton Keynes council website ( https://www.milton-keynes.gov.uk/ ).

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Milton Keynes rail station has five rail terminals with three on the mainline serving routes between London, Birmingham and Manchester. Fast frequent services mean that MK acts as a commuter location for employment in London and Birmingham. The city supports a bus fleet made up of large and medium sized vehicles. The bus fleet is around 100 vehicles out of which approximately 85 buses are operational and serve the city from 7:00 to 20:00. Lower frequency services operate on limited routes outside these times.

Bus stops are focused in two areas: the rail station (A2 and A3 in) and the retail centre (D2, D3, and E2); there are a limited number serving the business area on Midsummer Boulevard. The bus stops are contained on the main roads and within residential areas – street side. The main site being within the detailed study area in Central Milton Keynes. The city operates a real time passenger information system with 50 stops that have illuminated information displays. Travel information is currently available at all these 50 stops, but recent trends have moved information to smart devices.

The model will be a microsimulation model being built in VISSIM. The baseline model is detailed and quite comprehensive covering in details of main road networks around the city centre and most feed in points within the area. The baseline central area model will be adapted through the addition of the intercept locations which will make allowance for the approach junction and lane designs. The adapted model will then be exercised to investigate the effectiveness of the measure and how the penetration of AVs will affect the city. (i.e. reducing traffic congestion in the city centre area without introducing an unacceptable increase in peripheral road congestion). In the second case the modelling will investigate the impact of placing the intercept points at the edge of the city centre area. This could indicate the amount of future road-space required to support city activities, and what if any could be reallocated to other uses. The analysis will also help understand what parking allocation whether if any will be required for AVs.

The modelling work will proceed in the following sequence:

- Network coding,
- Verification,
- Calibration & validation,
- Development of a second model upgraded over the baseline with intercept locations modelled and network changes,
- Exercise adapted model to explore the potential for intercept point locations for AV's to alleviate congestion in and around the city centre area.

## 2.3 Included and excluded in the model of base scenario

Almost all main arterial roads near the centre of Milton Keynes are included in the model. Figure 50shows the links that are included as part of the modelled network. As the network modelled area outlined in Figure 13 does not contain many bikes or pedestrian journeys being more arterial rather than urban in nature it is statistically insignificant to add these modes. For the second part of the modelling process with introduction of CAVs, the PODs themselves would not be simulated however their effect and the causal rate for vehicle intercept locations as a result of the introduction the last mile journeys in effect will be calculated.

Within the baseline model the vehicle intercept points and other measures are excluded. Other exclusions are the small inner urban roads which are near the feed-in point zones. The final model will not include the

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motorway M1 and A5, however if during the iterative process it is deemed necessary an analysis might be carried out at some of these external legs. See Figure 50 extended out from the base model.

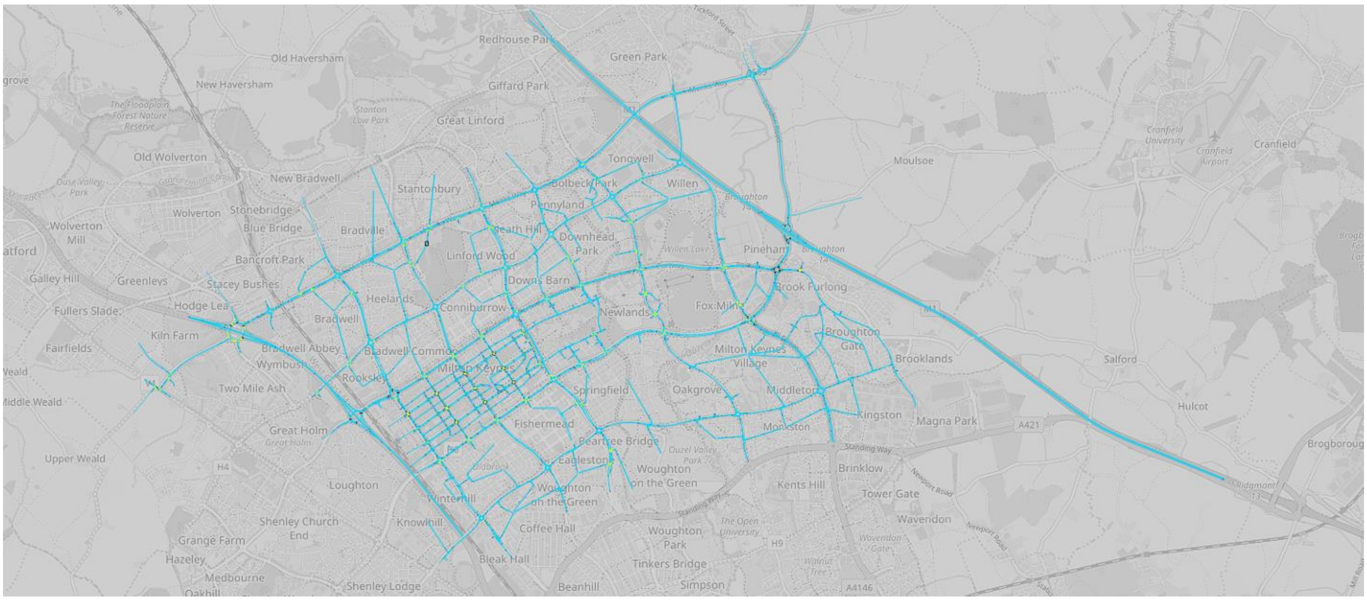


Figure 50 Extended model layout for further testing if required

# 3 The network

## 3.1 Detailed description of the network and how it is modelled

The Vissim network that is built is not converted from VISUM or automated through OSM but built internally within Vissim. This is done to provide a good check where individual roundabouts are tested for bottlenecks or errors by applying maximum flows to them. The network is built a single intersection at a time and then all of them are interconnected together.

There is a total of 3078 links including connectors in the model. The link behaviour types for non-AVs are set to VISSIM default values. The conflict areas are 2581. With the default frontGapDef[6] and RearGapDef set at 0.4s while the SafDistDef at 1.5s. The anticipated route is set at 50.0% and avoidBlockminor is set to 90.0%. Conflict areas are defined manually according to the right of way established within the city. Driving behaviour parameter values such as look ahead distance and look back distance are set to default for the baseline model. There on average 5000 agents active in the network in a given second.

The turns are added as static routes from the flows in the macroscopic model. The turns are coded with the relative proportions at every intersection ensuring the exact flows across the network. These relative proportion flow values are obtained from the macroscopic Saturn model. The total number of static routing decisions added within Vissim are 1094.

[6] Please refer to the Vissim user manual for the definition of parameters.

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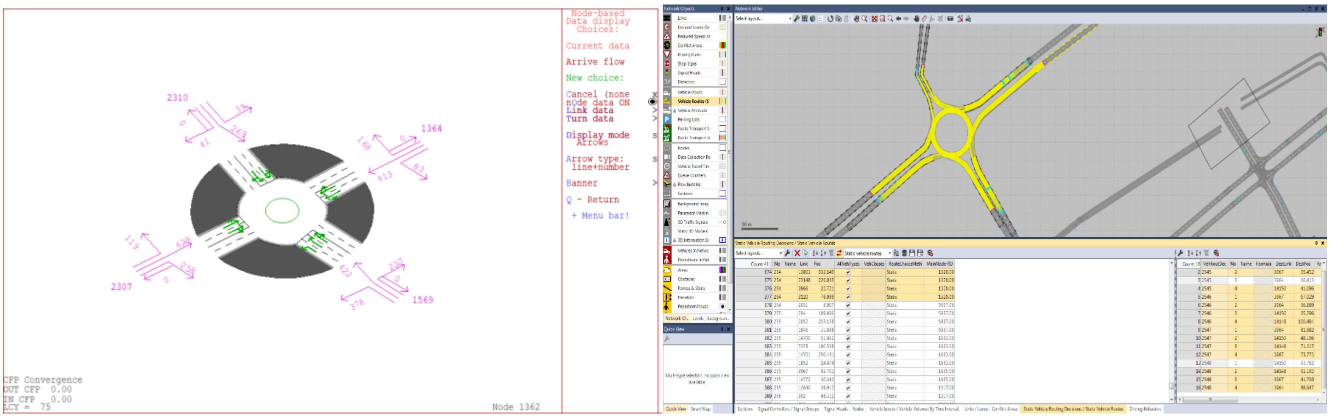

Figure 51 (Left) Shows values from the macroscopic Saturn model showing turn flows (Right) Shows those values added as static routing decisions into VISSIM

## 3.2 Description of the data utilized for the network

The data used to specify the demand is adopted from the Saturn model. The data from the Saturn OD matrix was used for assignment. The flows from the assignment results were then used as vehicle inputs into the Vissim model. There is a total of 220 external origins and simplified 146 input points into the model. These points are where the vehicles originate from into the model. The travel demand matrix used in the macro model Saturn from which the flows obtained are entered into Vissim. These values were obtained as part of travel survey conducted in 2009 and 2016. Furthermore existing 2015 and 2016 ATC data collected at 15-minute intervals was analysed for a representative sample of 13 locations as shown in Figure 52 and Figure 53.

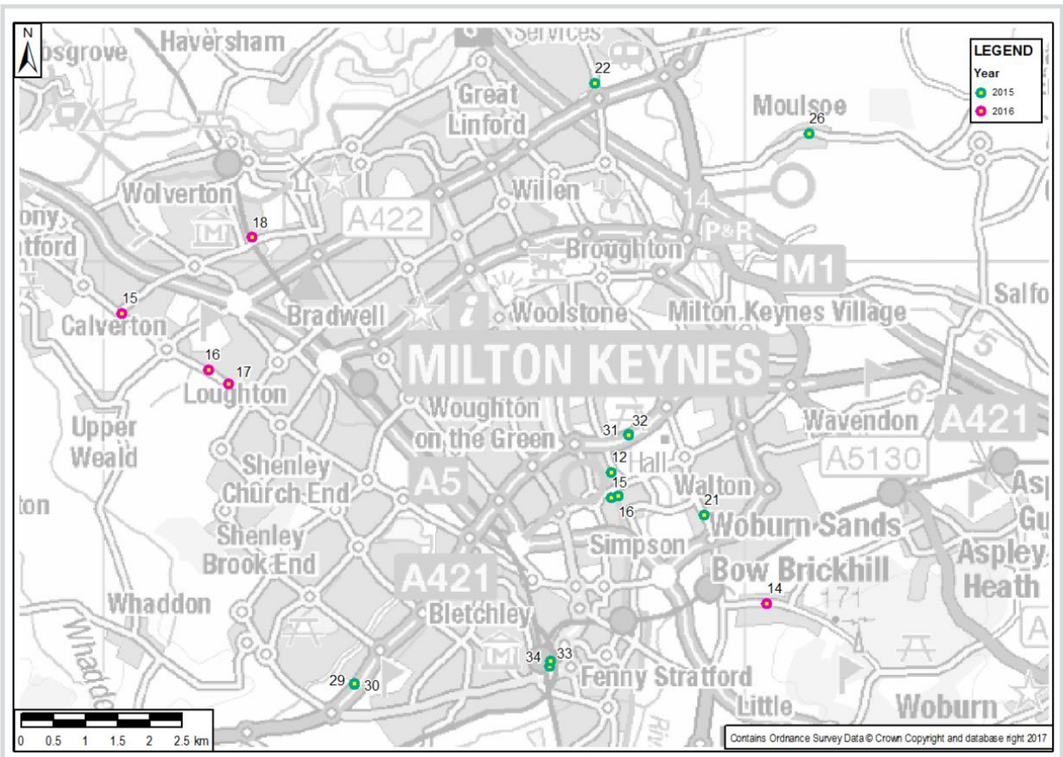


Figure 52 thirteen locations where travel survey was conducted

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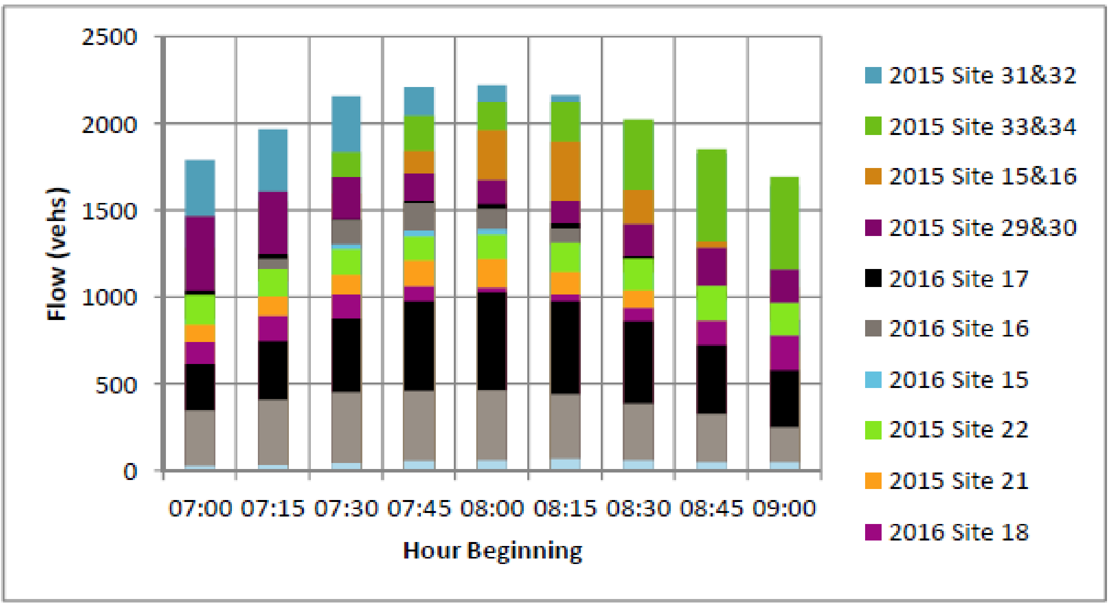


Figure 53 Distribution during the morning peak hour at survey sites

# 4 The traffic

## 4.1 Detailed description of the traffic and its implementation in the model

The current traffic situation can be seen in the highway models in VISUM and Saturn (Figure 54 and Figure 55). The total number of vehicles being added to the VISSIM model are 51697 / per sim hour with approximately 20000 going toward the wider MK area and 9000 going to central Milton Keynes.

The simulation is run for a period of 13000s. This ensures a warm-up and cool-down period. The AM period is for 3 hours of the morning. The system simulates the AM peak period times. The simulation

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resolution is kept at 10-time steps/sim sec. The simulation speed is set at max but averages out at 1.5 real hours to 1 simulated hour due to the number of agents in the model.


**Figure 54 Current traffic situation in Milton Keynes**

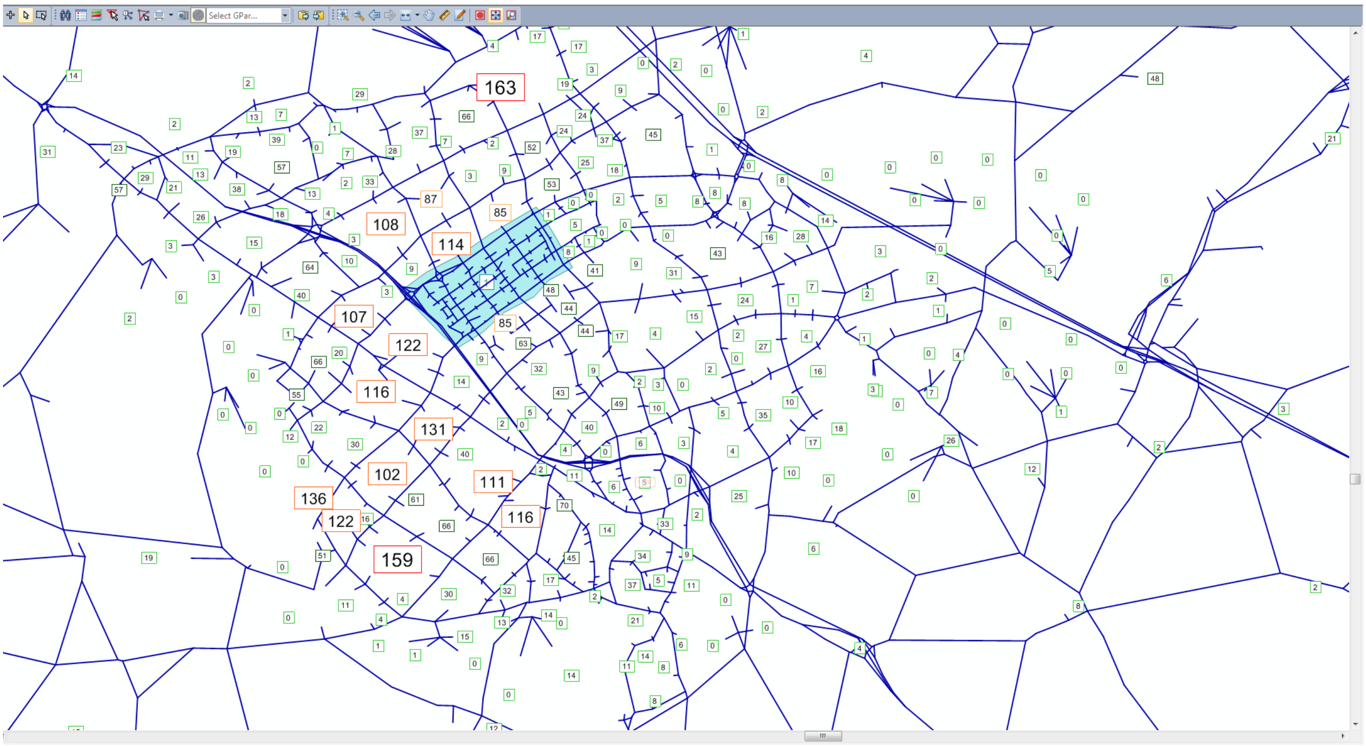

**Figure 55 Current traffic situation in Milton keynes origin of trips to the central area from external areas**

## 4.2 Description of the data utilized

The data used for the demand and supply of the network were the assignment results from the Saturn macroscopic model built in 2016. The flows are shown in the Figure 56.

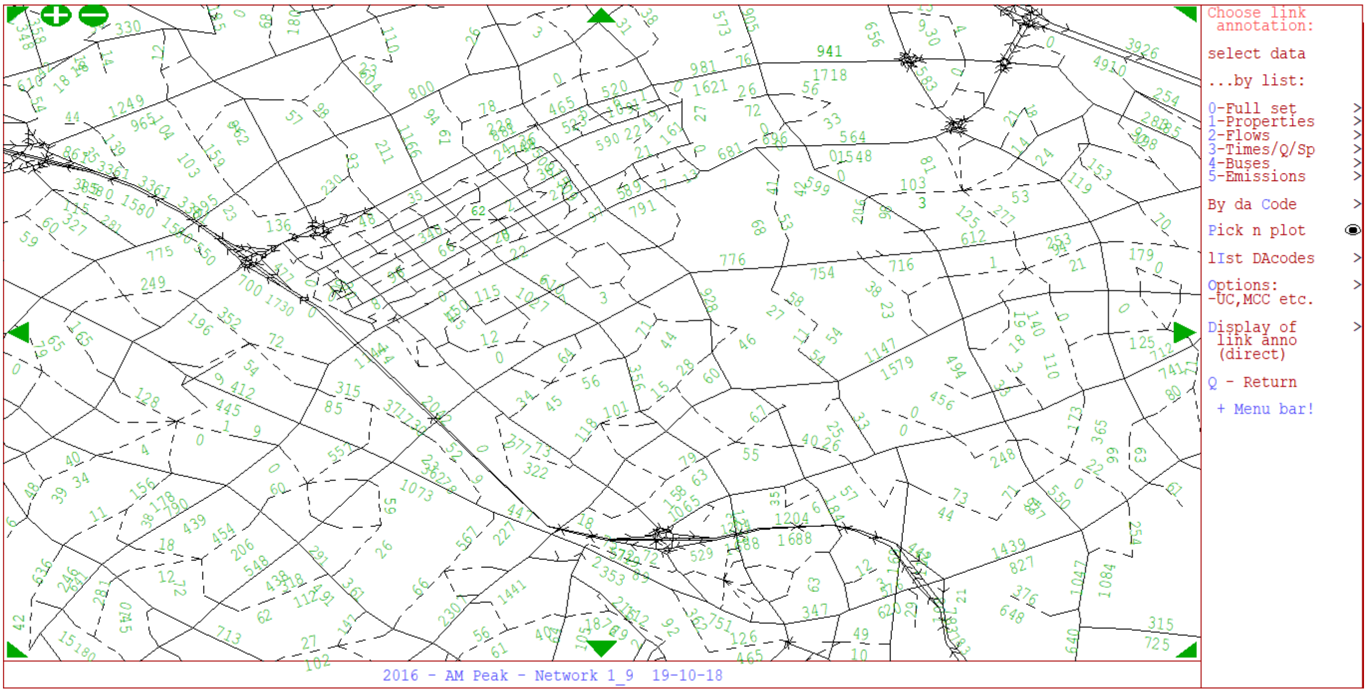


Figure 56 Flows used for demand and supply configuration in the microsimulation model

# 5 Verification

## 5.1 Verification process

During the model building a process a total of 9412 values were typed in manually. On top the model was built manually building every single intersection at a time and tracing geometric roads onto the background map. To keep human errors to a minimum all values were checked three times again by different individuals. Major roads and rules were Google street view verified multiple times during the model building process. For junctions that had been signalized between 2009 and June 2016 the green splits were based on the ratio of flows through the junctions. Signal plan was added from the Saturn macroscopic model into Vissim. Signal controller group, cycle times being in sync and placement of signal heads were verified through simulation runs of individual intersections.

The network coding such as link lanes and conflict area priority definition was added manually. Hence these were also QA verified by two other individuals who cycled through the network and once the model was completed and intersections joint together another verification stage was undertaken during which the modeller ensured any wrong conflict definition points that would be observed to be fixed.

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Each and every intersection and links were manually verified by adding demands at varying levels. The process commenced with low demand and gradually raised it up until 150% of the peak demand. These helped find errors in improper movement pattern at specific locations and even clogged intersections.

No extra functions were coded through the COM script for the baseline case.

## 5.2 Verification results

The process to verification was undertaken as the following loop of steps:

- 1. Simulate,
- 2. Verify,
- 3. Fix,
- 4. Isolate part of the network out and test individually,
- 5. Test complete network with fixed part,
- 6. Iterate.

Multiple errors emerged from the verification checks. There were 50 incorrect typed values that were fixed for static route choice turns. There were 11 FROM and TONODE incorrect values typed into Vissim from Saturn that were fixed. These errors were fixed by typing in the correct values into Vissim.

During verification there were 6 intersections that caused clogs and a ripple effect of clogs through the system. This would then not allow enough throughput in the model. There were also 10 incorrect turn movements geometrically leading to the wrong area which were fixed during the process. An example of an intersection that was verified and fixed is shown in the image below in Figure 57.

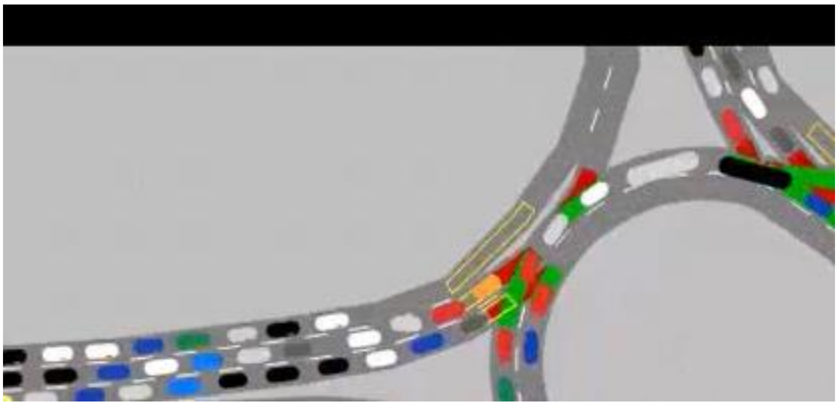

Figure 57 example clog badly coded network intersection roundabout that was verified and fixed

In house full day consultations were taken over the course of building the model with PTV experts. PTV experts visited to verify the model building process and provide feedback as how-to best approach the problems. They specifically verified priority rules, any modified values from default for the model and construction of the model geometry. The tests provide reasonable results and there does not seem to be any part that causes a problem now in the baseline model case. This whole procedure is deemed appropriate for investigating the behaviour and system effect.

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# 6 Calibration

## 6.1 Description of the calibration process

A total of 146 vehicle inputs were calibrated against the macroscopic model. The quality quotient is described as the model ability during one hour of simulation time that all the flows originating from vehicle input points should be able to enter within the same amount of passenger car units/hour (pcu/hr). This signifies that there are no unnecessary blockages and the input points are able to feed-in to the model accurately. By adding data collection measurements near the entry point of the146 input points the data was calibrated with Saturn data to ensure the optimum quality quotient.

## 6.2 Description of calibration result

This section describes the calibration result, for instance, how well the model output for the relevant performance metrics fit the measurements. Remember that results from stochastic models always should be presented by mean values and confidence intervals.


Figure 58 Pre-validation outcomes from calibrating vehicle inputs

# 7 Validation

## 7.1 Description of the validation process

To optimise the Vissim baseline model to best match the traffic situation the model was validated against Saturn macroscopic model assignment flow values pcu/hr. The reason these were used as they provide the best averaged out values for a peak hour in Milton Keynes. 778 data collection points were manually added into the Vissim model. These points collected data for 3 hours of simulation time. The pcu/hr value for every link where the data collection point was on was then compared to the Saturn values. The GEH standard and flow comparisons were used as performance metrics to validate the model. The GEH standard was calculated as follows:

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$$GEH = \sqrt{\frac{2(M - C)^2}{M + C}}$$

Where M was the hourly traffic volume from the Vissim baseline traffic model and C was the real-world hourly traffic count as depicted by the Saturn macroscopic assignment flow values. The aim was to validate 85% of the links to have a GEH under 5.

For flow comparisons the modelled Vissim flow were validated against the Saturn Vissim flow. For links Qobserved (Qobs) were Saturn flows while Qmodelled were the Vissim flow outputs. Where Qobs was < 700 the maximum allowable difference was 700. For Qobs 700-2700 the max difference was 15%. And for Qobs>2700 the maximum difference allowed was 400.

## 7.2 Description of validation result

The Vissim model results with a comparison on Saturn flows just for the central area is shown in Figure 59. The webtag standard in the UK requires 85% of the links to have less than 5 GEH value. The model averages out 1.0 value for GEH with 99% of the links having a value of GEH less than 5.

Flow checks showed that more than 99% of the results conform to the flow comparison standards. Where Qmodelled and Qobs were within required thresholds. The GEH results for all 778 data collection measurements are shown in Figure 59 and Figure 67.

**Figure 59 Comparison of flow values Qmodelled and Qobserved for validation**

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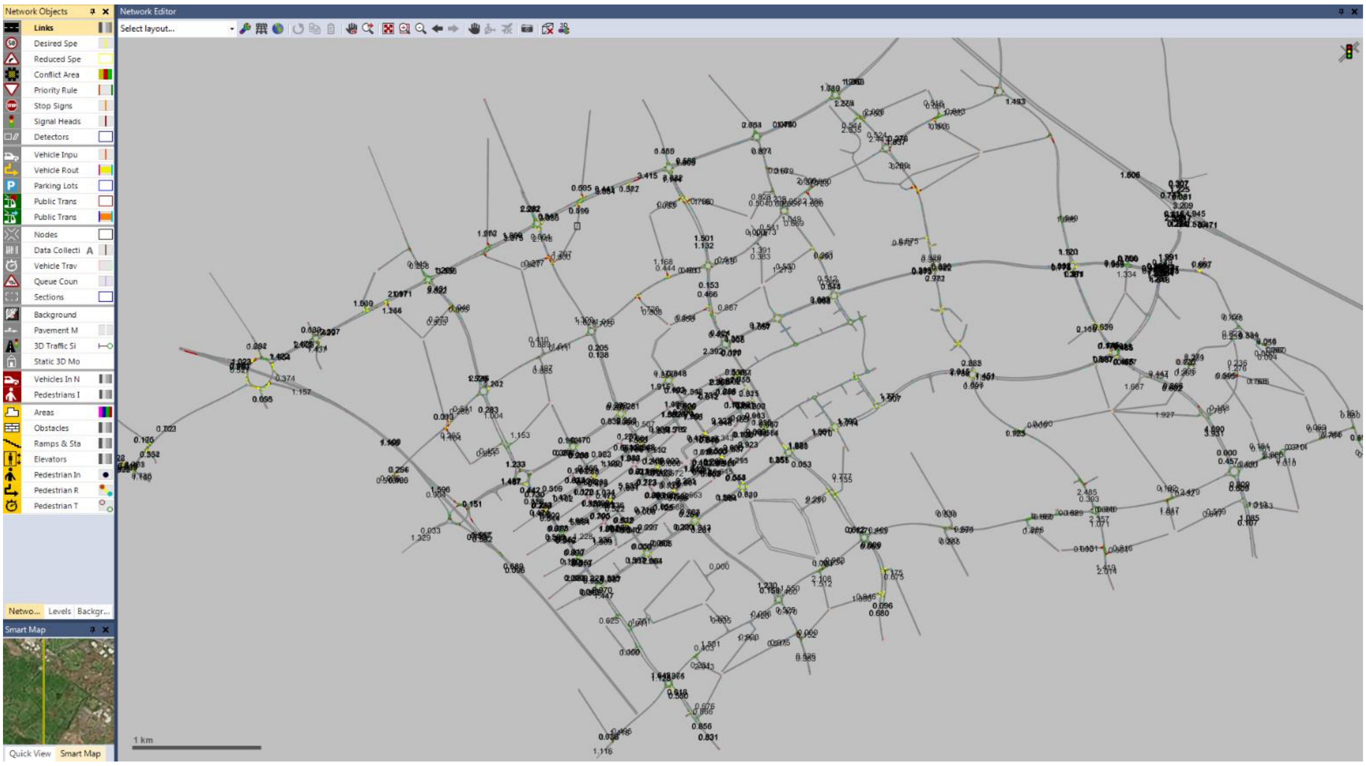


Figure 60 GEH values for all 778 data collection points in VISSIM

# 8 Results and conclusions

## 8.1 Conclusions of the verification-calibration-validation process

The verification-calibration-validation process had to be carried sometimes iteratively to be able to get the desired results. With the inputs fixed and the flows correlated the baseline model is an accurate representation of the real situation. To summarise the model is highly accurate. The GEH standard averages to 1 and the flows correlate at 99%. Given the size of the microscopic model it has been able to correlate well with the data sources that were present.

## 8.2 Handling of model uncertainty and/or limitation

As turning movements are defined at every intersection the possibility of changing end to end routing cannot be possible. The Vissim model size is quite extensive for a dynamic assignment to produce results that could converge and after considerable testing and consultations with PTV experts it was thought to be appropriate to carry out assignment in the macroscopic Saturn model and use Vissim for static routing hence dynamic rerouting by changing the OD matrix is not a possibility. However as in the case of cordoning of the centre area the model will be able to reroute cars to pick-up and drop off points.

# 9 Reference

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No. 723201

None

# Appendix E Use case 6: Loading and unloading areas for freight

# Baseline model for use case 6

## Priority Junction (roundabouts) Operation

Version: 1.0
Date: 2018-10-30
Authors: Brian Matthews, Ammar Anwar and Prof John Miles



This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No. 723201-2

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This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No. 723201

# 1 Introduction and background

## 1.1 Study area characteristics

The areas to modelled is located at H3 Monks Way Milton Keynes (CMK). This modelled area is approximately 2.5km by 1km covering three key roundabouts. The generic UK post code for the area is MK14 6GD. The area of interest is displayed in Figure 61 below.

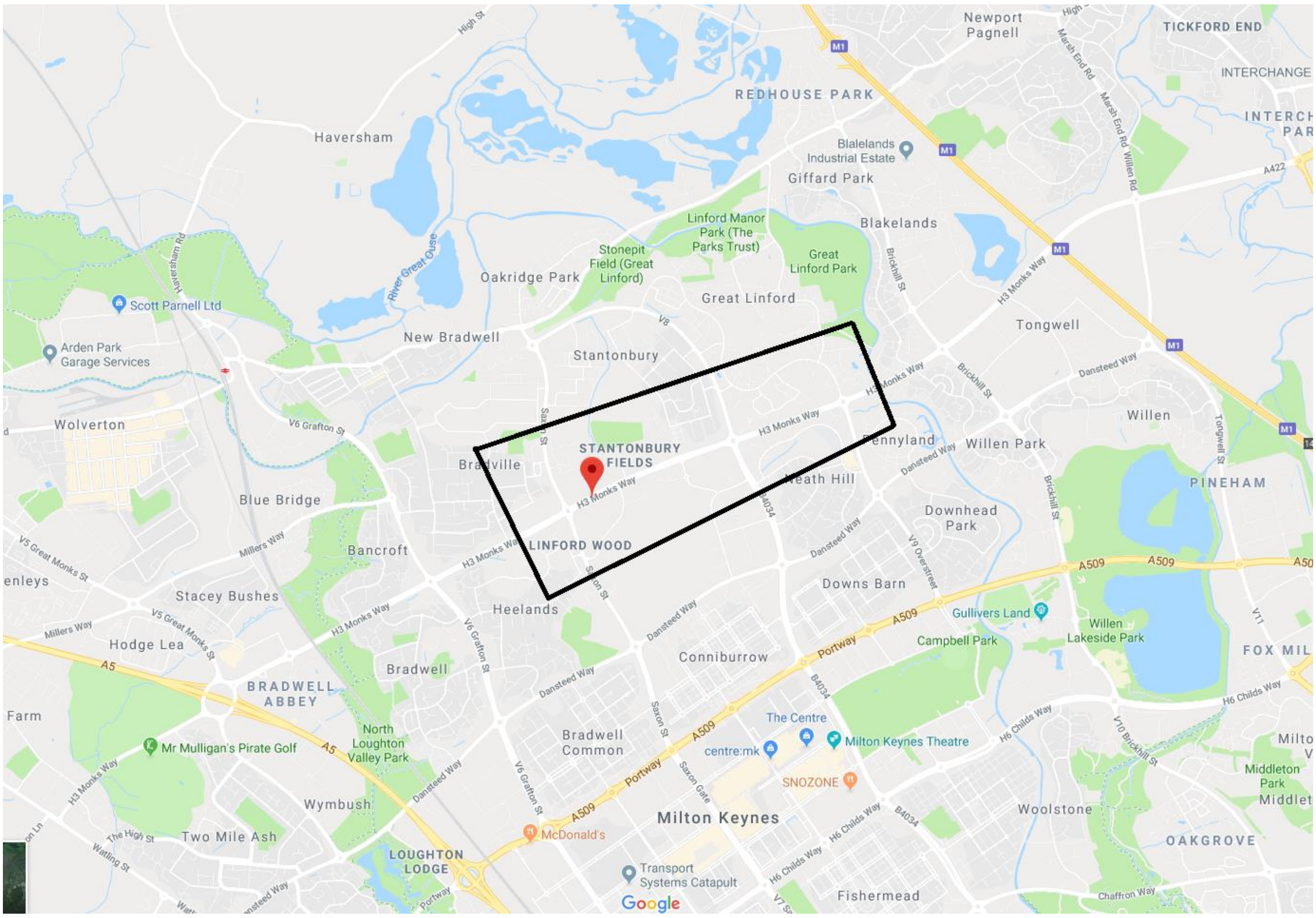


**Figure 61 Area of interest**

Milton Keynes (MK) is a city located in Buckinghamshire, England. The Milton Keynes administrative area includes the city of Milton Keynes and surrounding boroughs displayed in Figure 46 by the red boundary line.

The city centre provides the economic hub with 30,000 employees, regional retail facilities and leisure activity. The city is served by the national rail network with services from London, Birmingham, North of England, and Scotland. There are a relatively low number of residential properties areas within the centre area.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No. 723201

There is a focus of public transport operation through the central spine route – Midsummer Boulevard. The centre has around 25,000 parking spaces. The Highway typically has a speed limit of 30mph (48kph) having mainly four lane carriageways with some bus priority. Outside the city centre area highways are generally high quality high speed links (60 or 70 mph) with segregated cycle lanes and grade separated pedestrian crossings. Intersection are typically roundabouts with side road priority T junctions. There is limited bicycle infrastructure within the city centre.

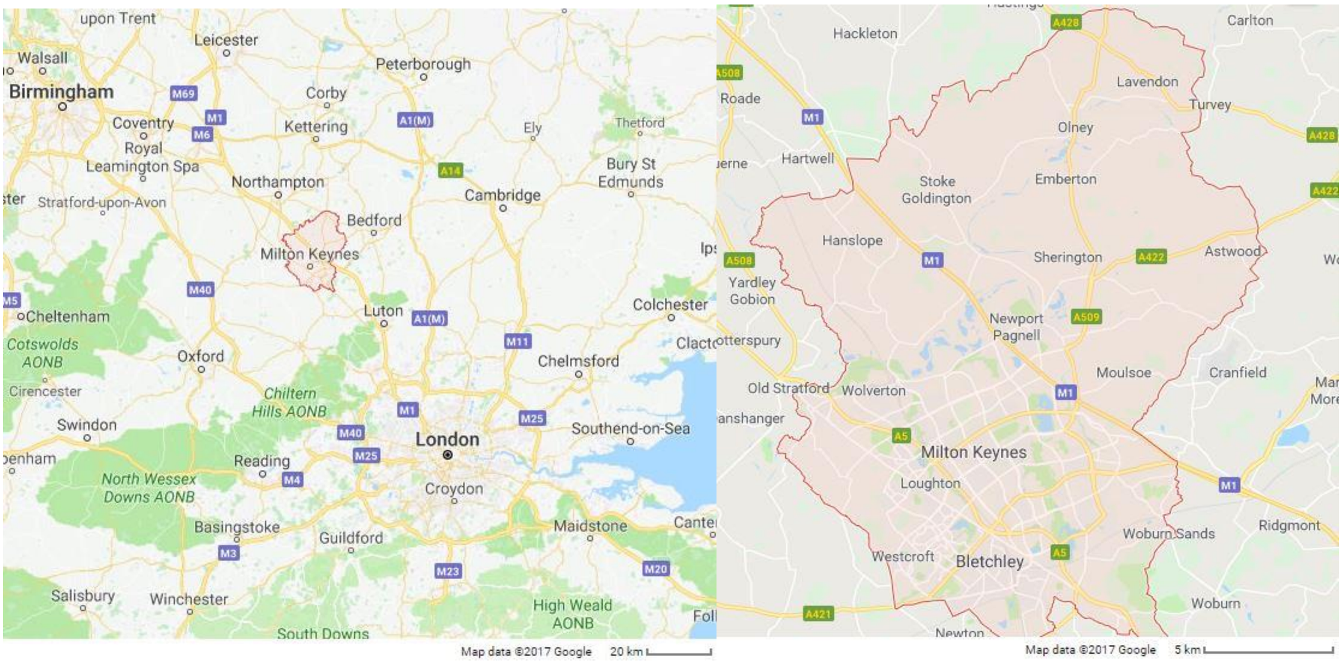


**Figure 62 Milton Keynes administrative area**

The city has an autonomous Pod (automated last mile service) network defined in anticipation of services starting in 2018. A Pod is a low speed autonomous vehicle generally designed to work in road and off-road spaces and with a high degree of interaction between pedestrians and the built environment. See link for further information: https://ts.catapult.org.uk/innovation-centre/cav/cav-projects-at-the-tsc/self-driving-pods/. Private car is the main mode of transport. The current modal split from surveyed data of 2017 is presented in Figure 63. Modes to be modelled for the purpose of this use case are cars and heavy goods vehicles (HGVs).

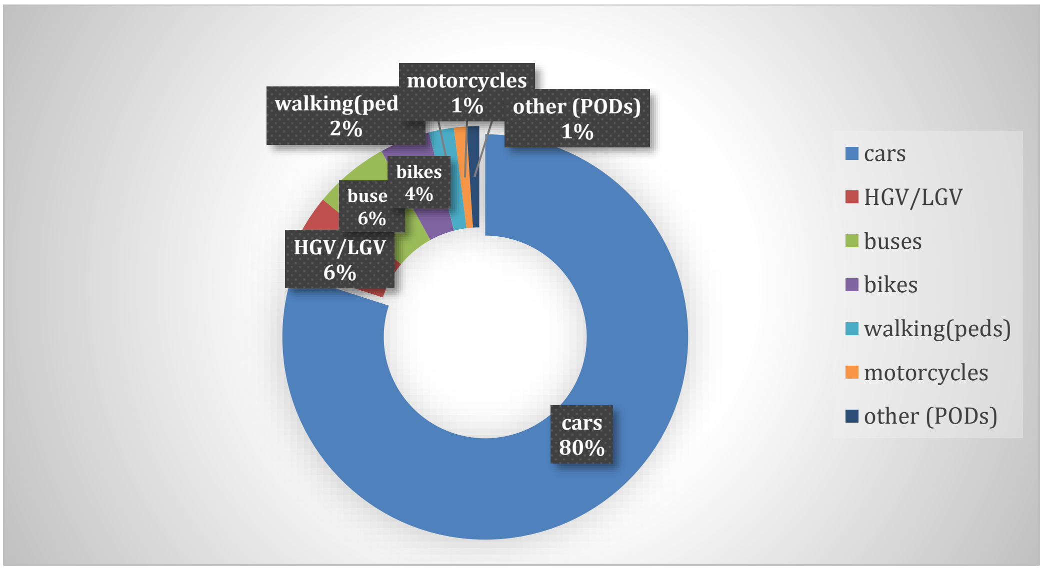


Figure 63 Modes of transport prevalent within the city

### 1.2 Questions to be investigated by applying the modelling approach

The following questions will be investigated in this use case:

- What is the effect on congestion on the roundabouts during the different stages of CAV's?
- Gap acceptance for intersections?
- Facilities to assist passive CAVS (lane allocation)?

# 2 Scope and modelling approach

## 2.1 Type of model

The H3 monks way model for the purpose of CoEXist is being built within Vissim software using real traffic OD values and signal times from 2016 surveyed data. Base scenario road network to modelled will be the current situation that means all cars will have normal non-AV behaviours. The exact road network that will be modelled is highlighted below.


Figure 64 Road network built in Vissim for modelling the usecase

## 2.2 The area and the level of detail of the model for base scenario

The area has a mix of roundabouts varying by busyness. There are no traffic signals. The side road junctions within Milton Keynes based on a grid network and the model is a stretch of road from the grid. The H3 is a dual carriage way is amongst the busiest roads within Milton Keynes during the morning peak period. There are no bus priority lanes. There are a very low number of dedicated cycle paths across the city. All pedestrian routes within Milton Keynes are segregated with underpasses available at all highway junctions.

The model will be a microsimulation model being built in VISSIM. The baseline model is comprehensive enough to carry out investigations on intersections and roundabouts. It covers the dual carriage way along the H3 and other parts of dual carriage on opposite end of the roundabouts. It essentially models all four legs of the roundabouts. The adapted model will then be exercised to investigate the effectiveness of the measure and how the penetration of AVs will affect roundabouts using H3 as a use case. The initial concept is that the intersections improvements will be at a modest scale to respect the environment they are operating/located. Designs and scale of the intersections will be influenced by demand, operational capabilities of the vehicles, safety, mode share and air quality improvements.

The modelling work will proceed in the following sequence:

- Network coding,
- Verification,
- Calibration & validation,
- Development of measures on top of base model,
- Exercise adapted model to explore the potential for AV's to alleviate congestion at intersections.

## 2.3 Included and excluded in the model of base scenario

All legs of the roundabouts are included in the model. Traffic flows at peak demand during AM time is included. As the network modelled area outlined in Figure 64 does not contain many bikes or pedestrian journeys being more arterial rather than urban in nature it is statistically insignificant to add these modes.

Within the baseline model any measures such as new approach lanes, lane allocation between modes or any intersection control measure is not simulated. Other exclusions are the small inner urban roads which are near the feed-in point zones.

# 3 The network

## 3.1 Detailed description of the network and how it is modelled

The Vissim network that is built is not converted from VISUM or automated through OSM but built internally within Vissim. This is done to provide a good check where individual roundabouts are tested for bottlenecks or errors by applying maximum flows to them. The network is built a single intersection at a time and then all of them are interconnected together.

There is a total of 54 links including connectors in the model. The link behaviour types for non-AVs are set to VISSIM default values. The conflict areas are 100. With the default frontGapDef[7] and RearGapDef set at 0.4s while the SafDistDef at 1.5s. The anticipated route is set at 50.0% and avoidBlockminor is set to 90.0%. Conflict areas are defined manually according to the right of way established within the city. Driving behaviour parameter values such as look ahead distance and look back distance are set to default for the baseline model.

The turns are added as static routes from the flows in the macroscopic model. The turns are coded with the relative proportions at every intersection ensuring the exact flows across the network. These relative proportion flow values are obtained from the macroscopic Saturn model. The total number of static routing decisions added within Vissim are 74.

[7] Please refer to the Vissim user manual for the definition of parameters.

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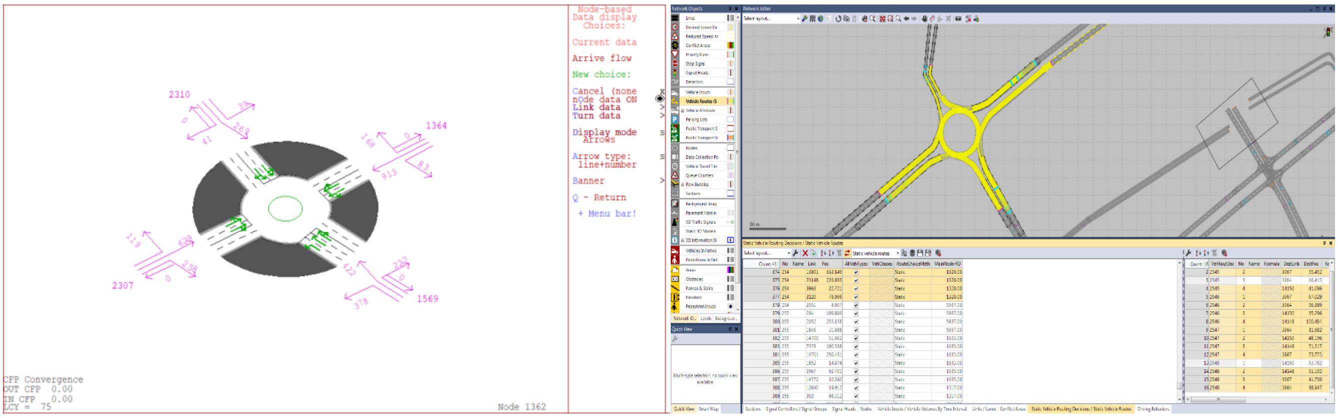

Figure 65 (Left) Shows values from the macroscopic Saturn model showing turn flows (Right) Shows those values added as static routing decisions into VISSIM

## 3.2 Description of the data utilized for the network

The data used to specify the demand is adopted from the Saturn model. The data from the Saturn OD matrix was used for assignment. The flows from the assignment results were then used as vehicle inputs into the Vissim model. There is a total of 11 external origins input points into the model. These points are where the vehicles originate from into the model. The travel demand matrix used in the macro model Saturn from which the flows obtained are entered into Vissim. These values were obtained as part of travel survey conducted in 2009 and 2016. Furthermore existing 2015 and 2016 ATC data collected at 15-minute intervals was analysed for a representative sample of 13 locations as shown in Figure 66.

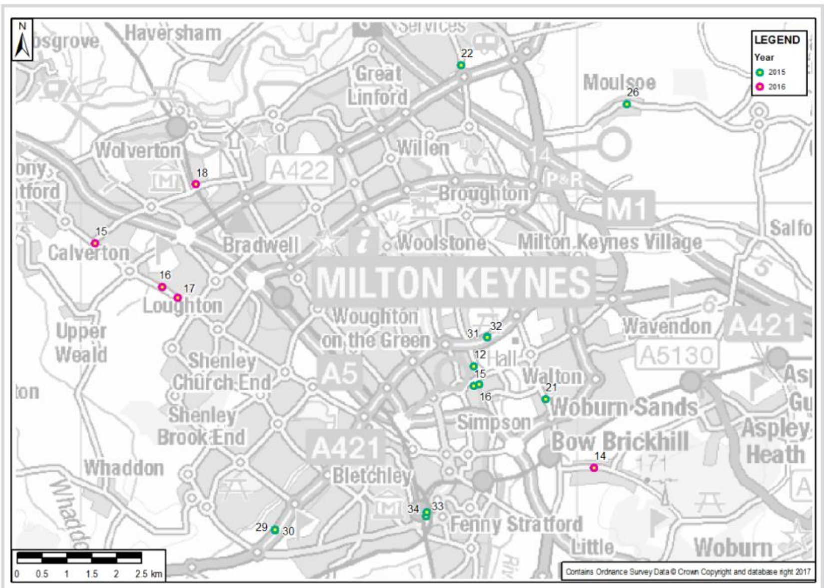


Figure 66 thirteen locations where travel survey was conducted

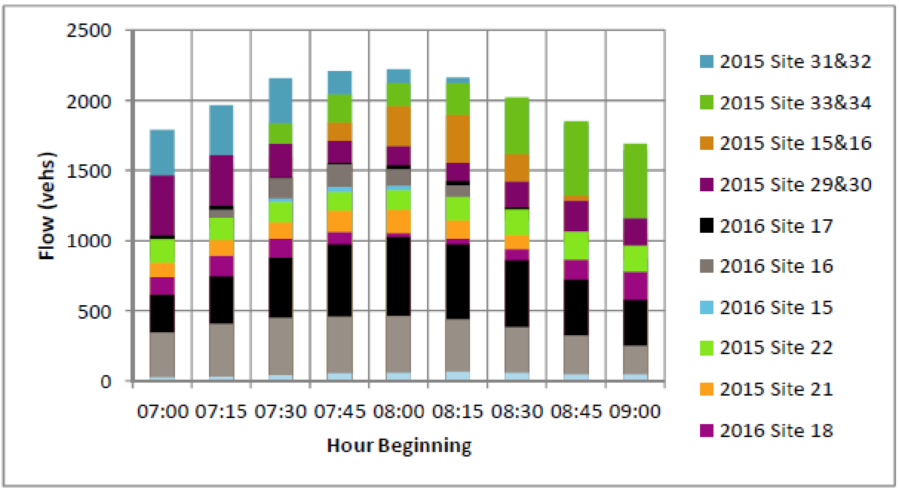


Figure 67 Distribution during the morning peak hour at survey sites

# 4 The traffic

## 4.1 Detailed description of the traffic and its implementation in the model

The current traffic situation can be seen in the highway models in VISUM and Saturn (figure11 and 12). A total number of approximately 20000 vehicles are going toward the wider MK area and 9000 going to central Milton Keynes.

The simulation is run for a period of 13000s. This ensures a warmup and cool down period. The AM period is for 3 hours of the morning. The system simulates the AM peak period times. The simulation resolution is kept at 10 time steps/sim sec. The simulation speed is set at max.


Figure 68 Current traffic situation in Milton Keynes

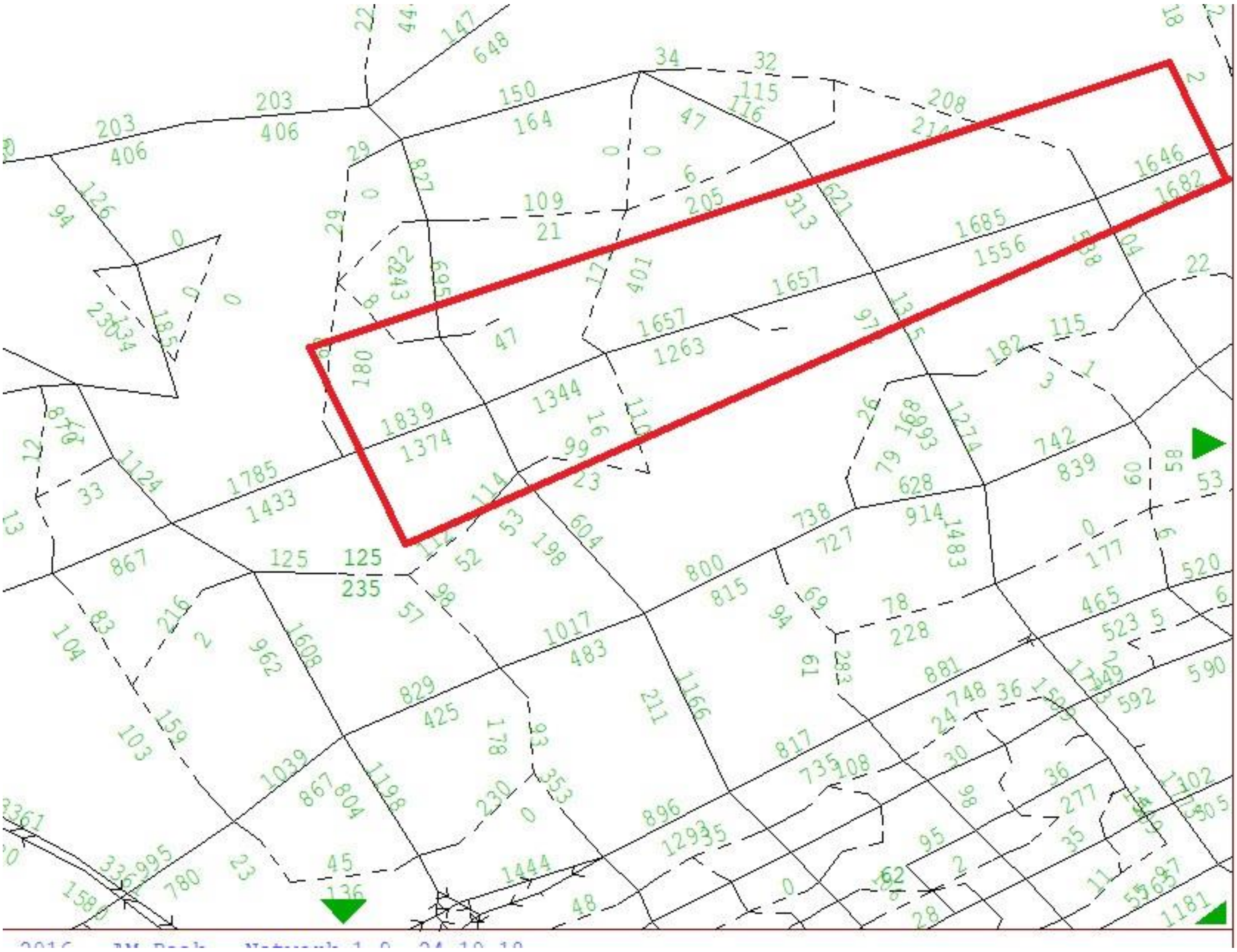

Figure 69 Current traffic situation for the area that is being modelled

## 4.2 Including description of the data utilized

The data used for the demand and supply of the network were the assignment results from the Saturn macroscopic model built in 2016. The flows are shown in the Figure 70.

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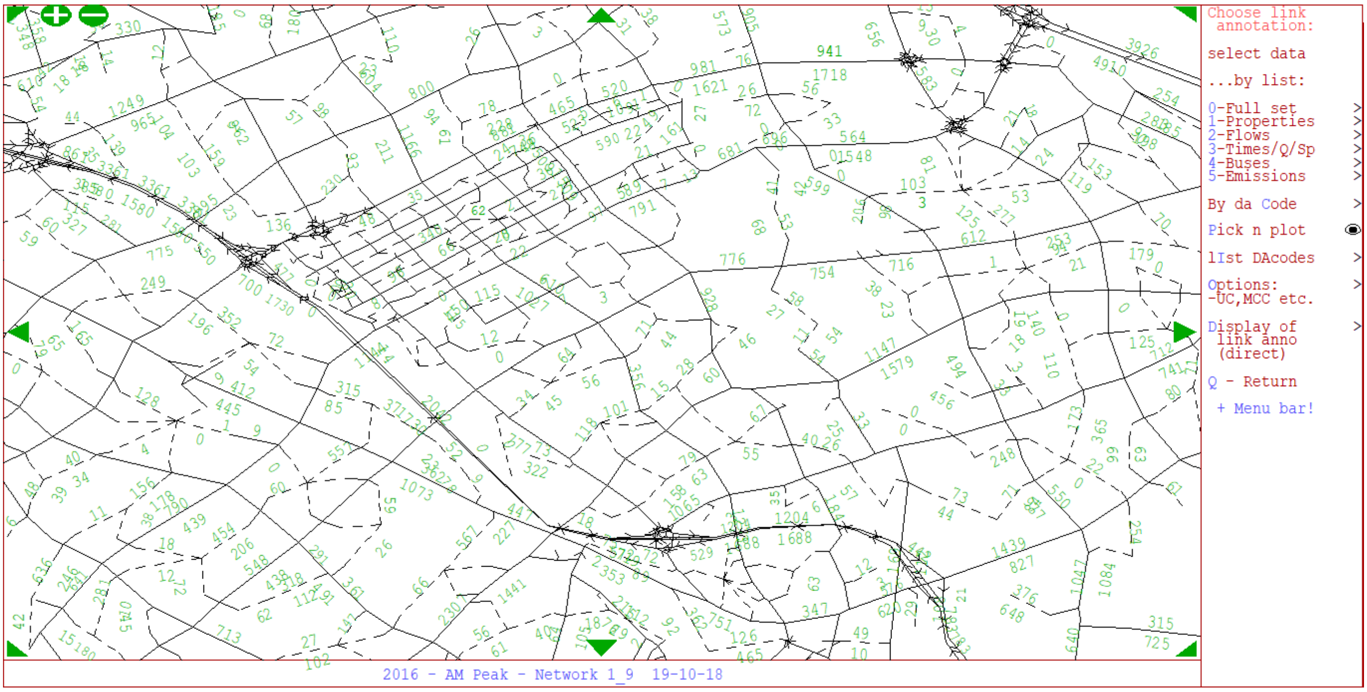


Figure 70 Flows used for demand and supply configuration in the microsimulation model

# 5 Verification

## 5.1 Verification process

During the model building a process values were typed in manually. On top the model was built manually building a single intersection at a time and tracing geometric roads onto the background map. To keep human errors to a minimum all values were checked three times again by different individuals. Major roads and rules were Google street view verified multiple times during the model building process.

The network coding such as link lanes and conflict area priority definition was added manually. Hence these were also QA verified by two other individuals who went through the network. Once the model was completed and intersections joint together another verification stage was undertaken during which the modeller ensured any wrong conflict definition points that would be observed to be fixed.

Each and every intersection and links were manually verified by adding demands at varying levels. The process commenced with low demand and gradually raised it up until 150% of the peak demand. These helped find errors in improper movement patterns at specific locations and even clogged intersections.

No extra functions were coded through the COM script for the baseline case.

## 5.2 Verification results

The process to verify was undertaken as the following loop of steps:

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- Simulate,
- Verify,
- Fix,
- Isolate part of the network out and test individually,
- Test complete network with fixed part,
- Iterate.

Multiple errors emerged from the verification checks. There were 2 incorrect typed values that were fixed for static route choice turns. There was 1 FROM and TONODE incorrect values typed into Vissim from Saturn that were fixed. These errors were fixed by typing in the correct values into Vissim.

During verification there was 1 incorrect turn movements geometrically leading to the wrong area which were fixed during the process. An example of an intersection that was verified and fixed is shown the image below in Figure 71.

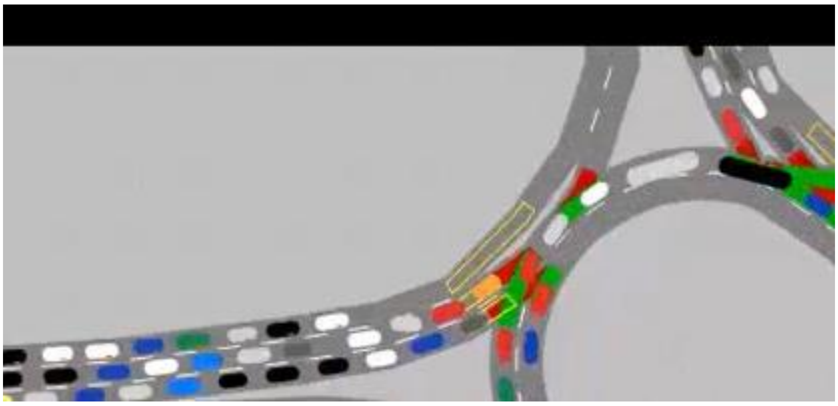

Figure 71 example clog badly coded network intersection roundabout that was verified and fixed

In house full day consultations were taken over the course of building the model with PTV experts. PTV experts visited to verify the model building process and provide feedback as how-to best approach the problems. They specifically verified priority rules, any modified values from default for the model and construction of the model geometry. The tests provide reasonable results and there does not seem to be any part that causes a problem now in the baseline model case. This whole procedure is deemed appropriate for investigating the behaviour and system effect.

# 6 Calibration

## 6.1 Description of the calibration process

A total of 11 vehicle inputs were calibrated against the macroscopic model. The quality quotient is described as the model ability during one hour of simulation time that all the flows originating from vehicle input points should be able to reach within the same amount of passenger car units per hour (pcu/hr). This signifies that there are no unnecessary blockages and the input points are able to feed-in to the model accurately. By adding data collection measurements near the entry point of the 11 input points the data was calibrated with Saturn data to ensure the optimum quality quotient.

## 6.2 Description of calibration result

This section describes the calibration result, for instance, how well the model output for the relevant performance metrics fit the measurements. Remember that results from stochastic models always should be presented by mean values and confidence intervals.

The calibration procedure was carried out iteratively for the run for all the 3 hours of simulation time. During this period values were observed averaged across the 3 hours. The final calibration results showed that the quality quotient was at 100% for the average value.

# 7 Validation

## 7.1 Description of the validation process

To optimise the Vissim baseline model to best match the traffic situation the model was validated against Saturn macroscopic model assignment flow values pcu/hr. The reason these were used as they provide the best averaged out values for a peak hour in Milton Keynes. 28 data collection points were manually added into the Vissim model. These points collected data for 3 hours of simulation time. The pcu/hr value for every link where the data collection point was placed was then compared to the Saturn values. The GEH standard and flow comparisons were used as performance metrics to validate the model. The GEH standard was calculated as follows:

$$GEH = \sqrt{\frac{2(M-C)^2}{M+C}}$$

Where M was the hourly traffic volume from the Vissim baseline traffic model and C was the real-world hourly traffic count as depicted by the Saturn macroscopic assignment flow values. The aim was to validate 85% of the links to have a GEH under 5.

For flow comparisons the modelled Vissim flow were validated against the Saturn Vissim flow. For links Qobserved (Qobs) were Saturn flows while Qmodelled were the Vissim flow outputs. Where Qobs was < 700 the maximum allowable difference was 700. For Qobs 700-2700 the max difference was 15%. And for Qobs>2700 the maximum difference allowed was 400.

## 7.2 Description of validation result

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The Saturn Vissim model results with a comparison on Saturn flows just for the central area is shown in the figure below. The webtag standard requires 85% of the links to have less than 5 GEH value. The model averages out 1.0 value for GEH with 99% of the links having a value of GEH less than 5.

Flow checks showed that more than 99% of the results conform to the flow comparison standards. Where Qmodelled and Qobs were within required thresholds. The GEH results for all 28 data collection measurements are shown in Figure 72.

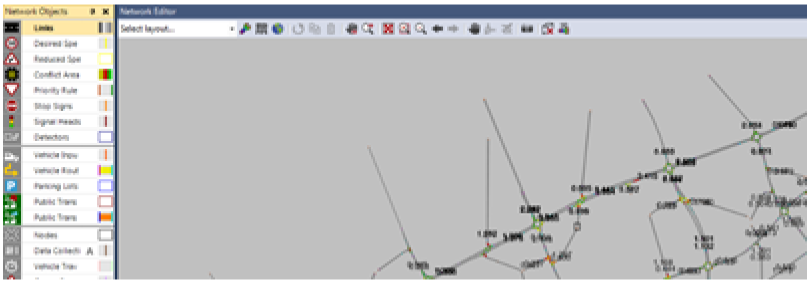

Figure 72 GEH values for all 28 data collection points in VISSIM

# 8 Results and conclusions

## 8.1 Conclusions of the verification-calibration-validation process

The verification-calibration-validation process had to be carried sometimes iteratively to be able to get the desired results. With the inputs fixed and the flows correlated the baseline model is an accurate representation of the real situation. To summarise the model is highly accurate. The GEH standard averages to 1 and the flows correlate at 99%.

## 8.2 Handling of model uncertainty and/or limitation

As turning movements are defined at every intersection the possibility of changing end to end routing cannot be possible. Dynamic rerouting by changing the OD matrix is not a possibility. However as in the case of introducing measures such as specific lanes at approaching junctions there is a possibility to reroute cars to those lanes.

# 9 Reference

None.

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# Appendix F Use case 7: Impacts of CAV on travel time and mode choice on a network level; and Use case 8: Impact of driverless car- and ridesharing services

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# Baseline model for use case 7 and 8

## Impacts of CAV on travel time and mode choice on a network level

## Impact of driverless car- and ridesharing services

Version: 1.0

Date: 2018-10-30

Author: Markus Friedrich and Jörg Sonnleitner



This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No. 723201-2

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This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No. 723201

# 1 Introduction and background

Since use case 7 and use case 8 will use the same baseline macroscopic model, the baseline model description of these two use cases are merged together. CAV may increase the capacity of road infrastructure. Using the Stuttgart Region Travel Demand Model SRTDM, within CoEXist project the following research questions will be investigated: To what extent the road capacity increases, which is expected to be higher on motorways than in urban areas and how it will affect travel time and mode choice on a network level. The hypothesis is that increased capacity and higher safety will reduce journey time and increase travel time reliability. This may also improve the general utility of the car, as drivers can use their in-vehicle time more efficiently. Introduction of a CAV-ready road network and an extension of it are measures that might be investigated.

Driverless cars will provide new choices to travellers as car- and ridesharing services can be organized in new ways which even may affect urban public transport. An extended version of the existing travel demand model of the Stuttgart Region will be used to examine the potentials of driverless cars for automated car- and ride-sharing services and their impact on public transport and urban traffic flow. In addition to this the use case will also investigate differences in impacts of public transport integrated vs. private competing ridesharing services and how many privately-owned cars can be replaced by a high-performance car- or ridesharing service.

## 1.1 Study area characteristics

The study area for this use case covers the entire Stuttgart Region, an area with 2.7 million inhabitants. Figure 73 shows a map of the study area.

Stuttgart is the capital of the state of Baden-Württemberg and forms with about 180 other cities and smaller towns in five counties the Stuttgart Region. This Region is the economic centre of the state with one quarter of the state's population and nearly one third of the economic power on 10% of the land's space.

Furthermore, Stuttgart City is the cultural and political centre of the region. It is the home of several large international companies (Bosch, Daimler and Porsche), two universities and several polytechnics. It offers a large number of workplaces in the service and industry sector. Stuttgart central station, Stuttgart airport and Stuttgart harbour connect Stuttgart and the Region to other places in Germany and Europe.

Important current modes for person transport in the study area are walking, cycling, public transport, car driver and car passenger. Figure 74 shows the modal split for the City of Stuttgart and the Stuttgart Region. Beside these main modes, a set of mobility services are provided by private organisations:

- Public bike sharing system Call-a-Bike
- Station-based carsharing Stadtmobil with approx. 500 cars
- Free-floating carsharing Car2Go with approx. 500 electric cars
- Free-floating carsharing Flinkster

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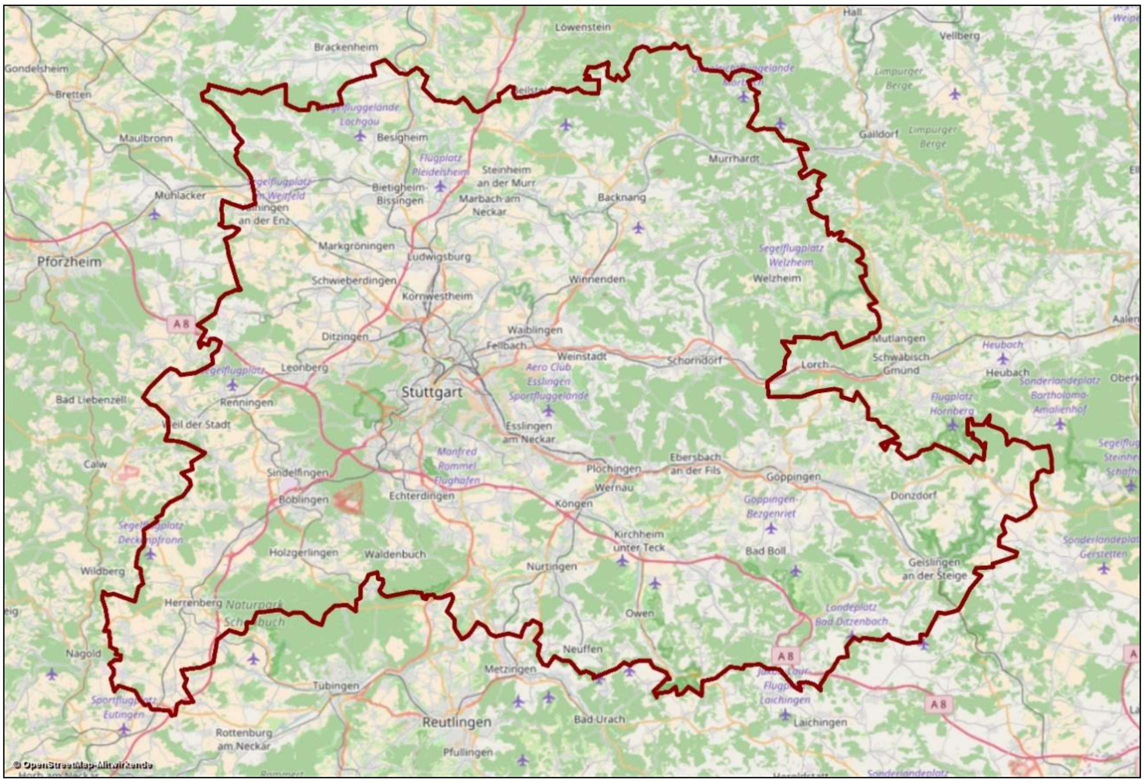

Figure 73: Study area Stuttgart Region (Source: SRTDM / OpenStreetMap)

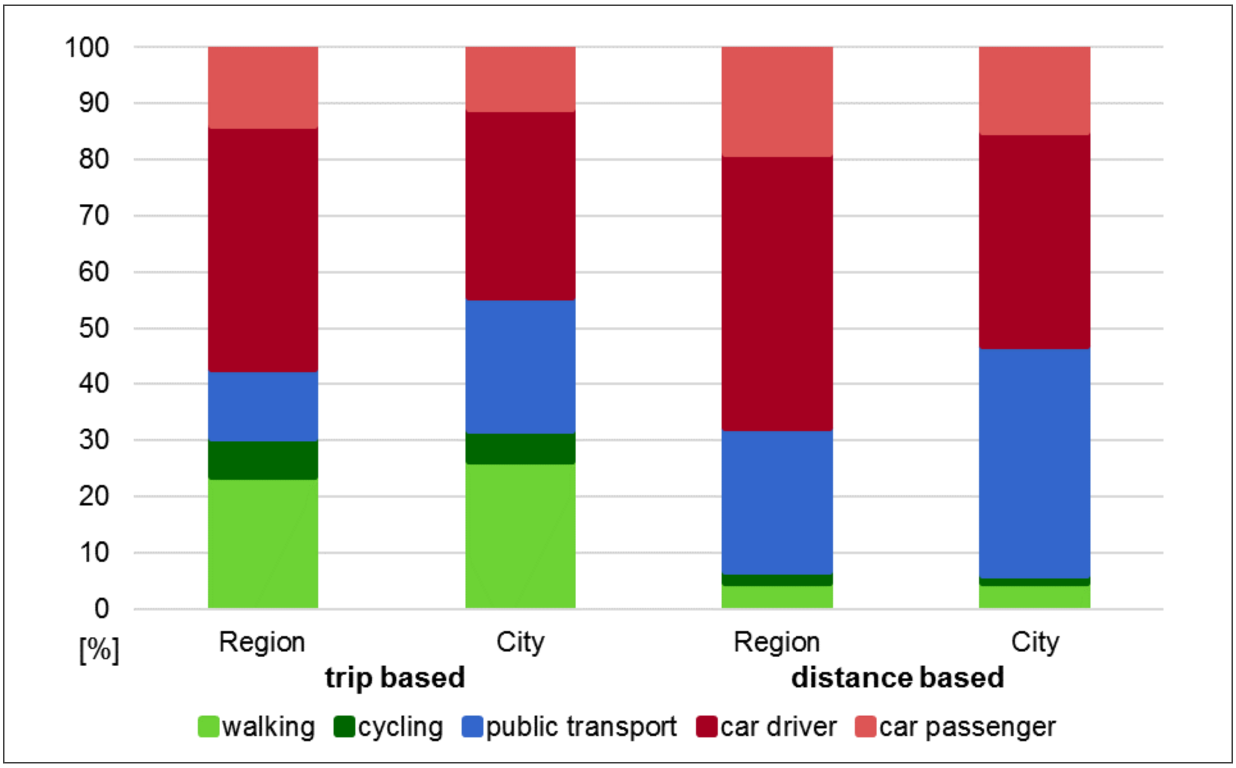


Figure 74: Modal Split for the inhabitants of Stuttgart City and the entire Region (Source: SRTDM)

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## 1.2 Questions to be investigated by applying the modelling approach

**Use Case 7**

Stuttgart City requires information to what extend the introduction of CAV will decrease or increase the road capacity, car travel demand and the level of congestion within the Stuttgart City limits and the Stuttgart basin for scenarios with different penetration rates and CAV levels. Use case 7 will investigate the following questions:

- Road capacity: What changes can be expected on motorways, on urban arterials and on urban roads with mixed traffic. Can a capacity increase reduce congestion levels and provide more reliable travel times?
- Route choice: To what extent will changes in travel time and the suitability of certain road types for CAV influence route choice? Can a higher reliability on motorways surrounding Stuttgart reduce through traffic in the City?
- Mode choice: CAV will only be successful, if they provide a benefit to the car user. CAV promise that drivers can use their in-vehicle time more efficiently and that valet parking makes parking easier. Will more comfortable cars cause a shift in mode choice leading to more car traffic?

Use case 8 will investigate the following questions:

Developing urban public transport requires long term planning processes. Stuttgart City and the public transport operator are interested in better understanding the impacts of driverless sharing systems on public transport and on required street parking places:

- What impact will the introduction of car- or ridesharing services have on modal split?
- What impact will the introduction of car- or ridesharing services have on traffic volumes?
- What are the differences between the impacts of public vs. private ridesharing services?
- How many privately-owned cars can be replaced by a high-performance car- or ridesharing service?
- Which price levels are economically feasible for car- or ridesharing services?

# 2 Scope and modelling approach

## 2.1 Type of model

Both Stuttgart use cases will utilise an existing macroscopic travel demand model for the Stuttgart Region. The model has the following characteristics:

- Modelling Software: PTV Visum 15 - 17
- Base year: The model is calibrated and validated for the year 2010. The model was updated for the year of 2015 with the latest land use data and finalised infrastructure measures.
- Forecast year: 2025. This year is used for the baseline model for CoEXist. The baseline model contains all planned infrastructure measures and demographic changes that can be expected by 2025.
- Population: The travel demand model replicates the trips of the 2.7 million inhabitants of the region.
- Traffic zones: 1,175 zones.
- Modes: The modes included to date are car driver, car passenger, public transport, walking, cycling, Park & Ride and six HGV modes. For the baseline scenario, CAV are not available.
- Person groups: 23.
- Trip purposes: 19.
- Model type: Activity-chain-based model, with simultaneous destination and mode choice.
- Highway Assignment: Deterministic User Equilibrium, 7 user classes.
- Public Transport Assignment: Timetable-based, one user class.
- Temporal segmentation: The model describes the demand of an average working day. It is a static 24-hour model without any temporal segmentation. It contains desired departure times for each trip purpose. With this data it is possible to compute hourly demand matrices for each mode.

## 2.2 The area and the level of detail of the model for base scenario

The area and the level of detail of the model are the same for all scenarios within Use Case 7 and 8. The 1175 zones of the model can be divided into five classes as shown in Figure 75. The zones in the outer area whose shape is not shown in detail represent important locations for generating and attracting external traffic.

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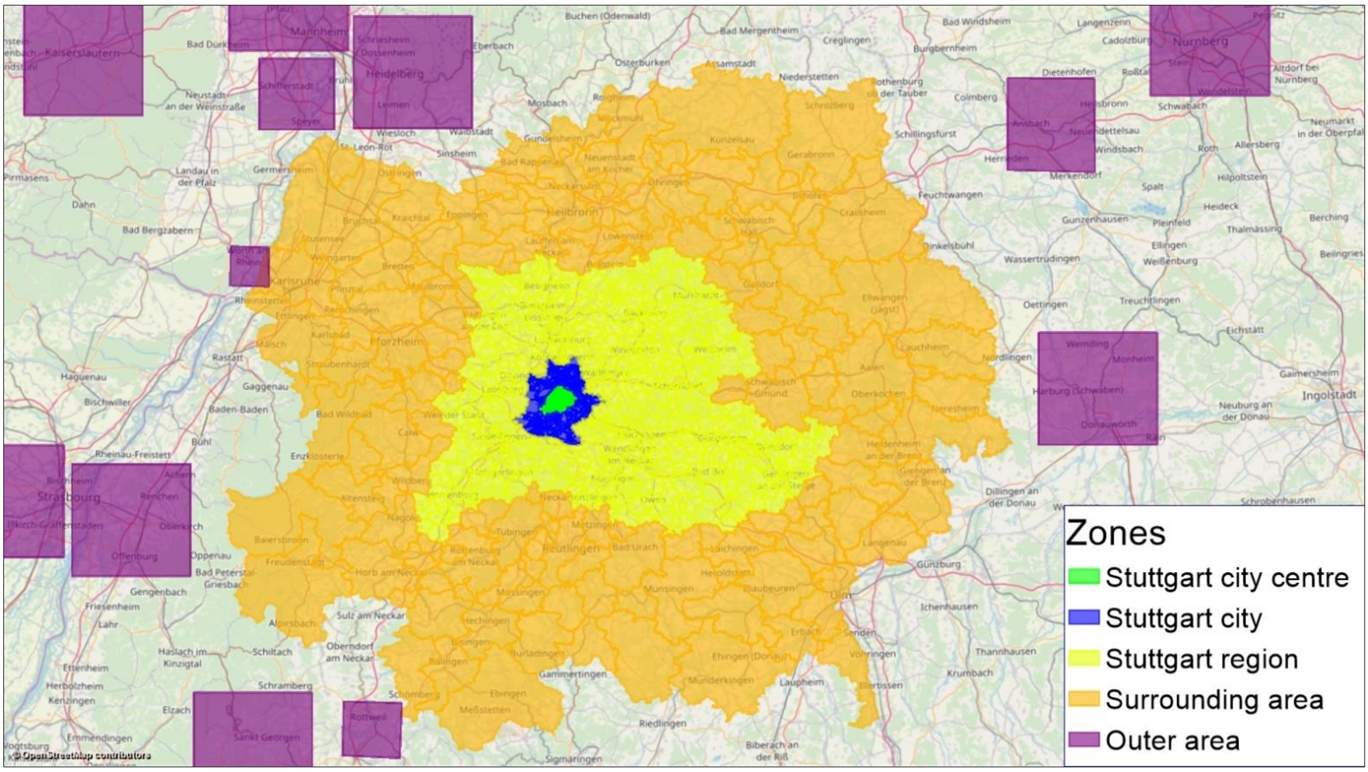

Figure 75: Overview of the area in the Stuttgart model (Source: SRTDM / OpenStreetMap)

As distance from the city centre increases, the level of detail of traffic zones and links decreases (see Figure 76 and Figure 77). The number of zones for each class is as follows:

- Stuttgart city centre 173
- Stuttgart city 340
- Stuttgart region 500
- Surrounding area 136
- Outer area 26

Stuttgart region represents the study area for Use Case 7 and 8.

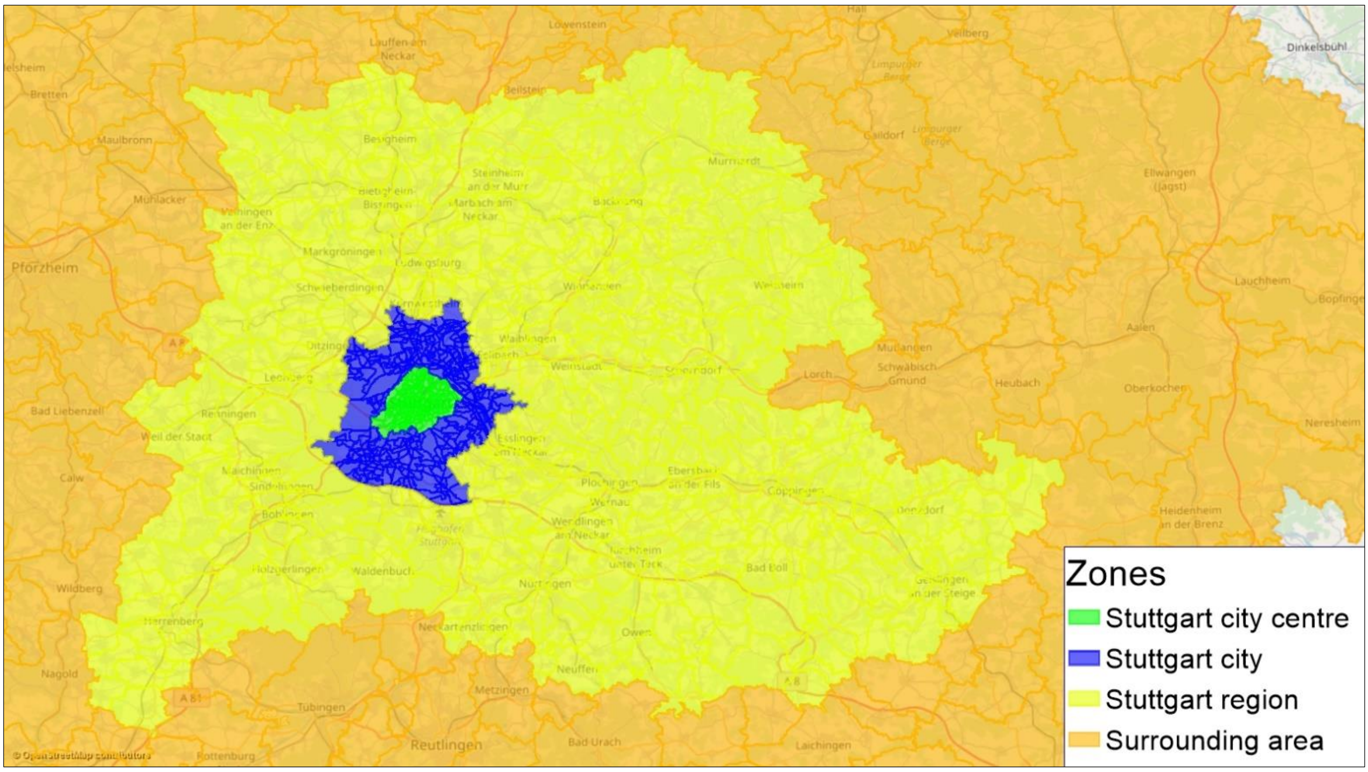


Figure 76: Stuttgart Region and surroundings (Source: SRTDM / OpenStreetMap)

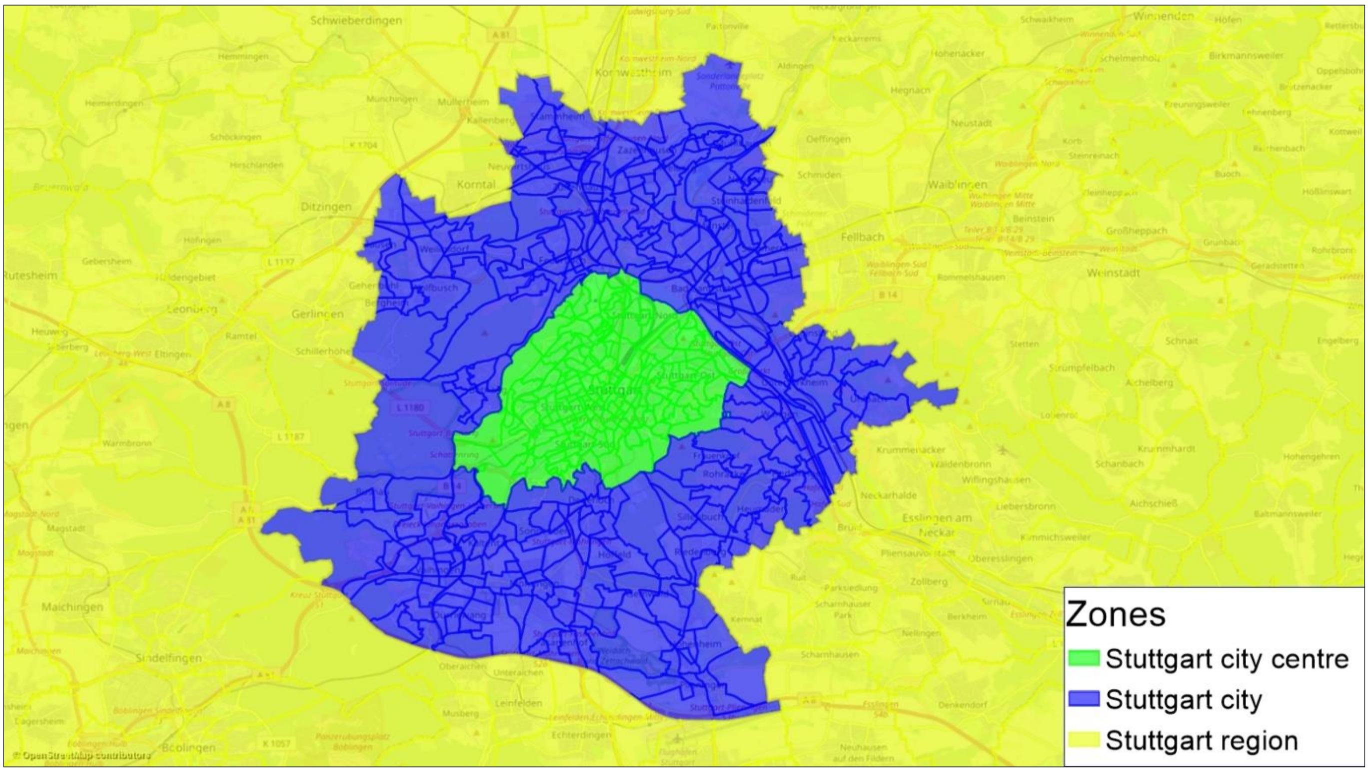


Figure 77: Traffic zones in Stuttgart city and the city centre as represented in the model (Source: SRTDM / OpenStreetMap)

## 2.3 Included and excluded in the model of base scenario

The baseline scenario excludes any traffic systems or modes related to automated driving or automated vehicles respectively. The baseline scenario only considers modes that are already implemented in the travel demand model like car, car passenger, public transport, walking, cycling, park and ride and HDV.

Use Case 7 will not include a car ownership model which incorporates CAV. The share of CAV functions are input for all scenarios.

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# 3 The network

## 3.1 Detailed description of the network and how it is modelled

The VISUM model consists of approximately 370,000 links, 150,000 nodes and one million turns. The links can be divided into 100 different link types. Simple intersections are represented by one node whereas complex intersections contain separate links for each direction as can be seen in Figure 78. Turns include penalties, but no capacity constraints. Parking prices are represented on zone level.

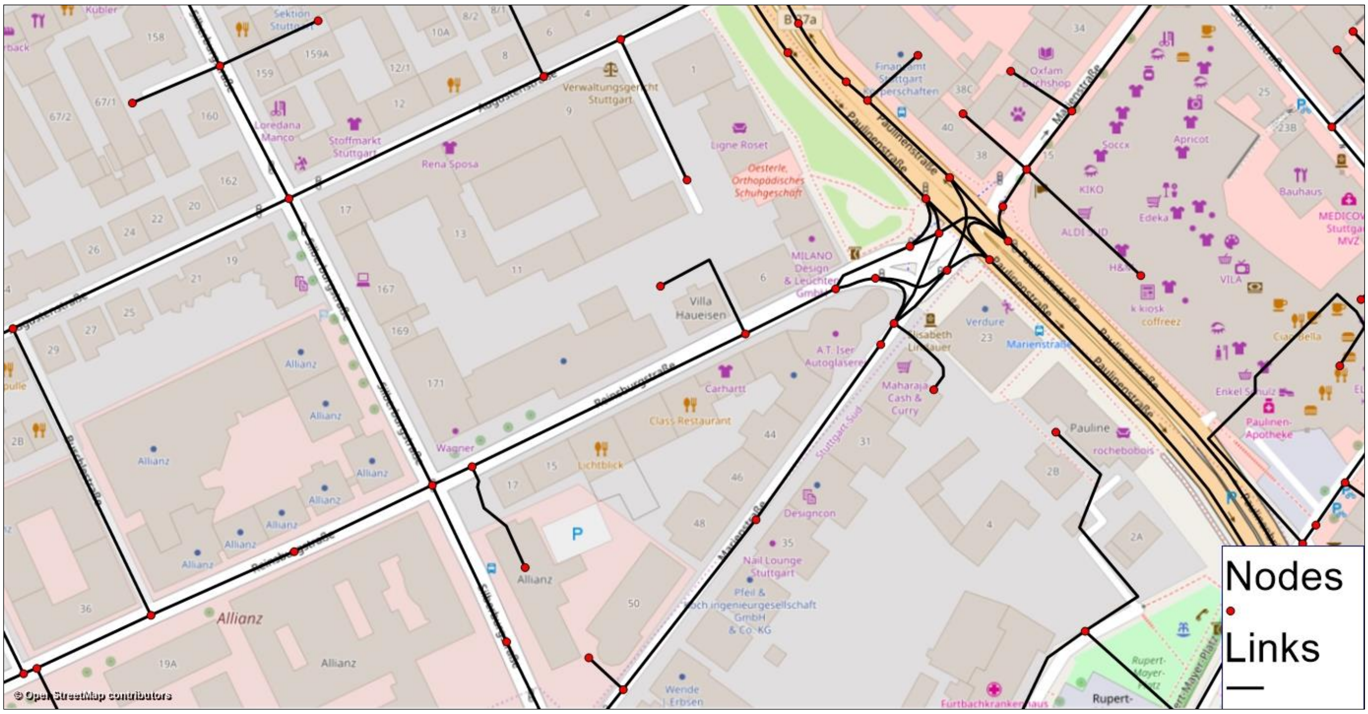


**Figure 78: Example of the road network representation with simple and complex intersections (Source: SRTDM / OpenStreetMap)**

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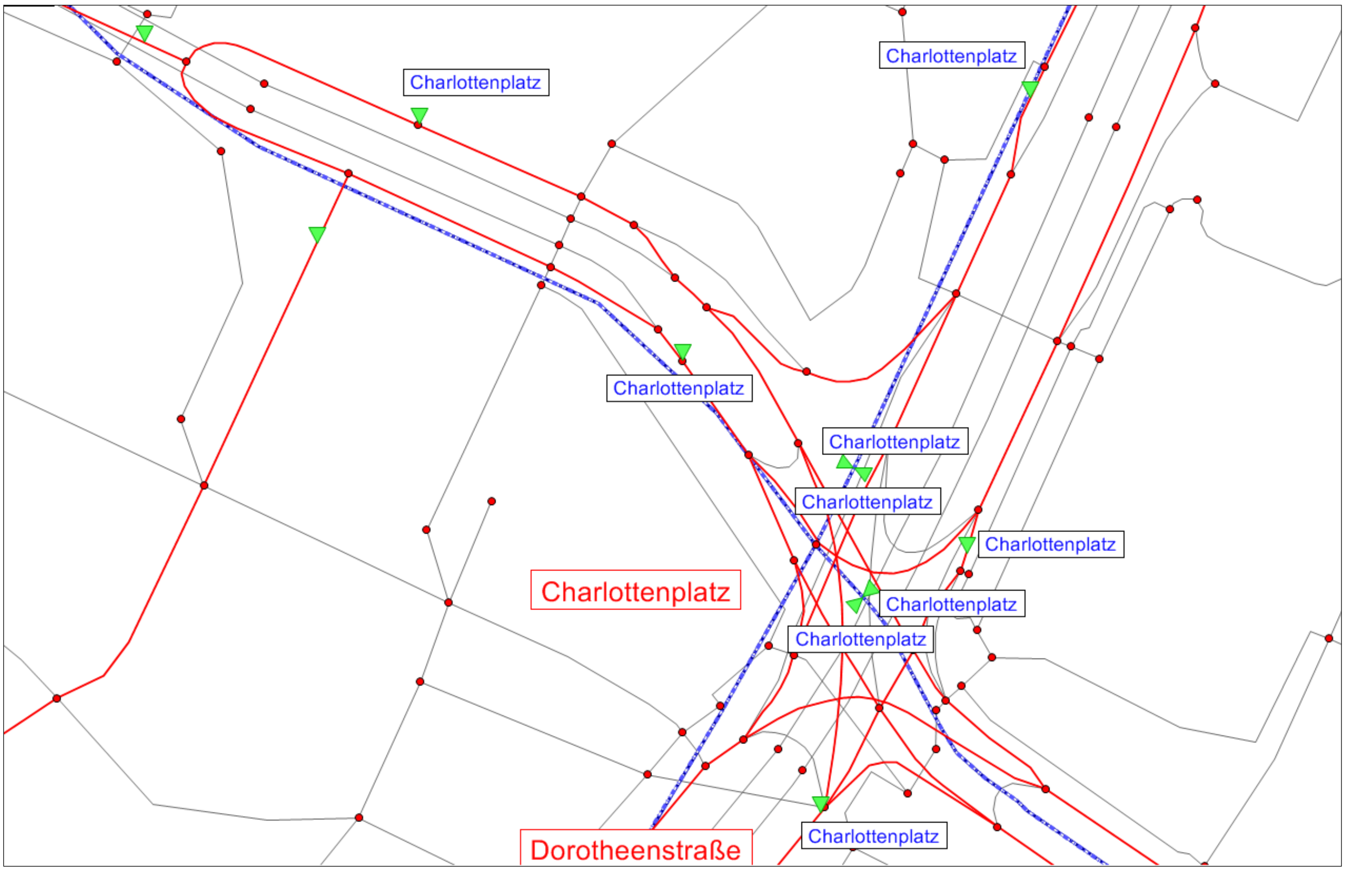


**Figure 79: Example of the public transport network representation with stops and stop points (Source: SRTDM)**

The Public Transport Network consists of 1,200 lines, 50,000 vehicle runs, detailed stop points, fares and fare zones. Figure 79 shows an example of the public transport network, where the blue lines represent railways and the red lines represent road links where the Bus operates. Through nodes, the public transport network is connected to the rest of the network only available for private transport, represented with grey lines.

The level of detail of the network is higher for the Stuttgart Region area, where all minor roads are included. Outside the Stuttgart Region, the link network is made up only with the major roads (see Figure 80).

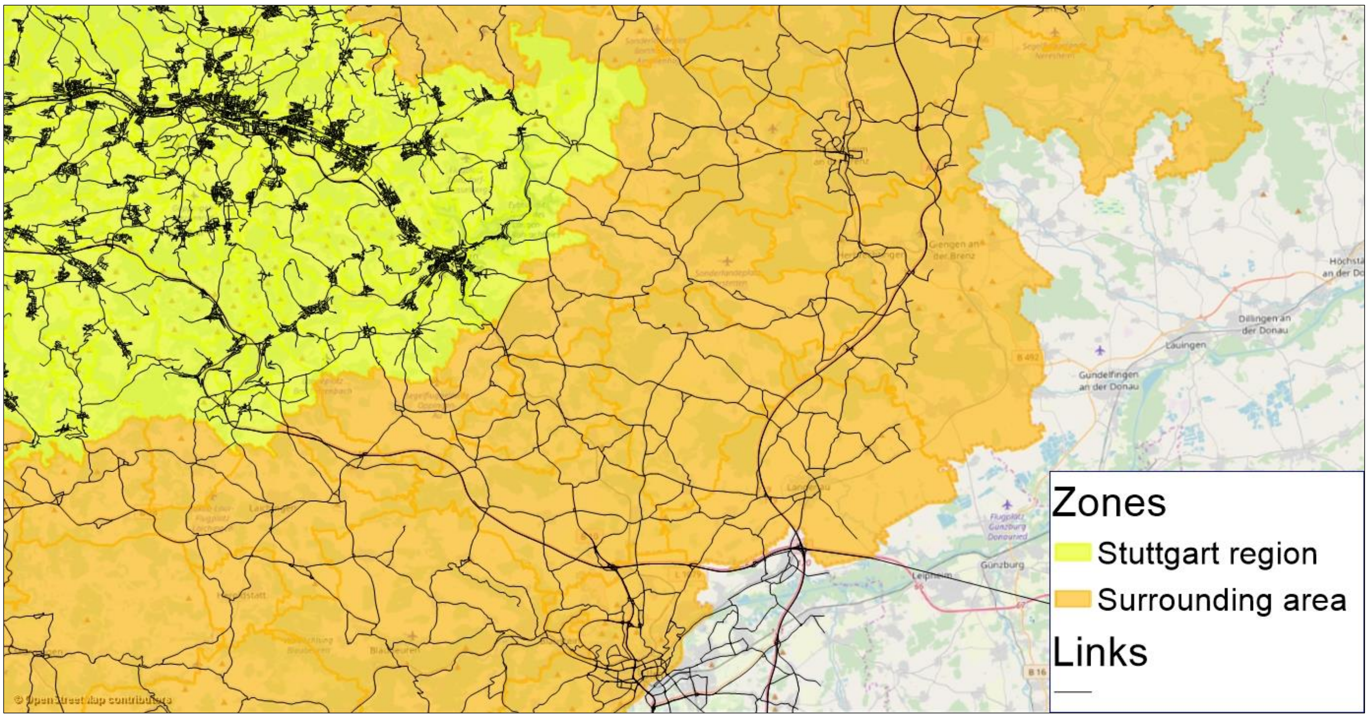


Figure 80: Link network detail in the Stuttgart Region and surroundings (Source: SRTDM / OpenStreetMap)

## 3.2 Description of the data utilized for the network

The road network uses data from the data provider Navteq (now HERE). The road network was extended to include planned and suggested measures until the year 2025. Validation refers to the reference model of the year 2010, since there are no observations possible for a network including measures that have not yet been implemented in reality.

The public transport data cover line route and timetable data for a typical working day. It comes from the passenger information system of the local transport authorities VVS.

The following table shows aggregated characteristics of the network:

| network element | number (rounded) |
|---|---|
| nodes | 150,000 |
| stops | 11,500 |
| road links | 309,000 |
| rail links | 4,000 |
| turns | 1,020,000 |
| public transport lines | 1,250 |

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# 4 The traffic

## 4.1 Detailed description of the traffic and its implementation in the model

Stuttgart City suffers from congestion, noise and air pollution through fine particles and nitrogen oxide. Despite all the efforts taken in recent years, the basic truth is, that too many conventionally powered vehicles are running into the Stuttgart basin on a daily basis, despite the fact that the City operates a high-quality public transport system, a state-of-the-art traffic management centre and despite the improvements which have been implemented for cyclists. The topography and the resulting network structure affect the reliability of the urban transport network as congestion on the motorway directly influences the traffic flow in the urban area.

Figure 81 describes the daily traffic flow levels of Private and Public Transport on the network in the Stuttgart region. The A8 and A81 motorways passing by Stuttgart in the north-south and west-east direction carry large volumes. For long-distance traffic in Public Transport, the highest volumes can be observed to south-east direction to Ulm / Munich and to north-west direction to Karlsruhe / Mannheim.

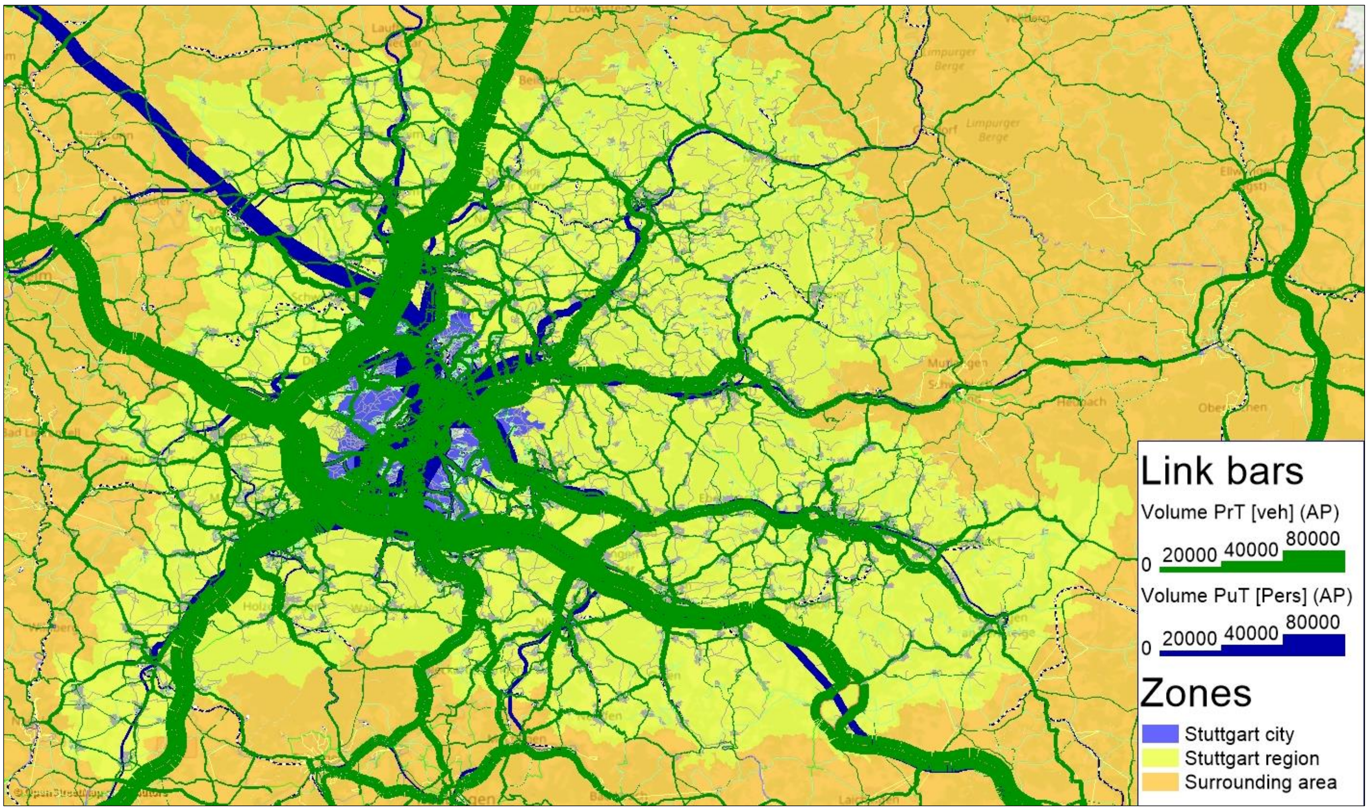


**Figure 81: Daily traffic flow in the Stuttgart Region (Source: SRTDM / OpenStreetMap)**

Figure 82 shows the traffic flows for the city of Stuttgart. The federal highways B10, B14 and B27 are noticeable, since they are leading high volumes to and through the basin. For local Public Transport, the S-Bahn network provides the main axes and carries high volumes to the city and the surroundings respectively.

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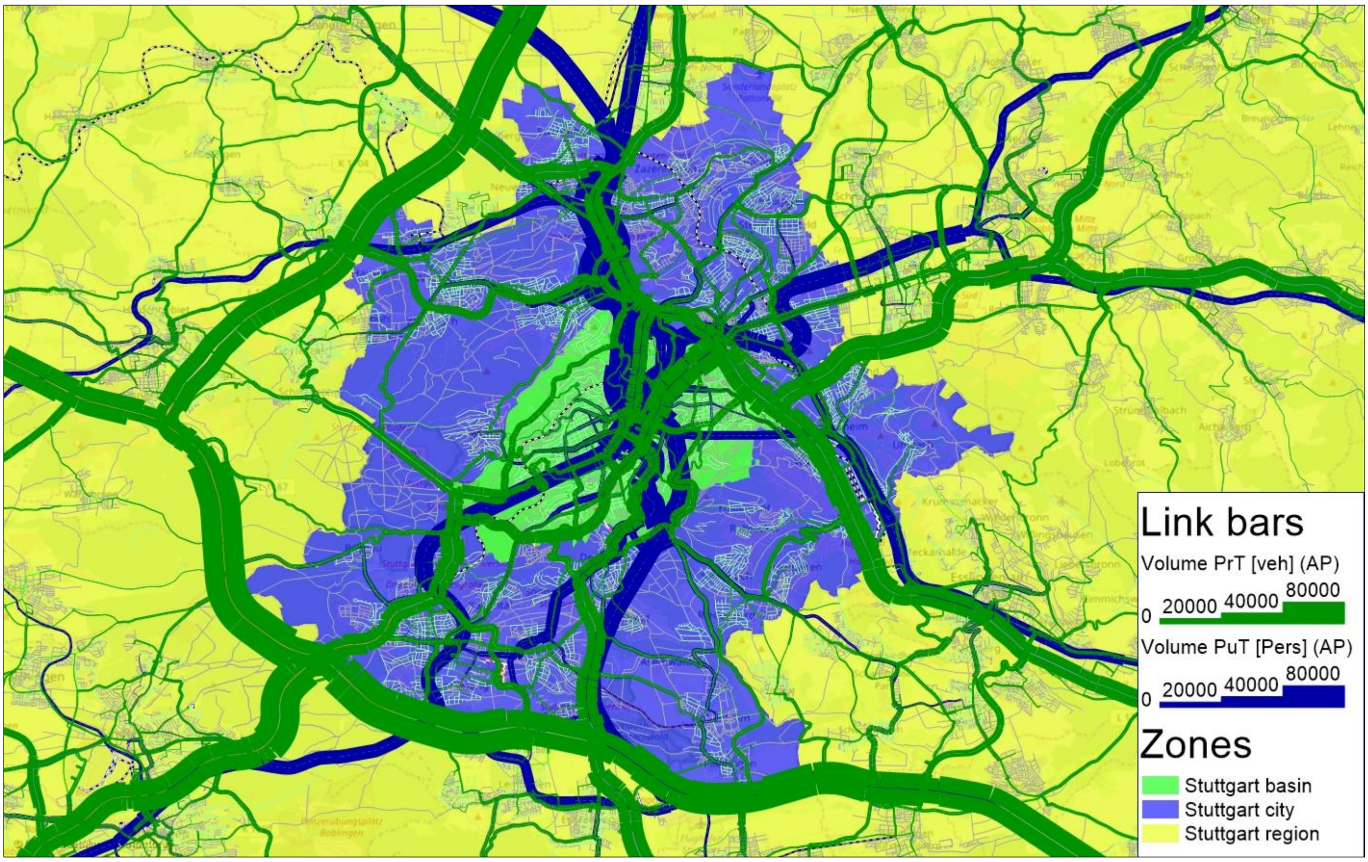


**Figure 82: Traffic flow in and around Stuttgart city (Source: SRTDM / OpenStreetMap)**

The Stuttgart Region experiences recurrent traffic congestion during the morning and afternoon peak hours. Figure 83 shows the congestion level in the road network. The congestion level is derived from the travel time index TTI during peak hour using observed speed data from TomTom for the year 2014:

$$TTI = \frac{t_{PeakHour}}{t_{Target}} = \frac{t_{PeakHour}}{t_{OffPeak}}$$

This recurrent traffic congestion leads to average delays of approximately 6 minutes for car trips with destinations in Stuttgart. Some of this delay, especially on inbound arterial roads, is a part of the equilibrium between car and public transport. More or less deliberate bottlenecks at the Stuttgart City border meter the traffic flow to downtown causing regular delays between 10 and 15 minutes. Different from other cities the peak period is rather short. Between 9:00 and 16:00 the level of service is usually good throughout the region.

Random disturbances (e.g. accidents) and temporary capacity reductions from road works increase the recurrent congestion. As the road network in the region is already highly saturated such disturbances can usually not be compensated by alternative routes. As a consequence, the travel time reliability is relatively low. Disturbances on the motorways often lead to higher traffic volumes in the City of Stuttgart and other regional centres, which is not desirable.

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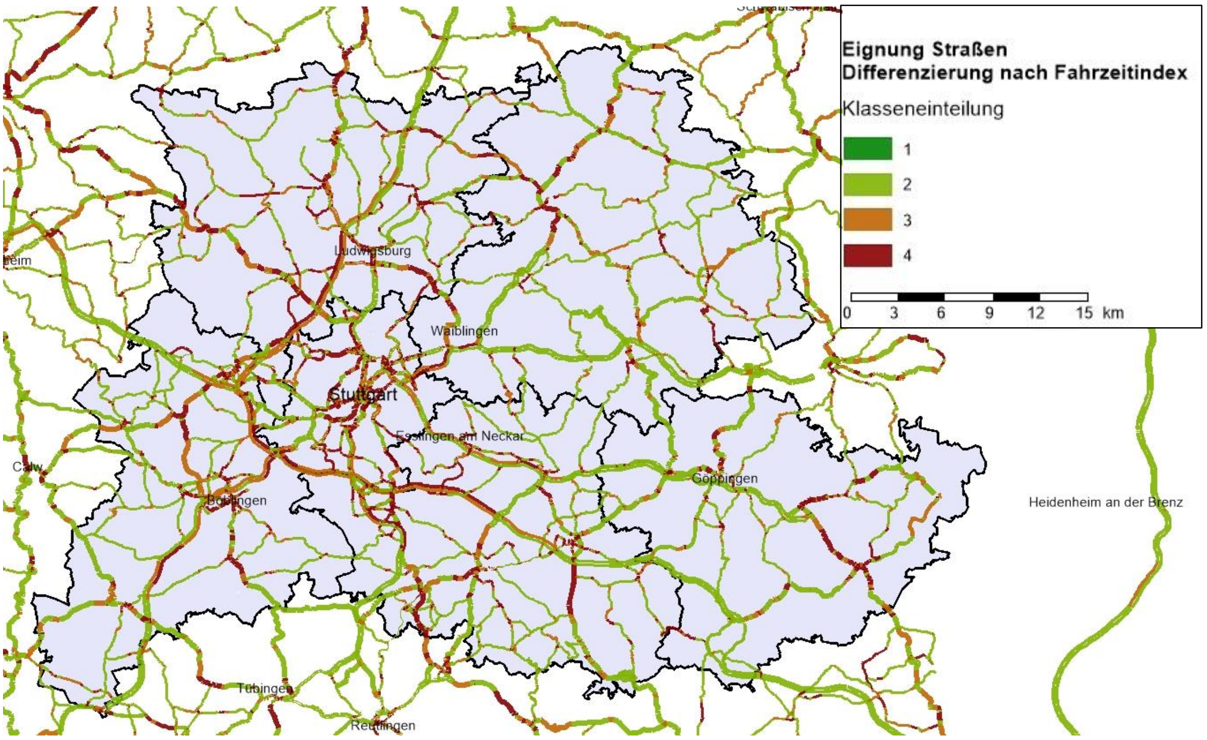


| congestion level | travel time index car | road length [km] |
|---|---|---|
| 1 | <1,1 | 6.400 |
| 2 | <1,3 | 2.000 |
| 3 | <1,5 | 265 |
| 4 | >1,5 | 265 |

Figure 83: Recurrent congestion in motorized vehicle traffic: road length by congestion level (source: SRTDM)

Considering the temporal distribution of car traffic within the Stuttgart Region over a whole day, the average delay times can be seen in Figure 84 for all trips and in Figure 85 for trips into the City only. It can be seen, that the highest delay times occur in the morning peak hour for inbound trips to Stuttgart. However, most of the trips affected by delay occur in the afternoon and evening peak hours.

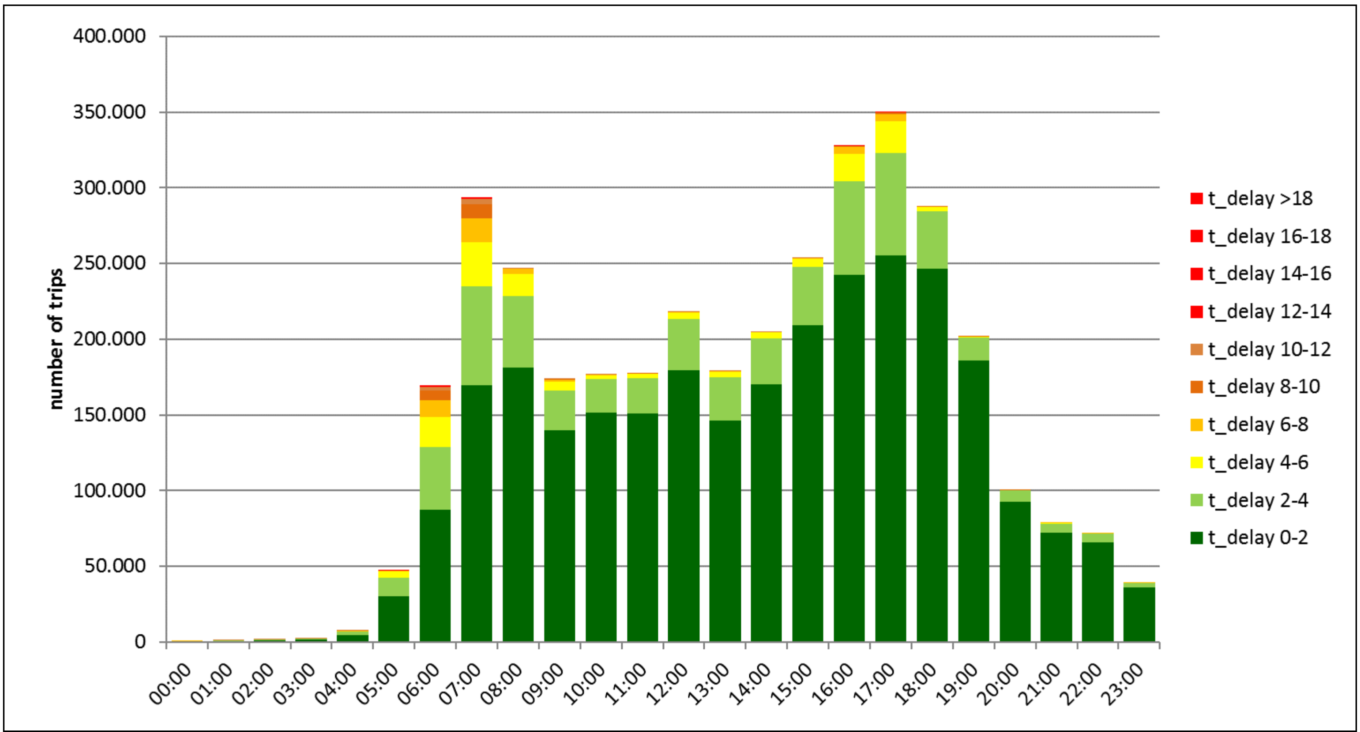


**Figure 84: Number of trips and delay minutes (t-delay) for car trips with origin and destination in the Stuttgart Region by time of day (source: SRTDM)**

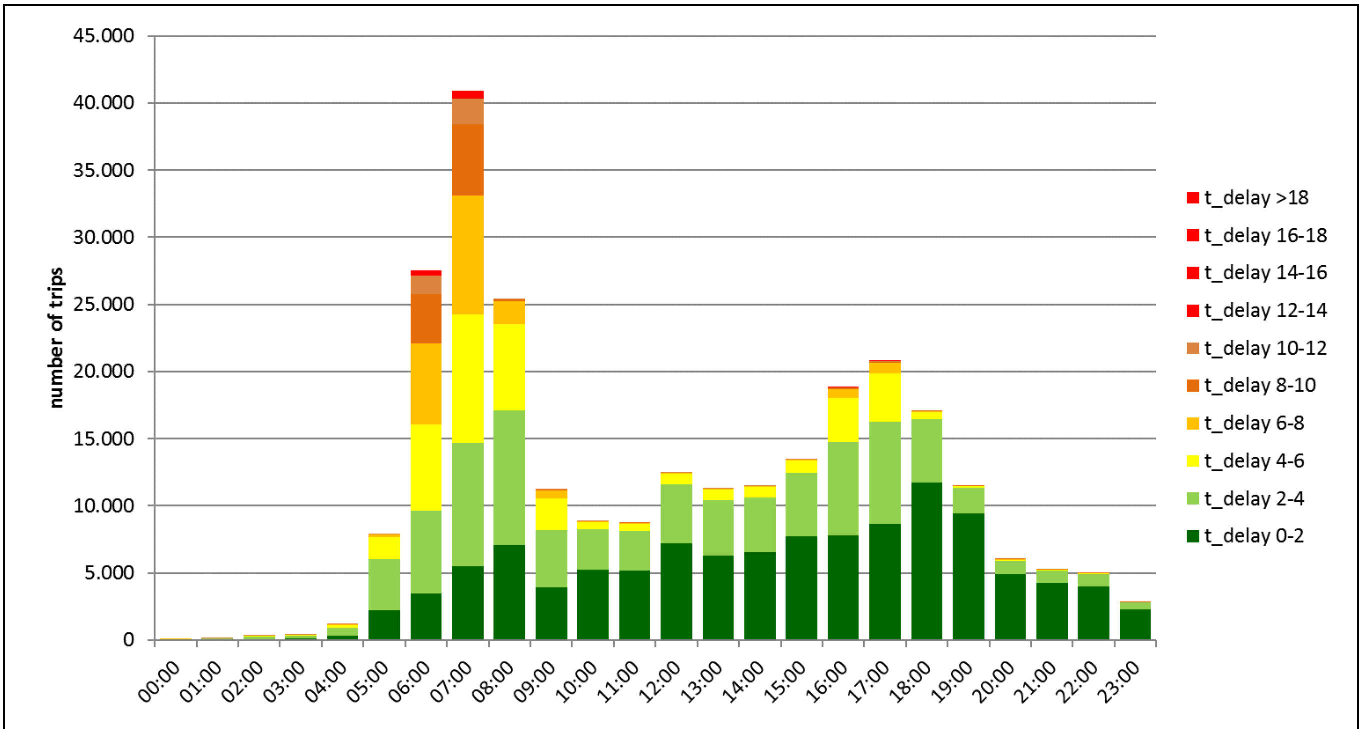


**Figure 85: Number of trips and delay minutes (t-delay) for car trips with origin in the Stuttgart Region and destination in Stuttgart City by time of day (source: SRTDM)**

Public Transport offers an adequate alternative for many travellers. However, it is difficult to accommodate additional travellers during peak periods in the S-Bahn network. During peak periods in approximately half of the network length the vehicles are at capacity. Figure 86 shows the congestion level in the S-Bahn network.

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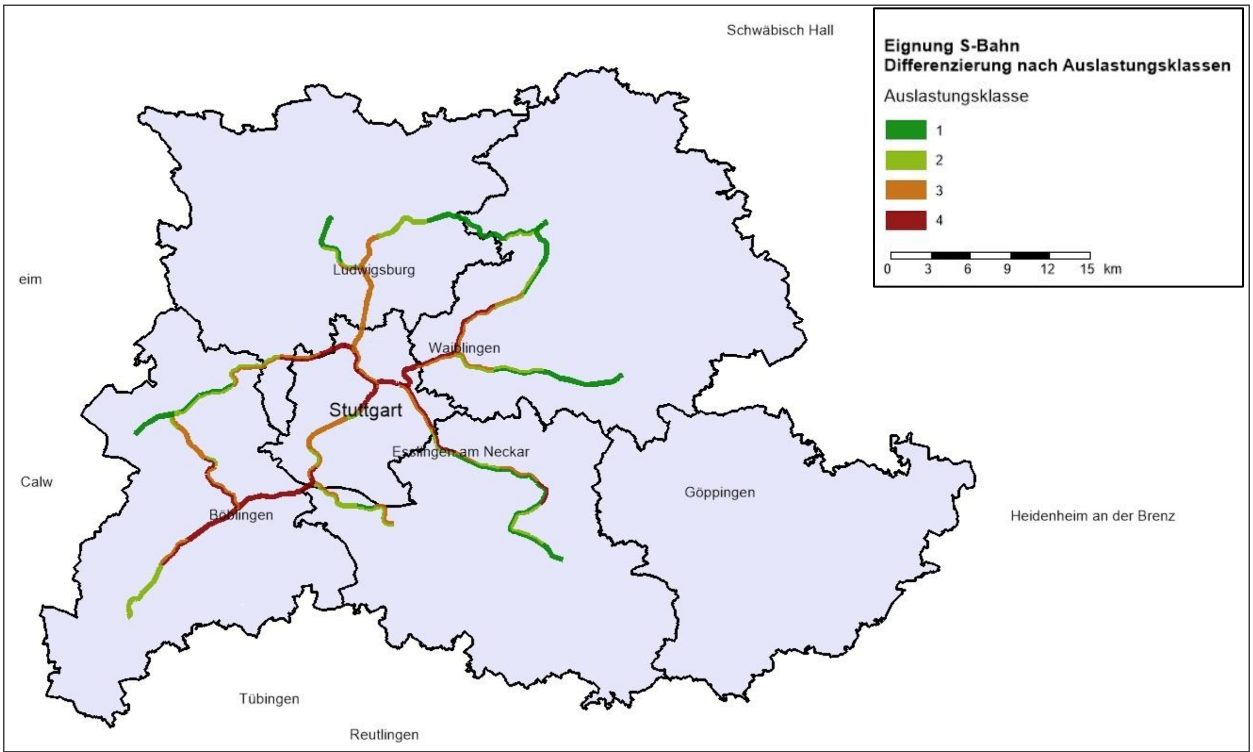


| congestion level | saturation rate PuT | line length [km] |
|---|---|---|
| 1 | <75% | 109 |
| 2 | <100% | 99 |
| 3 | <125% | 116 |
| 4 | >125% | 99 |

**Figure 86: Recurrent congestion in public transport: line length by congestion level for the S-Bahn network (source: SRTDM)**

The baseline scenario for Use Cases 7 and 8 yields for the indicators number of trips and passenger kilometres the values in Table 6, aggregated by mode.

**Table 6: Number of trips and passenger kilometers by mode for the baseline scenario**

| mode | person trips | | distance travelled | |
|---|---|---|---|---|
| | trips (mio) | share | person km (mio) | share |
| total | 8.5 | 100% | 60.5 | 100% |
| car | 4.1 | 48% | 40 | 66% |
| car passenger | 0.8 | 9% | 5.3 | 9% |
| public transport | 1.1 | 14% | 12.3 | 20% |
| cycling | 0.6 | 7% | 1.8 | 3% |
| walking | 1.9 | 22% | 1.1 | 2% |

## 4.2 Description of the data utilized

For the external traffic (origin or destination outside the study area) several external matrices were provided by different authorities:

- Private long-distance transport: one matrix for both light and heavy traffic by the State of Baden-Württemberg (Straßenverkehrsprognose 2025)
- Public long-distance transport matrix by the Schienenverkehrsprognose for 2020
- Commercial traffic from a commercial transport model of PTV AG
- Airport traffic divided by private and public transport from a survey from IFAK (2009)
- Fair traffic from various sources (event calendar, SSB, SWITCH, intraplan)

# 5 Verification

## 5.1 Verification process

The model was developed by PTV AG under contract of VRS, Stuttgart City and SSB AG. They performed several model checks concerning the input and output data. The calibration and validation process is described below. The final model was approved by VRS and USTUTT. In this step it was verified that the model fulfils all requirements requested in the tender.

## 5.2 Verification results

The verification process and the usage of the model after the model submission by PTV AG showed some shortcomings. This led to several corrections and improvements. By now the model has been applied successfully for examining more than 200 scenarios in approximately 10 projects for the regional transport plan and various local studies. In some of the applications new shortcomings were detected. This led until now to two model revisions. As any model the current version of the model will contain unknown errors and shows known limitations. The large number of successful applications proofed that the model produces reasonable results.

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# 6 Calibration

## 6.1 Description of the calibration process

The travel demand model for the baseline scenario (without CAV) is already calibrated. The model calibration is based on a household survey, which covered 5,000 households, 13,000 persons and 270,000 reported trips within a 7-day trip diary. The calibration and validation process is described in the model project documentation (PTV AG, Verkehrsmodellierung für die Region Stuttgart, 2010) in German language.

The model parameters were estimated with biogeme (http://biogeme.epfl.ch/). The estimated model parameters are documented in the model project documentation. The destination and mode choice model distinguishes 23 person groups and 19 trip purposes. The estimation process resulted in 86 different parameters for mode choice and 110 different parameters for destination choice.

## 6.2 Description of calibration result

The results after the model calibration are shown in the three figures below:

- Trip generation, trips per person and day by person group in Figure 87. All deviations between model and household survey are smaller than 0.1 trips per day, so the model manages to match the data very well. The average value for the trips per day is 3.2 and marked as dashed red line.
- Trip destination, trips with trip distance by trip purpose in Figure 88. Again, the model meets the data from the household survey quite well. Deviations worth mentioning concern the trip distance for the trip purpose ‘university’ and ‘vocational school’ which is about 1km too short.
- Trip distribution, deviation of trip share by mode between observed and modelled trips in Figure 89. The relative deviation for mode choice is smaller than 0.3% for all modes (car driver, public transport car passenger, bike, walk, park & ride), which is in accordance to the specified target value of 1.0%, marked as red lines in the figure.

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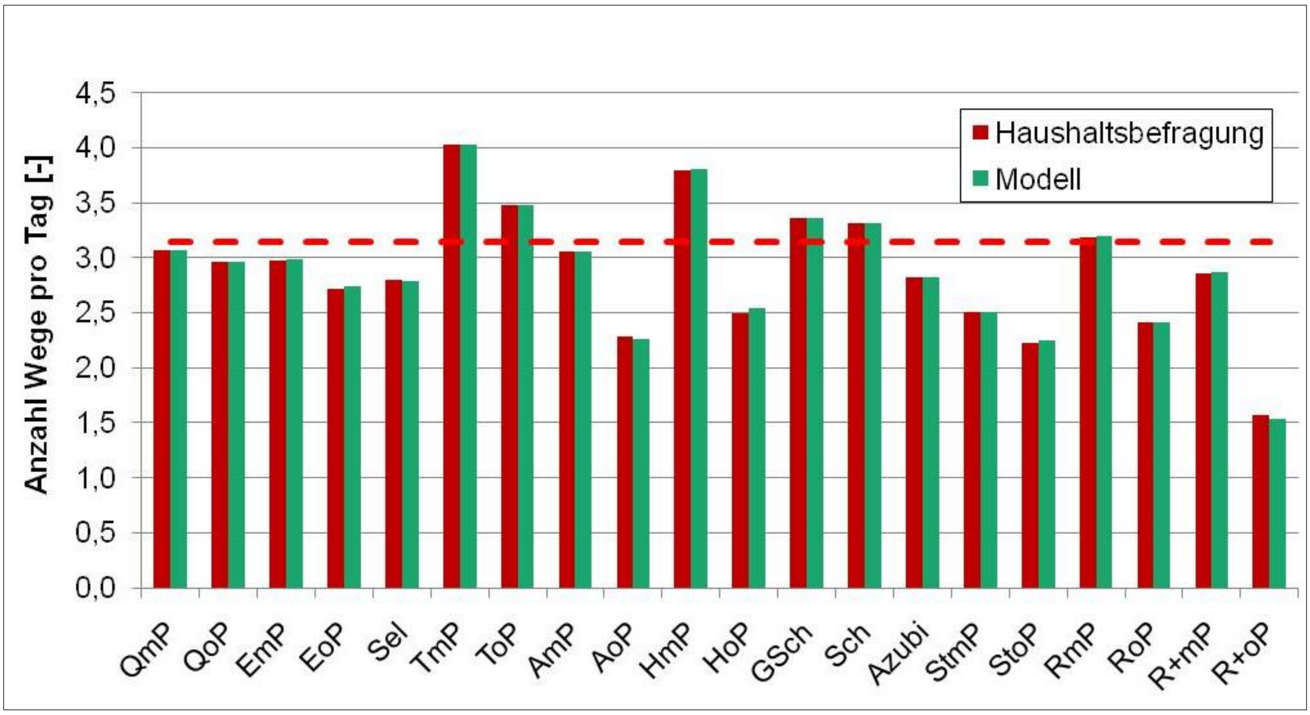


**Figure 87: Model results for trip generation after calibration: Comparison of observed and modelled trips per person and day by person group**

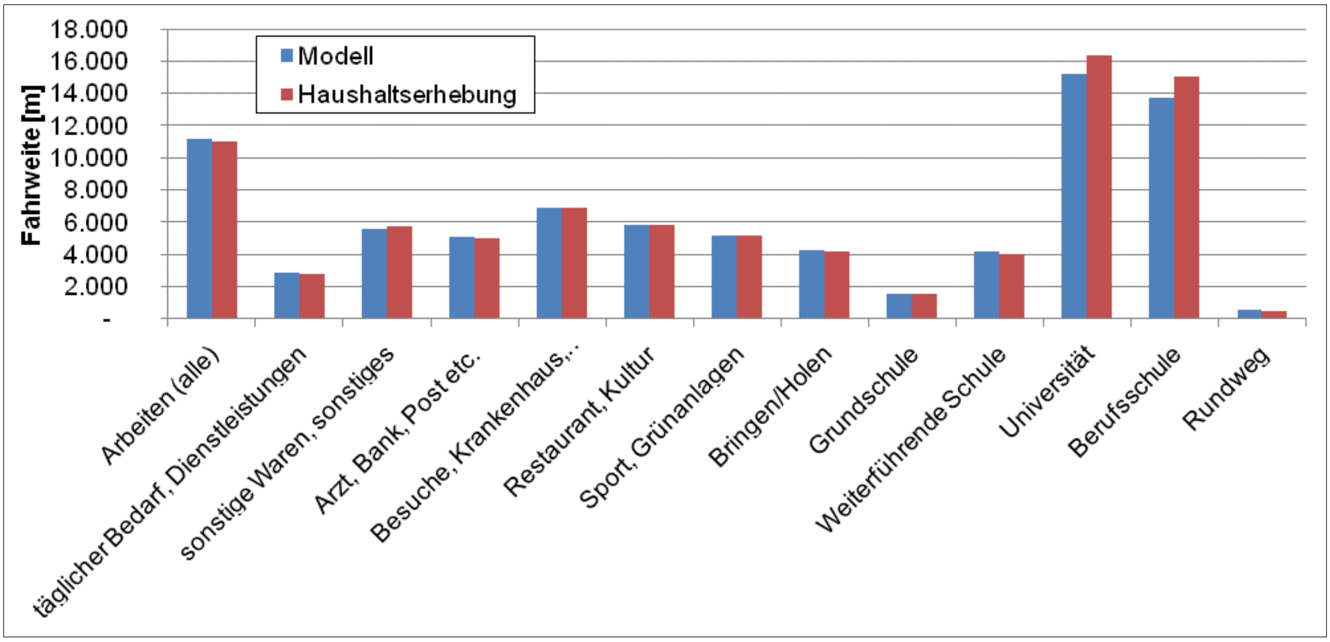


**Figure 88: Model results for trip destination after calibration: Comparison of observed and modelled trip distance by trip purpose**

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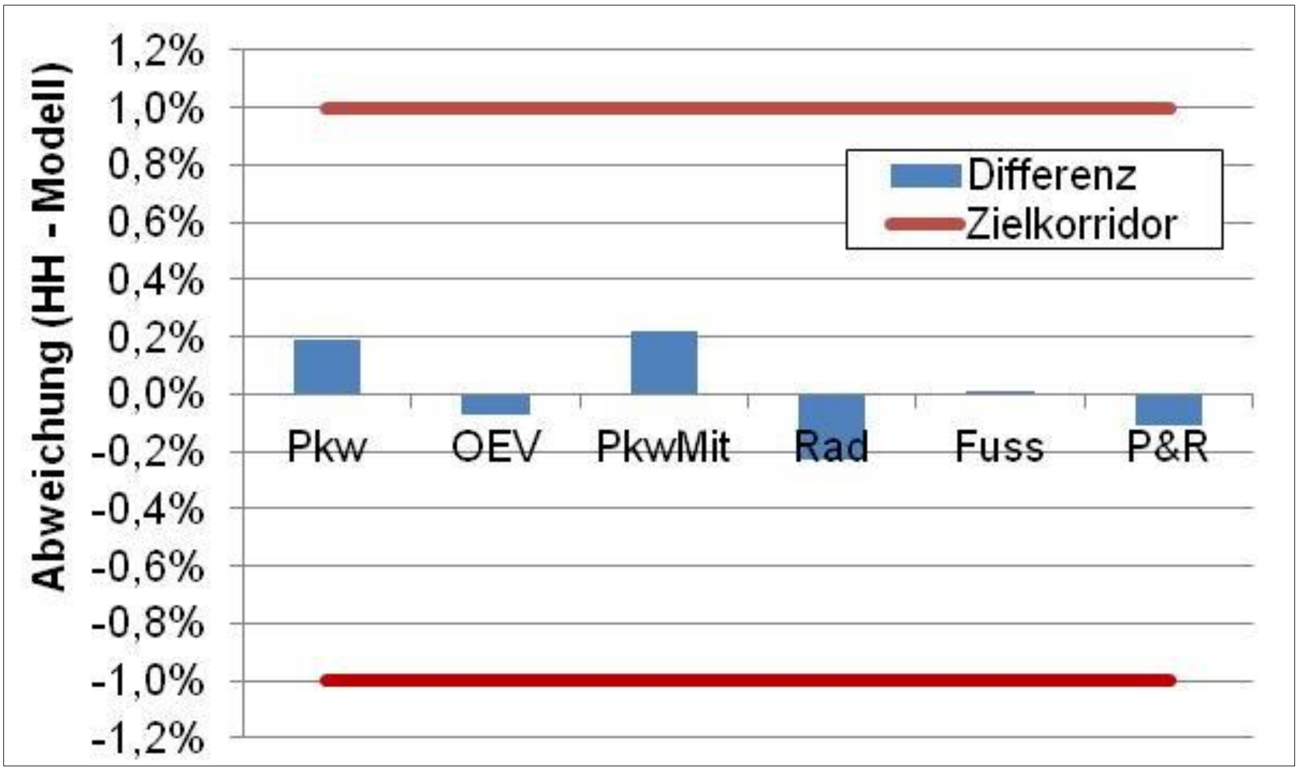


Figure 89: Model results for mode choice: Deviation of observed and modelled trip shares by mode

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# 7 Validation

## 7.1 Description of the validation process

The model is calibrated and validated for the reference year 2010 against observed volumes in the road and in the public transport network.

Providers for 550 road counts:

- Count data of permanent count locations from the state Baden-Württemberg
- Count data from the federal road authorities BASt
- Count data observed at the city limits and at the inner city of Stuttgart City
- Count data from various other sources.

Regarding public transport, the local public transport authorities (VVS) provided average counting data for each working day for 6,000 counting locations in the Stuttgart region. Additionally, the number of boarding and alighting passengers for stops related to rail transport was used to validate the model.

## 7.2 Description of validation result

Indicators used for validation of vehicle and passenger volumes in private and public transport respectively are the coefficient of determination ($R^2$) and the GEH-value. The GEH-value is a number computed depending on the similarity between the modelled and the observed value, where a value GEH<15 (for daily volumes) represents a good match. Figure 90 - Figure 92 show results of the validation:

- Coefficient of determination related to vehicle volumes in Figure 90
- GEH values related to vehicle volumes for all count locations in the study area in Figure 91
- Coefficients of determination related to passenger volumes in public transport for different rail vehicle systems in Figure 92

After the calibration all indicators fulfilled the requirements stated in the model specifications.

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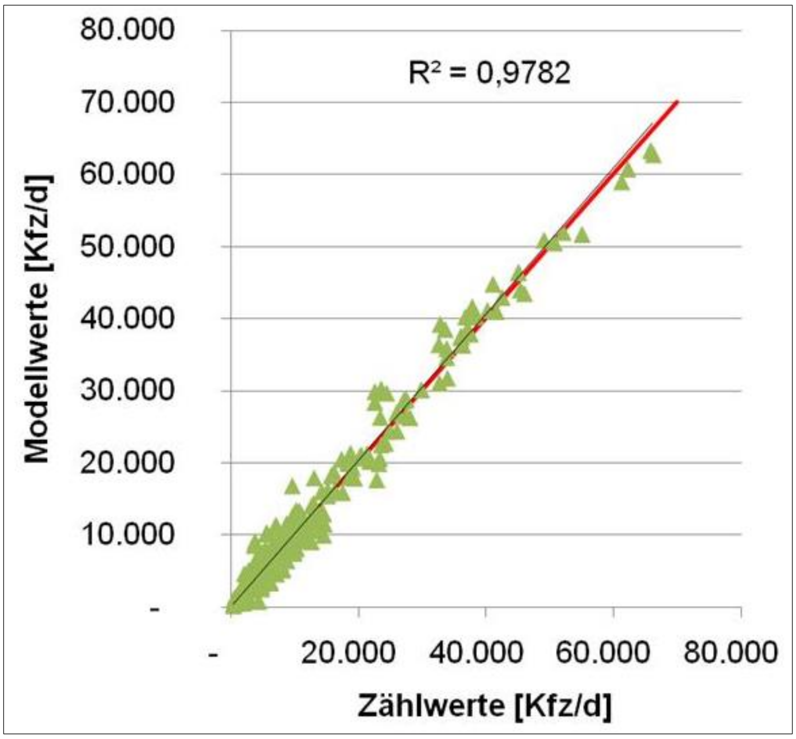


Figure 90: Comparison between modelled and counted vehicle volumes

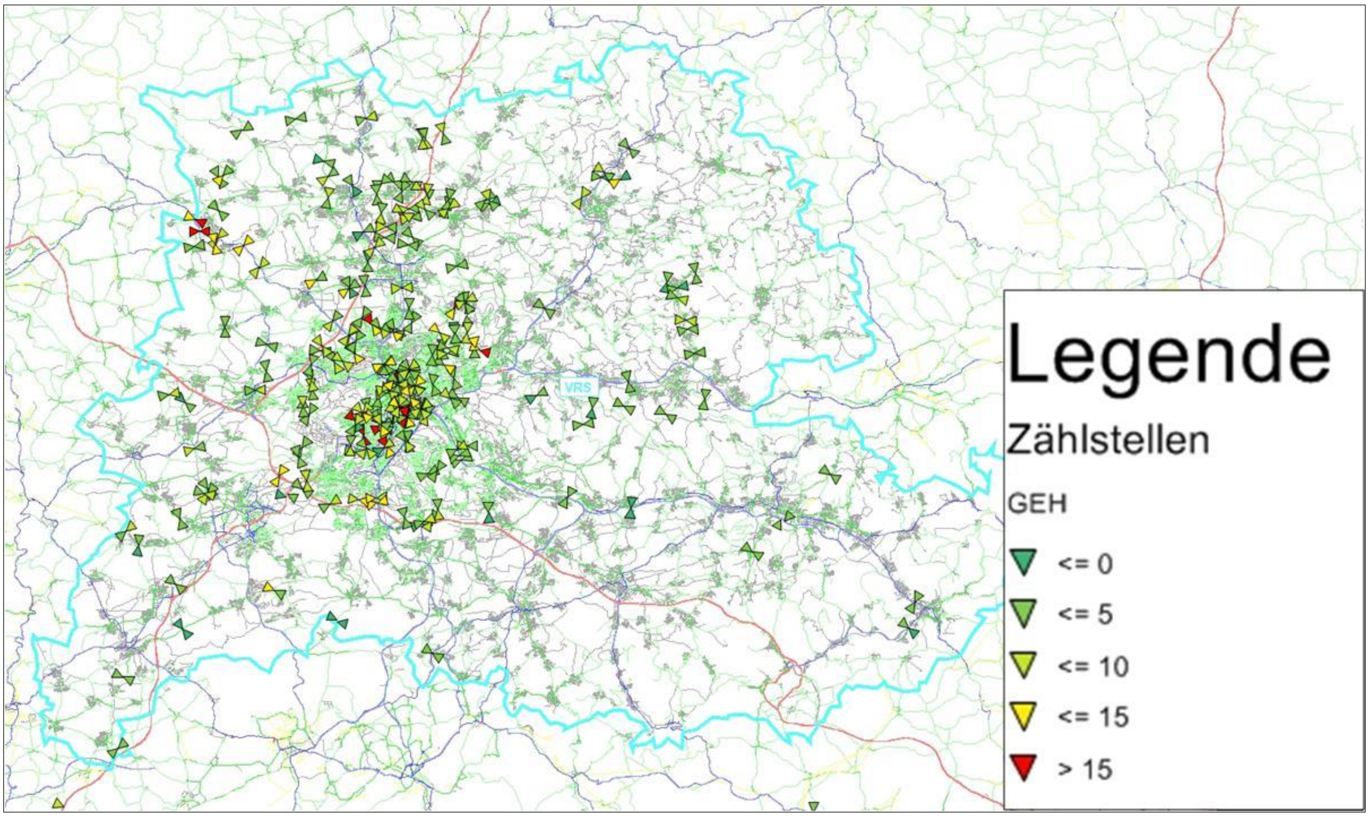


Figure 91: Deviation as GEH-value between modelled and counted vehicle volumes

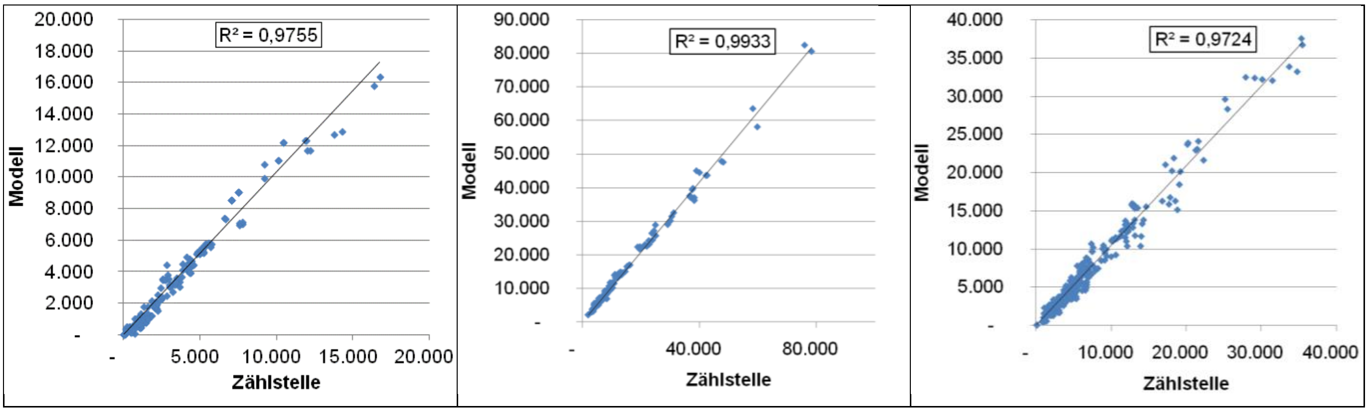


**Figure 92: Comparison between modelled and counted person trips for regional train (Regionalbahn), heavy rail train (S-Bahn) and light rail train (Stadtbahn) (from left to right)**

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# 8 Results and conclusions

## 8.1 Conclusions of the verification-calibration-validation process

This section concludes the findings from the verification-calibration-validation process by summarising the findings discussed above:

- The model development was tendered out. The model developer PTV AG implemented a specification which was jointly developed with PTV AG and the clients (VRS, SSB and Stuttgart City). The client and USTUTT verified that the VISUM implementation fulfilled the requirements of the specification.
- The model is calibrated using an extensive household survey, which covered 5,000 households, 13,000 persons and 270,000 reported trips.
- The model is validated with observed volumes at 550 road count locations and 6,000 counts in the public transport network
- By now the model has been applied successfully for examining more than 200 scenarios in approximately 10 projects for the regional transport plan and various local studies. The large number of successful applications proofed that the model produces reasonable results.

## 8.2 Handling of model uncertainty and/or limitation

The SRTDM is a macroscopic travel demand model with the typical limitations of such a macroscopic travel demand model:

- The travel demand is fed into the model at selected connector nodes. This means that traffic volumes at minor roads are not realistic.
- Some traffic zones in the model are relatively large. This influences the quality of the results.
- The delay functions at intersections consider the type of control, but are constant and do not consider the level of saturation.
- The original model does not include a time dimension. It models and assigns the traffic of an entire day. Model extensions for CoEXist use case 8, which requires time depended demand, are not validated.
- The model provided a fixed-point forecast and does not estimate uncertainty values.

The model does not provide specific methods for handling or estimating uncertainty. Uncertainty will be handled by discussing and interpreting the results. The consistency of model runs will be checked by sequentially varying selected parameters (e.g. perception of travel time) and variables (e.g. share of CAV).

# 9 Reference

None.

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