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Traffic analysis and evaluation for Lindholmsallén: current and 2035 situations

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Gothenburg, Sweden 2019

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Abstract

Traffic-related issues are major concern in cities for their current development and functioning, but also for future development and expansion. The ever-growing population and the economic development combined with constant change of land use brings further traffic and infrastructure issues.

The Lindholmen area in Gothenburg is being developed and going through a major land change use. Different studies have been conducted to assess the traffic situation, queue length and travel time in Lindholmsallén and the roads connecting to it. The traffic demand in the area is heavy during peak hours, and normal to light during the rest of a day. The main artery, Lindholsallén, is the entry connection to Lindholmens residential and office/school areas. The land use of Lindholmen is transforming from a semi/industrial – residential area to a fully residential/office space area. The main changes include the new student housing buildings, the new office space besides the Radisson blue hotel and a new luxury skyscraper of the city (i.e., the Karlatornet). The analysis, simulation and predictions are continually used to help with intra-city and inter-city traffic management and improvement. A Vissim model is build and the traffic counted in the area during the peak hours is used as base for simulations of a heavy traffic situation. The future traffic situation is predicted for the year 2035, when almost all the changes in the area will be finished.

The main outcome from the simulation and result analysis shows that the area has problems with travel time and queuing. These problems negatively affect the L.O.S and user experience. Lindholmsallén needs a remodelling and intervention since in its main connections with the other systems and some parts within the are itself have queuing problems and longer travel time of users. The same problems but in a more severe matter are seen also in the future scenario simulations. The problems become even more visible since they effect other areas in the future. In order to improve the traffic situation in the area, some measures to improve the current traffic situation are recommended. Dedicated turn lanes and signals in some parts where there are none can help the traffic. While based in the future traffic growth and area development, an intervention in the infrastructure system and construction of new lanes and corridors to lower the traffic flow, together with measure that make the area more accessible through public transport. The measures are focused on making the infrastructure system users experience and the overall traffic situation in the area better, while separating the vehicle mode corridors. This and other solutions are recommended and are also being researched currently by governmental entities.

Keywords: Traffic flow, Travel time, Queueing, Peak hour, Traffic Simulation, Scenarios, Traffic Prediction, Lindholmen, Gothenburg

Preface and acknowledgments

This thesis concludes my studies at the Master of Science program of Infrastructure and Environmental Engineering at Chalmers University of Technology.

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1. Introduction

Traffic analysis and simulation is a process largely used today to help with the planning and management of infrastructure and mobility of different modes for both intra-city and inter-city connection. The growth of economic and population brings new challenges to traffic systems. Population growth also brings change to land use and thus leads to change in the infrastructure system. Based on calculations and predictions of population growth, traffic simulations as useful tools can be utilized to predict the traffic situation in the future with a certain degree of confidence.

Gothenburg is a city that is developing at a fast pace and has a rapid population growth. This leads to infrastructure system problems, and changes in land use. Such developments bring the need to continue to analyse and control the infrastructure in different parts of the city, with sort and long-term predictions. An area that is experiencing rapid changes is Lindholmen, situated in the western part of the city near the Gothenburg port, which is a very important node. The land use of the area has changed through the years: starting as a totally industrial area, evaluating to be a semi-industrial and semi-residential area, and in the future to be an almost completely residential area with a large number of office buildings. Many important and large companies have their offices in Lindholmen, making the area an important hub for the whole region. The presence of these companies gives a reason for the existence of schools nearby, to strengthen the relationship between school and industry. The presence of school gave a reason for the construction of student apartment buildings. As the area is seeing big development, a large number of residential buildings were constructed and are planned to be constructed. All the development has brought a big strain on the infrastructure system, especially for motorized vehicles and public transport vehicles (only busses are present in this area). The importance of the area is also seen in the future plans that the Gothenburg Municipality has for the area, as there is a number of large projects to be implemented.

The aim of this thesis is to analyze the current traffic situation in the Lindholmen area and the state of the infrastructure system using agent-based simulations. Besides, this thesis will investigate the changes in land use and generated traffic to the change of land use and increase in population and economy. The traffic increase will be analyzed and its weight in the current infrastructure. Moreover, this thesis will make a prediction of the future traffic demand based on the city planning for the future and assess how the traffic in the future will affect the traffic system in Lindholmen. It is to evaluate the infrastructure system for future traffic of personal motorized vehicles and highlight the main potential concerns and problems that may arise. Based on the results, suggestions and potential solutions will be given to relieve the predicted problems and to support scientific planning as well as management in current and future traffic system of Lindholmen area.

1.2 Problem Description

Lindholmsallén is the main road and arterial connection link to the Lindholmen area. Many facilities are situated there and it also connects to the south-western part of Hisingen. Since the land use of the area has changed a lot, the infrastructure system for motorized vehicles in the Lindholmen area has also changed, but is still lacking and problematic. The last major changes of the infrastructure system that happened in the area were in the early 2000s. At that time the area was still an industrial zone with some office spaces. The new development of the area and the population growth in Lindholmen area has also brought an increase in trips and travels done using Lindholmsallén link. The area is known to have some very problematic and stressful road nodes and links. Queuing is a daily phenomenon and signal timing is also causing problems in some points. These problems cause severe queues, oversaturated traffic flow and heavy traffic delays.

1.2.1 Lindholmens history

Lindholmen used to be one of the main harbours of Gothenburg and the main port in Scandinavia. An area full of docks and shipbuilding facilities. In the 1980s, the city was hit by one of its most harsh economic crises. This meant that a lot of shipbuilding yards and docks had to shut down, leaving thousands unemployed and the area underdeveloped and deserted.

In order to re-integrate the area and make it profitable again, initiatives were taken such as the creation of schools to retrain the unemployed shipbuilders and in turn led to more creation and construction of schools in general. These schools help to attract companies to move their offices into the area in order to establish a stronger collaboration between academia and industry with a lot of economic initiatives.

The late 90s and early 2000s shaped the area to more or less what it is today. These changes brought also a need for change and adaptation of the infrastructure system to support the development. The early 2000s were the last time when a major infrastructure change occurred in Lindholmsallén that gave it current shapes. While the development has continued in the area, the infrastructure has had minimum changes. This brings a lot of problems for the traffic including congestions, queues and signals time failure sometimes.

Developing dockland area, Lindholmen has upscaled waterfront cafes, smart bars and rooftop restaurants, set against a skyline of harbour cranes and gleamed new residential towers and hotels. Walks along the Göta Älv River take in the nearby Älvsborgsbron and Göta Älvbron bridges, while ferries run from the waterfront to the city centre. Keillers Park has a sweeping city and harbour views from the Ramberget lookout point. All this development and growth will also induce more traffic demand and influence the operation of the traffic system.

Figure 1: *Lindholmen in late 19th century early 20th century*

Figure 2&3: *Lindholmen 2004*

Figure 4: *Lindholmen in 2035*

1.2.2 Planned future of Lindholmens

As a centre and major contributor to the city's economy and development in all areas, Lindholmen's future is full of growth and expansion. Some of these projects are listed below:

- Centrala Lindholmen, a continuous expansion in coordination with Chalmers real estate will make it possible for Chalmers to grow and incorporate new possibilities and cooperation with Lindholmen Science Park.
- Karlastaden, one of the most ambitious projects for Gothenburg and Lindholmen. Kalrastaden will be a complex of high buildings, including the tallest skyscraper in Scandinavia, Karlatornet, and 7 neighboring buildings, for a grand total of 32000 sqm of a multifunctional complex.
- Geelys innovations center, in Pumpgatan construction, has already begun for Geely's innovation center. A European coordinated innovation and research environment with an area of 70000s sqm and about 3400 employees.
- Lindholmshamnen, Kvarteret Dockan, HSB Brf Blanka, two new and attractive residential centres of more than 600 apartments and services for the residents with a stretch from Regnbågsgatan to Lindoholmen Science Park.
- Lindholmens tekniska gymnasium, in 2018 new technical high school started near Northern Älvstranden.
- Göteborgs Hamn, the Port of Gothenburg has a number of major projects that will be completed in the near future. The new port in Arendal will be completed in 2025. In the Vadhav, Gothenburg Port and the Swedish Transport Administration are building a shallow pool for waders in Torsviken. The Wadden Sea is a way of restoring nature after the area has been used as clay storage for almost forty years. This should be ready by 2020.

All this project and developments will make Lindholmen a bigger part than it already is and a more focal point for work and living. The number of residents that are planned to move into the new buildings is quite big to cause problems in the traffic and public transport lines. Adding to the residents, the number of temporary passengers to the restaurants, schools and other service providers in the area will increase as well. The current infrastructure system is quite under pressure and extra traffic will cause big traffic problems. New routes, new modes of public transport or even a total intervention in the infrastructure will be necessary.

1.3 Aim and outcome

The aim of this thesis is to analyze the current infrastructure and traffic situation in Lindholmen, find where the most vulnerable sections are, congestion points and queue lengths. Also, based on the population growth predictions from Gothenburg's Municipality, the thesis predicts and analyzes the traffic situation in *2035* if the infrastructure system remains as it is for future vehicle traffic, based on the city planning for the future of the area. Agent-based simulation tool VISSIM will be used to investigate how the traffic will affect the system. The outcome of the thesis will be to evaluate and identify all the problems and their reasons, identify present and future traffic challenges that the area will face and offer possible solutions to help with these problems.

1.4 Limitations

Counting limitations: traffic surveys were all conducted during the same time intervals (i.e., 7:30-8:30 and 16:00-17:00) in one day. Different points were counted on different days under different conditions. The traffic flow varies during the day and during different days. This means the flow which is analysed and used for the simulation is an aggregate of these flows.

Zone definition for matrix limitation: For the dynamic simulations, the zone separation and definition were done based on the type of usage of the area, trying to keep similar usage in one zone, and also based in neighbourhood concept or block separation. Although the zone composition was kept in mind, the separation does not accurately represent how the zones are divided and interconnected.

Signalling limitation: Signal timing representation in the model is too deal and does not accurately represent the situation in reality, but this is to a certain point compensated by studying the worst-case scenario.

4 step model setbacks and credibility: critique for the 4-step model:

- Created to estimate the impacts of building new roadway infrastructure
- Does not account for the induced demand or peak spreading
- Fails to incorporate information technologies
- Too many assumptions related to parameter values
- The eternal issue of capturing human factor properly

Closeness to reality regarding driving behaviour and pattern: Driving behaviour is set as aggressive according to a study from WSP. However, no matter how the model simulates, it lacks the randomness, unpredictability and motion of driving decision-making to accurately reflect the reality and include the observations made during the filming of the flow.

Effects of the new E6, new Hisingen Bridge and works in the central area and the areas around Lindholmen: The new highway E6 and new Hisingen Bridge will have effects on the area and the ability to access Lindholmen, which are not included in the simulations. Only the effects of population growth are included and not how these changes will redirect traffic, accessibility, decision making and vehicle behaviour.

Dynamic analysis: the zoning is not done for area 1, area 6 and area 9 because of their big seize and difficulty to find a representative value for the different parameters to calculate the OD matrix. Instead, traffic was surveyed in crucial points for this area and this traffic count is taken as attraction and production.

Road works: Road works that have caused Karlavagnsgatan closed which make can be reflected on the re-routing of the traffic and the actual traffic situation.

All these uncertainties and limitations show that the simulations are a tool to predict, as close to reality as possible, different scenarios or the worst-case scenarios, and help in the decision making and preventive measures.

1.5 Structure of the thesis

The thesis is organized and structured in a way that follows a logical flow and it is easy to comprehend and follow.

In the first part, chapter 1, is an introduction to the thesis, background and information about the studied area. The second part is focused in the theoretical background in which the thesis is developed and tools used to support the thesis. Chapter 3 or part three describes the data collection process, where and how this data was used and the methodology Part 4 present the results from the analysis for all the studied cases, which are the present situation and future situation based in prognosis, and results from the dynamic simulation used as validation. Chapter 5, the fifth part is a discussion section where suggestions and recommendations based on literature study and implemented solutions can help improve the current situation and avoid future problems. The last part, part six gives a review of the problems and where the future work should be focused, conclusions.

Chapter 1 introduction and history

Chapter 2 theory, main concepts, and tools used for this thesis

Chapter 3 data collection, data usage, and methodology

Chapter 4 results

Chapter 5 discussions

Chapter 6 conclusions

1.6 Objectives

The following questions are to be answered:

- What is the current situation of the traffic flow in Lindholmen?
- What are the main problems?
- How will the future situation of the traffic flow look like?

2. Theoretical Background

In order to understand the report some basic concepts have to be explained. The theory supporting this thesis is based on a literature study of Highway Capacity Manual, Highway Engineering and Traffic analysis and Lectures from Advanced transportation engineering course.

2.1 Highway Capacity Manual and Highway engineering and traffic analysis (book)

Objectives of using HCM and highway engineering and traffic analysis:

1) Specify performance measures and depict surveying methods for important traffic aspects and characteristics.

2) Provide methods for calculating, estimating and forecast performance measures.

3) Explain methodologies and details to interpret the aspects and elements affecting multimodal operation.

Highway capacity manual can be used for:

- Level of analysis

-Travel modes

-Spatial coverage

-Temporal coverage

-Transportation planners

Highway and road analysis for 2-lane highways uses the one direction procedure and the 2-direction methodology analysis is dropped. So the results of 2-lane highway are appropriate averaging and grading the one-direction results.

Highway capacity manual analysis can be used in a broader aspect and processes, for example:

- Air quality: Emissions can be estimated based on vehicle speed, which through HCM tools can be measured at the link level.
- Economic analysis: depending on information generated from the HCM
- Multimodal planning analysis: HCM suggests a unified, integrated, multimodal set of level-of-service measures for roads and streets. It also presents an integrated approach to jurisdictions.

<u>**Highway Capacity and Level of Service**</u>

The main objective of traffic analysis is to realistically quantify a roadways performance with regard to a specified traffic volume. The main challenge during this process is the adoption of the theoretical formulations to numerous conditions and situations that occur on the field. Field conditions must always be taken into account during traffic analysis. Nonetheless, the methodology must always remain theoretically coherent. Most of the concerns are flow-related since a wide range of physical and operational characteristics influence it and temporal fluctuations in traffic distribution.

Level-of-service (LOS) is a qualitative ranking of the conditions of traffic as it is experienced by drivers in a specified road, under traffic control. In order to apply the level of service concept, the necessary performance measurements must be selected so that it represents how the users actually perceive the quality of service in a way of measurable variables.

System performance measurement

HCM procedures help to estimate the capacity of highway sections and to determine volume-to-service flow ratios, or estimate speeds on parts of the system for mobility performance measures reporting. HCM helps to determine time delay related measure and queuing measure.

2.2 Main concepts

Main terms, concepts, and notions that are needed to perform the analysis and understand the purpose of the thesis and traffic analysis, are found and interpreted from the literature study of HCM and Highway engineering and traffic analysis:

Passenger transportation modes and traffic congestion

Private vehicles as a mode of transport offer an unequal level of mobility and independence for users compared to all available modes of urban transport. Users have been and are willing to pay and abide by all the problems just to have the flexibility in travel departure time and destination choices. This can be seen in the number of trips that are taken in private vehicles which are over 90% of the trips. While the number of trips has increased. The occupancy has decreased from 1.22 to 1.09, which shows that single-occupant vehicles are an increasingly dominant mode of travel leading to high congestions. There is number of initiatives to make other modes also attractive, but no one is as good as private single-occupant vehicles.

Base conditions

Base conditions are defined as those conditions that represent unrestrictive geometric and traffic conditions (Principles of Highway Engineering and Traffic Analysis, 2015).

For an uninterrupted flow, base conditions are related to the roadway segment through physical and environmental conditions like lane width, lateral clearance, terrain, access frequency, the driver population characteristics and the effects that the vehicles themselves have on traffic. Capacity will be larger in roadway segments with traffic conditions that meet the base values or even exceed them.

Values in excess of the base conditions do not increase the capacity of a roadway but values less than the base conditions will result in a lower capacity.

Base conditions as identified by the Highway Capacity Manual (by the Transportations Research Board) for uninterrupted flows:

- 3.6 m minimum lane width
- 1.8m minimum right shoulder clearance
- 0.6m minimum media lateral clearance
- Only passenger cars in traffic

- Urban areas only
- 3,2km or greater interchange spacing
- Level terrain (no grades greater than 2%)
- A driver population of mostly familiar roadway users.

Basic automobile flow parameters: Volume and flow rate are two parameters that help to quantify the number of vehicles passing through a point on a roadway during a certain given time interval. The primary function of a roadway is to provide mobility, while always keeping safety in mind, and achieving an acceptable level of performance.

Volume: The total number of vehicles that passes through a given point during a given time interval.

Flow rate: The equal hourly rate at which vehicles pass on a given point during a certain given time interval. There are 2 main categories of facility type: uninterrupted flow facilities and interrupted flow facilities.

PHF: Peak hour factor. Since the input data are expressed in hourly demands, the HCM uses PHF to translate hourly volume into a peak 15min flow rate.

$$PHF = \frac{Hourly\ volume}{peak\ hour\ flow\ rate} \text{ (within the hour)} \qquad (1)$$

$$PHF = \frac{V}{4} * v_{15} \qquad (2)$$

Average travel speed: A traffic stream measure based on a travel time observed on a known length of highway.

$$V_{avg} = \frac{L}{average\ travel\ time} \qquad (3)$$

Free-flow speed: The average speed of vehicles passing through a given segment, measured under low traffic volume conditions when drivers are free to drive at their desired speed.

Density: The number of vehicles occupying a given length of a lane or roadway at a particular instant.

$$D = \frac{V}{S} \qquad (4)$$

V-flow rate (veh/hour)

S-average travel speed

D-density (veh/km)

Traffic flow, speed and density

Traffic flow, speed and density are basic parameters/variables in traffic analysis. Traffic flow is defined as the number of vehicles that are passing specified road segments during a specified time t.

$$q = \frac{n}{t} \qquad (5)$$

q- traffic flow of vehicles per unit time

n- number of vehicles passing

t- duration of time interval

Usually, flow is measured by the duration of an hour, and referred as hourly volume. Speed for traffic models is defined as the necessary time for a vehicle to travel some known length of a roadway.

$$Us = \frac{l}{t} \qquad (6)$$

Where Us represents the space-mean speed with a unit of distance per time. l is the length of the roadway selected for measurements and t is the average vehicle travel time.

Traffic density represents the number of vehicles occupying a given length of roadway at some specified time.

$$k = \frac{n}{l} \qquad (7)$$

k- density, in veh/unit distance

n- number of vehicles

l- length of roadway

Flow Rates

Based on the facility type and type of traffic passing through a given segment at a given type flow rates can vary, also flow rates are affected by the road category. A generalized assumption is made based on this criteria for the 4 main road categories (Highway Capacity Manula, ss. 3-14):

- Freeways, considered to have a flow rate of 2400 passenger cars/h/lane with a free flow speed of 110-120 km/h and a flow rate of 2300 passenger cars/h/lane for a speed around 100 km/h
- Multilane highway, estimated flow rate of 2200 passenger cars/h/lane for speeds of 95 km/h and 2100 passenger cars/h/lane flow rate for speeds of 90 km/h
- Rural 2-way, 2-lane roads, this kind of facilities rarely serve at near capacity volumes and as a result the observation of the capacity is troublesome.
- Single direction roads operate to flow rate capacities of 1700 passenger cars/h/lane as a capacity under base conditions.

Another type of road category is urban streets with interrupted flows, which is not as straightforward as uninterrupted flow to estimate and observe. Moreover, signal timing on urban streets also effect the capacity.

Another factor influencing traffic capacity in urban streets is the presence of Transit. This kind of vehicles are longer than automobiles and have particular performance characteristics. They are treated as heavy vehicles in all type of roadways. The delays are interpreted as the time needed to serve passengers and are incorporated in the signaling methodology and signalizing priority. The Swedish generalized assumed flow rates are lower, 1800 pass cars/h/lane for speeds of 70km/h (Hasselblom S.)

Level of service criteria

In order to quantify the experience of the users of a roadway in measurable variables and determine the level of service, the level-of-service variables connected to density and speed are proposed and used. They are recognized measurement in quantifying the traffic situation and drivers' comfort. The Table 1 gives an overview of how these parameters relate to the level of service. The relationship between the criteria and the level of service can also be expressed and correlated as shown in Figure 1.

Table 1. *L.O.S criteria corresponding to traffic density(for speed of 95km/h)*

Criteria	L.O.S: A	B	C	D	E
Max density(passcar/km/lane)	≤11	>11-18	>18-26	>26-35	>35-45
Average speed (km/h)	95	95	95	90	88
Maximum v/c	0,3	0,49	0,7	0,9	1,0
Maximum flow rate(passcar/hour/lane)	660	1080	1550	1980	2200

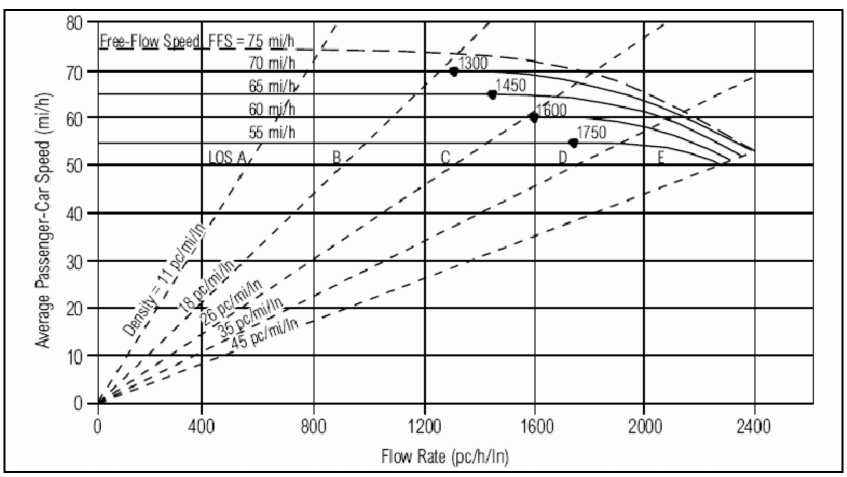


Figure 5: *L.O.S criteria and traffic parameters correlation*

Headway and spacing

Headway and spacing are 2 main concepts that are used during traffic analysis and especially useful and critical during the modelling of intersections and roundabouts.

- Spacing represents the measured distance between successive vehicles in a traffic stream, taken from the same point on each vehicle.
- Headway represents the time between successive vehicles as they pass through a point on lane or a roadway, also measured from the same point on each vehicle.

Both spacing and headway are microscopic characteristics, which relate to individual pairs of vehicles. Within every traffic stream, headway and distribution values are scattered over a range of values. The average vehicle spacing in a traffic stream is directly linked to the density of the traffic stream.

$$Density(veh/km) = \frac{1000\left(\frac{m}{km}\right)}{spacing\,(m/veh)} \qquad (8)$$

$$Headway(s/veh) = \frac{spacing\,(\frac{m}{veh})}{speeding\,(\frac{m}{s})} \qquad (9)$$

$$Flow\ rate(veh/h) = \frac{3600(\frac{s}{h})}{headway(\frac{s}{veh})} \qquad (10)$$

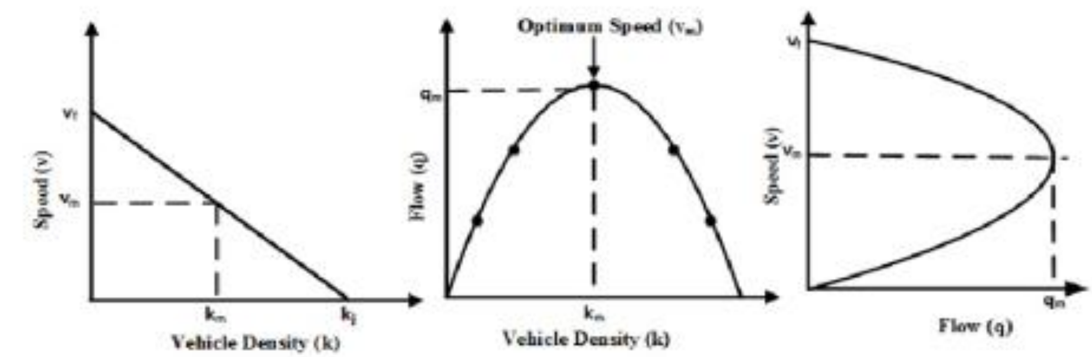


Figure 6: *Fundamental diagrams of speed-flow-density relationship (HCM, 2000)*

Signalized intersection flow

One of the most significant source of interruption in traffic flow is signal control in intersections. Effective green time is available for a moment, under which there can be uninterrupted flow. For example, if there is a 30s effective green time in a 90s cycle, it means that in an hour only 1/3 or 20min the flow can occur in an hour. If a lane has a capacity of 1800 veh/h, a total flow of 600 veh/h can be accommodated, since only 1/3 of the capacity can be accommodated effectively without interruptions.

Two concepts that are connected to signal timing and flow in intersections are saturation and total start-up lost time. The saturation flow rate describes the number of vehicles per hour per lane that could pass through a signalized intersection with an effective green time and the flow of vehicles never stopped without large headways were present. Start-up lost time is the lost time of the i_{th} vehicle in a queue that is passing through a signalized intersection.

$$l1 = \sum t_i \qquad (11)$$

l_1 – total start up lost time

t_i – lsot time for the i_{th} vehicle in queue

n – last vehicle in queue

For any given lane or movement in a roadway, vehicles use the intersection at the saturation flow rate for a period equal to the available green time plus the change interval minus the start-up and clearance lost time. Because lost time is experienced with each start and stop movement, the total amount of time lost over an hour is related to cycle number of signal timing (Highway Capacity Manual, 2016).

Queuing

When demand exceeds capacity for a period of time or when an arrival headway is less than the service time, at a microscopic level, at specific location, a queue is formed. Queuing is a key operational measure in traffic design. Queues longer than the average storage length can create several types of operational problems. In order to calculate and predict a queuing mathematically, it is necessary to specify some system attributes:

- Arrival pattern characteristics, which include the average arrival rate and statistical distribution.
- Service facility characteristics such as: service time, average rates, distribution and number of customers that can be served at the same time.
- Queue discipline characteristics, such as the means of selecting which customer is next.

In oversaturated queues, the arrival rate is higher than the service rate. In under saturated the arrival is less than the service.

$$Vtq = S * (t_q - r) \quad \text{or} \quad tq = S * r \qquad (12)$$

t_q – time duration of queue (s)

v – mean arrival rate (veh/h)

s – mean service rate (veh/h)

r – effective red time (s)

Lane distribution

The volume distribution by lane depends on the traffic regulations, traffic composition, speed and volume, number and location of access points. OD patterns of drivers. There is no typical lane distribution.

Variation in demand

The traffic volume counted in a given location on a given day is not always necessary representative. The amount of traffic should be counted on another random day or can be counted if an upstream bottleneck was not present or was removed. Traffic demand varies seasonally, weekly and hourly during a day. Variability in travel time has several sources including traffic incidents, work zones, environmental conditions, and fluctuations in demand, special events, traffic control devices (e.g., speed cameras) and inadequate base capacity.

During traffic or demand analysis for practical reasons, 15-min traffic surveying in the peak hour is conducted and used for investigation since the actual demand can be strenuous to identify. To account for all the variations, the peak hour demand volumes are reflective of conditions in peak days of the year.

Peak hour factor

The peak hour factor (PHF) is the hourly traffic volume during the maximum volume hour or peak traffic hour of the day divided by the peak 15-min flow rate within the peak hour. The demand fluctuation within the peak hour should also be considered in the analysis of the peak hour.

To account for the uneven variation arrival rate of the peak hour, the peak 15min vehicle arrival rate within the hour of analysis is usually used for practical traffic analysis functions.

$$PHF = \frac{V}{V_{15} * 4} \quad (13)$$

PHF – peak hour factor

V – hourly volume for hourly analysis

V_{15} – max 15-min volume within the hour analysis

4 – number of 15 min periods per hour

Travel time

Travel time can be defined as the time it takes to travel a certain stretch, from start to finish (Elefteriadou, 2013)

$$TT(h) = \frac{d}{Vavg} \quad (14)$$

TT- travel time (hours)

d- distance travelled (km)

Vavg- average speed (km/h)

Travel time is especially a useful expression as it is relatable and travellers or users of the infrastructure can plan their trip and choice of route when the travel time is known. However, as the travel time might be easy for the individual to measure it is hard to measure in a larger context, with a large group of vehicles. This because every car must be measured as individuals, which means that the same vehicle must be identified both at a starting point and its specific destination. This gets more complex as there are several starting points and destinations.

When the known ideal travel time is exceeded, the excess time is called delay (Elefteriadou, 2013). The same measuring problems for travel time also apply to delays, as the route of each individual vehicle must be known.

Travel demand and travel forecasting

Traveling is a human-driven behaviour and cannot be fully predictable, this is why travel volume tends to change over time and get effected by different socio-economic factors in different ways and respond to those factors in diverse ways. Also, traffic volumes are always under the effect of the physical characteristics of the highway network and will respond to any change that happens to it.

Traffic forecasting is a very useful tool that is used widely during the planning and design phases of new constructions in order to determine an appropriate pavement design and an appropriate geometric design for providing the right level of service and safety. Travel forecast also helps in improving the operational phase of a roadway and increase its effectiveness.

While forecasting traffic and travel demand, two elements must be carefully considered: the overall regional traffic growth or decline taken into account in a macroscopic perspective, and any possible traffic diversion that might affect the traffic flow and volume in a microscopic level. Forecasting should be done with the theoretical background in mind but also an understanding of travellers' decisions. There are 4 distinct but linked decisions concerning trips:

1) Temporal decisions
2) Destination decisions
3) Modal decisions
4) Spatial or route decisions.

The outcome of the combination of these traveller decisions with theoretical knowledge is highways traffic, the prediction of which is the objective.

The formula that will be used to predict the growth of the area and as a result, the future relevant flows in this thesis is based on an exponential growth compound. Exponential growth predicts the future volume for a given year based on a percentage of growth from previous years or predicts growth for next year. This growth can be associated with GDP growth, population growth and generally growth of an area where we have good knowledge and data about land use.

$$Future\,Volume = Base\ year\ volume * (1 + growth\,rate)^{number\ of\ years}$$

$$Volume\,F.Y = Volume\,B.Y * (1 + Gr)^{(F.Y - B.Y)} \qquad (15)$$

For future forecasts in a dynamic model, land-use change is considered. By considered I mean that the number of inhabitants, office space, apartment number and space and retail area is changed. Demand and users are changed by the information provided from future projects, if they give specifications to a number of users or inhabitants or through standard formulas with a margin of error. These changes are reflected accordingly to the number of attractions and productions produced (by means of regression analysis) by the areas and the number of trips exchanged between them (Trafikverket standards). The calculations and tables of the dynamic model are presented in the appendix.

2.3 PTV Vissim

Vissim is a software that is used as a tool to compare junction geometries, analyze public transport or analyzing signal effects through simulation of traffic patterns. Private motorized vehicles, goods transport, public transport of any kind, pedestrians and cyclists are simulated in a scientifically tested model providing realistic motion for all users.

The software offers flexibility in several respects: the concept of links and connectors allows for a more complex level of geometric modeling. Attributes for driver and vehicle characteristics enable individual parameterization. Furthermore, a large number of interfaces provide seamless integration with other systems for signal controllers, traffic management or emissions models. Another advantage of Vissimis its dedicated motion models for motorized traffic, bicycles, and pedestrians that make a valid assessment and a realistic representation of all traffic-related aspects possible.

The links and connectors concept offers a possibility for higher accuracy. They allow mapping the network in detail and model different geometries – from a standard node to complex intersections. The inclusion of scientific behavioral models such as Prof. R. Wiedemann's car-following model, or the Social Force Model for pedestrians, also ensures the realistic behavior of all road users within the existing and planned infrastructure. Vissim is a software package built on a base of intensive scientific research and continuous development.

3. Methodology

The main hypothesis in this thesis are that the current infrastructure system in Lindholmen area is not suitable and cannot support the changes that are happening, thus congestions and problems in traffic will arise. In the base of this prediction, a new infrastructure system will be required with added public access to support sustainability.

This section gives an overview and explains how the Vissim model was created for static simulation and dynamic simulation. The separation of the area in zones, the logic and reason of the division will be described. Explanation of calculations, effects of change of population and land use in the calculation will be given. Definition of some key concepts that will be used later, will be explained. Creation of the worst-case scenario based on the gathered data by filming the traffic flow will be given. Performance measurement and comparison parameters and mechanism will be provided in this section as well.

3.1 Data collection

Data for the static simulation were collected by surveying the traffic flow during peak hours of the days covering morning peak hour 7:30-8:30 and afternoon peak 16:00-17:00. The hours when everyone needs to go to work and leaves work. The surveys were done during November, which was a good representation since it is a month that most people are working and very few are on vacation. November is a month that usually has heavy traffic and the fact that is winter season which might push some people to use their vehicles more. Therefore, it is a good condition for my analysis. The surveys were done in 13 points (detailed data are available in the appendix). The traffic flow and vehicle behaviour was surveyed in the area. The survey in each point is divided in four 15-min clips. The sum of the max 15-min conjoint clips multiplied by 2 is taken as the bases for the max worst case scenario flow.

For the dynamic simulations, the area was separated into 12 zones. The zones were divided to ensure that there is a homogenous population or land use in each zone. Information about the number of employees was collected from a report performed by WSP (N.D.A) and residents from Eniro, an online source, and Gothenburg's Municipality data.

3.2 Model establishment

To create a computerized version of Lindholmsallén infrastructure system PTV Vissim was used. The software offers a background map that was oriented to show Lindholmen, more specifically Lindholmsallén.

Figure 7: *Map of the area taken as background for the construction of the Vissim model*

Using the command <u>links,</u> the infrastructure system was created in the software based on the map. Links represent the main roadway system but also are used to create connectors that are used to attach links together. With a clear division of entry points and exit points. 13 entry links and 13 exit links were specified in the model. This specification is decided by the direction of the flow in the link when it is created. All the entry links direct the traffic inwards, towards Lindholmsallén and the exit links take the traffic outwards. The main artery/link, which is mostly a straight roadway with direction from north-east to west, southwest is linked with the secondary links through connectors which create the curves and turns of this system. The links were carefully placed so that the geometry would be as close to the real one as possible and also the lanes where assigned as they are in reality, which is an alternation between 2 and 1 lane per direction. These lanes were assigned only for motorized vehicles for private usage or personal vehicles.

The 2-middle links consist of 1 lane each in opposite directions which are exclusively used by public transport, which in this area is only available as buses. The only links that are used by both personal vehicles and public transport are links of entrance 25 and exit 26, entrance 1 and exit 2.

The designed speed was set at 40km/h, for both public transport and personal vehicles. Reduced speed areas were assigned during the entrance on every curve, as it coincides with the real behaviour of vehicles on the roadway. Roundabouts were created through the add circular link command and connected with connectors to the links. The connectors were made as short as possible in modelling as to not affect the vehicle behaviour and approach reality as soon as possible. Parts of the roundabouts were made accessible for both personal vehicles and public transport.

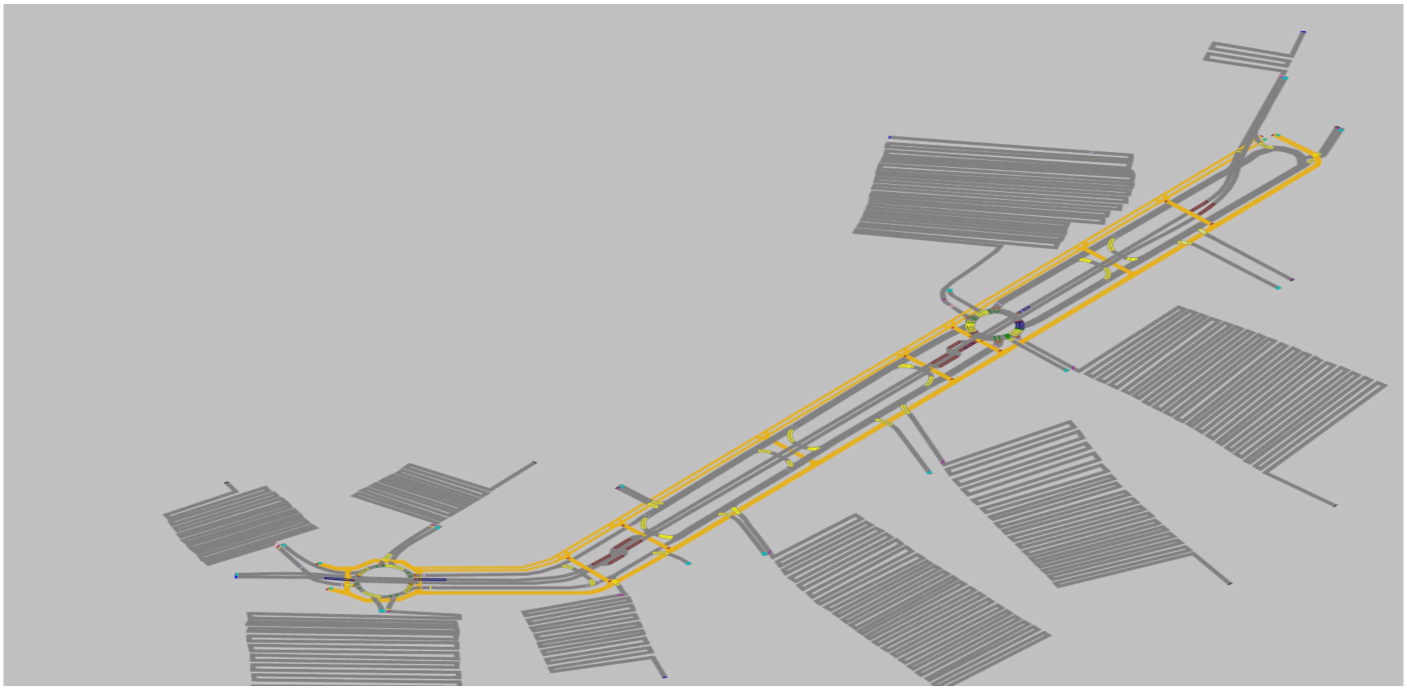


Figure 8: *Finished infrastructure system model in Vissim*

3.3 Traffic signals, priority rules and signal timing

Directing the traffic in the right sense is done by determining the lane direction when creating the link. Also where there are 2 lanes, the direction will indicate the path a vehicle should follow. In case of turns, the lane is connected with the outgoing traffic link through a short connector, while the rest continues straight. This short connector directs the vehicle behavior by suggesting that if they want to turn right they need to keep the right lane, because that is the one linked with the outgoing (exit) link.

In the roundabouts, the public transport link was made to go straight through it, with the exception of the public transport lines coming and going towards Lundby. The incoming and outgoing traffic was linked directly with short connectors to the appropriate lane of the roundabout and also short connectors were created that imitate the behavior of the vehicles inside the roundabout and the way they have to change or keep the same lane while in the roundabout and wanting to turn.

Priority rules were applied according to Swedish regulations. If there is no priority sign than the right-hand rule applies, it means that vehicles coming from the direction right of your vehicle have the advantage of passing, otherwise the priority signs should be respected. Bus lanes have been made to always have priority over the other modes in the points where they meet with other transport mode lanes. Also, pedestrian/cycle lanes always have priority of passing over vehicles.

Parameters for priority rules depend on the roundabout type. The parameters that mostly need to be adjusted are the minimal gap time and the minimal headway gap. The minimal time gap is the time period that the vehicles, traveling in the roundabout needs to reach the end of the conflict area with the entering link. As a consequence, all vehicles entering the roundabout have to wait until the time gap is bigger than the defined minimum time gap. The headway gap is the length of the conflict area.

The difference to a normal junction is that the minimum time, the minimum headway and the minimum gap time in a roundabout will be displayed separately in order to get results that are more realistic. For normal traffic flow, it is mostly the time gap that is relevant. In the case of slow-moving traffic and congestion, the headway is relevant. Every incoming vehicle checks 2 conditions:

1- Is the gap between two approaching vehicles inside the roundabout big enough to enter the roundabout?

2- And is there any slow-moving vehicle inside the roundabout blocking the area that I want to merge into (headway) {connector-connector conflict}.

In my model, the headway is expressed in terms of distance and set for both roundabouts at 8 meters and the gap time is expressed in seconds and set at 2,4 seconds, in the one-lane roundabout. In the 2 lane roundabout the gap time to the external lane is set at 1,8 seconds (attach snips from the model).

Signal timing was added through bussprio. Detectors were set in links before a junction or a roundabout that detect the approaching busses and signal the traffic in the roundabout or junction to stop, giving the buss priority to pass. The timing for the buss is set in automatic by the model by dividing 5400(which is how many seconds the one simulation run is) by the number of busses that go through the area during the observed hour. The software then calculates the timing between the busses arrival. Service time for users of public transport is 35-45 seconds.

3.4 Travel time and queuing results

- **<u>Time travel and queuing calculation</u>**

The travel time between the main nodes is calculated by the software with the help of vehicle travel time sensors. The sensor defines the section to be measured. For each section, we define a start and a destination cross-section. The average aggregate travel time is counted from the moment a vehicle crosses the start until it reaches the destination cross-section, this travel time includes also the waiting or dwells times. During a simulation run, VISSIM can evaluate average travel times (smoothed) if travel time measurement sections have been defined in the network. Only vehicles of the selected class(es) will be measured. The distance between the start and end cross-section is chosen and determined by the shortest route. Vehicles traversing both, start and end cross-section within a single time step, are not regarded for travel time measurements by default from the software.

- **<u>Queuing sensors</u>**

In order to measure queue length, Vissim offers a tool called queue counters which gives as output: Average queue length, Maximum queue length and number of vehicle stops within the queue

Queue measurement is done from the location where the queue counter is placed on the link or connector upstream to the final vehicle that is still in queue conditions. If the queue builds up and backs up to multiple and different approaches, the counter will gather information from all of them and report the longest as the maximum length of the queue. BOQ or the back of the queue is monitored and until there is no vehicle in queue conditions. Queue length output is expressed in units of length and not in number of cars. The sensor will gather information and monitor the queue as long as there is a ‘’queue remainder’’. Vissim counts vehicles as being in a state of queuing if they have a speed lower than 5 km/h or if it is completely stopped. The vehicles are no longer considered in a queuing state if their speed is higher than 10km/h or the vehicle gap distance is higher than 20m. This means that the vehicles are counted as in a queue both when they are stopped and are moving very slowly forward. The maximum a queue length can reach is until the location of the next queue counter located upstream. Queue counter sensors can be placed anywhere within a link or connector but, it is recommended and more suitable to be placed at the stop line of signalized intersections.

3.5 Computation of Traffic Measurement

- **<u>Computational Procedures for Delay Related Measures</u>**

The steps for estimating delay time from vehicle trajectories involve aggregating all delay means over each time step. The results of the computing are given as a combined delay and not a unit of time delay. In order to figure out the unit delays, the aggregate delays must be divided by the number of vehicles participating in the calculation. The steps used to measure and calculate the various delay related measures according to the Highway Capacity Manual are:

- *Time step delay*: the extent of the time step that it took for the vehicle in the simulation subtracted by the time it would have actually taken the vehicle to cross the distance traveled in the step at the determined speed.

- *Segment delay*: The time it actually took to traverse a given segment minus the time it would have taken to cross the same segment at the given desired speed. The segment delay on any step is equivalent to the time step delay.

- *Queue delay*: Queue delay is equal to the time step delay on any step in which the vehicle is in the queued state, if the vehicle is not in that state then it is zero.

- *Stopped delay*: This is equal to the time step delay on any step in which the vehicle is in a stopped state, if not then it is zero. A vehicle is considered to be ‘’stopped’’ if it's traveling at less than the starting speed. A coherent definition of stopped delay demands that the travel time at a target speed be subtracted.

- *Control delay*: Is the additional travel time caused by the operation of a traffic control device.

- **Computational Procedures for a Queue Relate Measures**

These procedures start by determining whether each individual vehicle in a segment is in a queued state. A vehicle is thought to be in a queued state if it has entered a queue and has not left it yet. The start of a queue happens when:

- The gap between a vehicle and the vehicle in front of it is less than or equal to 6 meters (20ft)
- The vehicle speed is greater than or equal to the front vehicle speed
- The vehicle speed is less than or equal to one-third of the desired speed

A separate case must be created and established for the first vehicle that arrives at the stop line. In an interrupted flow case, the beginning of the queued state also happens when:

- No leader is present on the link
- The vehicle is within 15 meters (50 ft) of the stop line
- The vehicle is decelerating or has stopped.

The ending of the queue state also needs to be determined. The analysis is done on a link-to-link basis. Hence a vehicle (in a queue state) leaving a link immediately enters the queue on the next link in a continuum. Other conditions need to apply at the end of the queue state to occur:

- The vehicle has reached two-thirds of the desired speed (in uncongested operation)
- The first vehicles speed is greater than or equal to the vehicle speed or the vehicle has no front running vehicle in the same link

The maximum queue reach (back of the queue, BOQ) is a more useful estimate than the number of vehicles in the queue because the BOQ causes blockage of lanes and congestions. The maximum BOQ is achieved when the queue has almost diffused. There are two important uses of the BOQ which help in the analysis, the probability that a queue will back up beyond a specified point and the amount time that the queue will be backed up beyond a specified point.

- **Procedure description**

The first step is to collect the basic data for analysis. The basic data are:

The number of time intervals: the number of time intervals is input to size the analysis with the correct time dimensions.

Time interval duration: fixed in 15 min. The simulation assumes that there is instantaneous travel time between segments when demands are computed on segments.

Time step duration: when oversaturation is reached the procedures move to time steps. The analysis interval moves from 15min to 1min time steps for queuing effects.

Jam density: the system wide jam density is required for oversaturated analysis. Default value is 190 pcu/min/lane.

3.6 Changes in Land Use

Information about planned changes in land use is gathered through official sites. The considered land use changes include the planned changes constructions, number of planned occupants and users for the changes plus rise of population in the areas that are outside of Lindholmen but affect it. Through the number of users, inhabitants, type, and number of buildings and their use, we can calculate the number of vehicle trips, as planned by Trafikkontoret, with the help of resekalkyl. Resekalkyl is an online service by Trafikkontoret that helps users calculate number of travel (journeys) and freight or general vehicle transport by exploitation. But also, we can only use the predicted number of users and areas of different buildings according to their planned usage to calculate demand in our OD matrix and predict the flows with the help of the user manual that set the parameters for the number of trips for each type of building.

Table2. *Number of trips per person and day for different categories (from top to bottom: housing, daycare, school, business, culture, office, health)*

Category	Area per person(m2)	Travel per person per day
Residential	1,7	2,6
Day-care	11,6	6,4
School	9,1	3,2
Business/shops	3,3	2,2
Culture	2,2	2,1
Offices	24,0	2,2
Care/healthcare	85,5	4,7

3.7 System performance evaluation

A complex infrastructure system like the one in Lindholmen, with interrupted flow, can be hard to evaluate in terms of capacity. In order to evaluate the systems performance, parameters that affect the user experience will be studied and compered. The two parameters that effect users most and can be quantified are travel time and queuing. Travel time estimation and prediction is of high importance to transportation professionals, transportation managers and off course travellers. The reliability of travel time estimates on a given corridor helps with understanding and predicting congestions (Lyman et.al 2008). Travel time will be expressed as the time it takes for the vehicles to go from one node to another. The concept of travel time can be connected with vehicle travel time, in order to help determine the level of service. Queuing can be connected to vehicle density, in the level of service parameters. Queuing can cause problems for users but also the system itself, if for example a queue is long enough to affect the traffic of an adjacent crossing or roundabout. In such cause a disruption of traffic can be caused. Based on the comparison of these two parameters the infrastructure will be evaluated and discussed for present use and future use.

3.8 Dynamic model creation

The dynamic model will be used as a validation and control model for the main static simulations. If the results are similar, it means that the static model stands and can be used to derive conclusions and recommendations.

In the base model for the dynamic model, mostly driver behaviour, driving conditions, vehicle type distribution and regulations are kept the same as for the static model. The model was constructed exactly the same way in its base, links, connections, public transport lines, pedestrians, roundabouts. The area was separated into 9 zones for the analysis and later matrix creation.

3.9 Dynamic coding

In dynamic coding the traffic demand is not specified by using vehicle inputs for different links, with a given relative traffic volume, instead, OD matrix/matrices are used. In origin-destination matrices, the start and endpoint are specified and the number of trips between them. The size of the matrix is equal to the number of zones squared. In a simulated network, there are, usually, multiple options the drivers can choose to go from one point to another. The simulated traffic flow must be distributed between these points as realistically as possible. Using the given traffic assignment, the traffic demand is distributed among various paths. Coding in Vissim follow these steps:

- **<u>Zone creation</u>**

After the area is separated in zones accordingly, these should be also reflected in the software. Open the menu zones – network- zones. We add all the zones using the same number and name as in the matrix and also keeping the same order.

- **<u>Create parking lots</u>**

Parking lots are added at the end of links, one representing the origin and one representing destination. Their type should be chosen as zone connector, carefully so to choose the right zone. The origin parking lot will have relative flow 1, which means that the traffic from this zone will be generated from this parking. If there are two or more origin parking lots for one zone then the relative traffic will be split between them, always making sure the sum will be 1(100%). Destination parking lots have a relative flow of 0, no vehicle generated, the parking lot is used only as a destination.

- **<u>Nodes</u>**

Nodes are created at the end of every link and at every intersection, for dynamic assignment use. Nodes at the end of links should not overlap with parking lots and the nodes at intersections should not overlap with connectors.

- **Add matrix**

At the traffic tab- dynamic assignment- matrices and choose the add button to add our matrix. One important step is defining the time interval, which usually is 1 hour. If not, then the matrix should be converted before adding it to Vissim. The second most important thing to choose in a dynamic modelling matrix is to choose an equilibrium assignment. This will redistribute demand across different paths proportionally to costs.

- **Creating paths by converging**

We activate the convergence and travel time on edges with parameters 15% and 95%.

3.10 Dynamic simulation

Dynamic simulation in Vissim uses the same matrix as static simulation for morning peak hour and evening peak hour. In this case, the software runs 50 simulated scenarios with the vehicles taking different routes until the best is decided. After the best route is decided and simulated in a scenario the results about travel time and the queue will be compared with my static model for validation and to check if the model stands and results are reliable.

3.11 OD Matrix Creation

A 12 by 12 matrix is created in excel. The rows in each cell are completed by dividing the main traffic that enters at that point and how the flows divide in different crossings and different nodes. This division gives also the relative flow for each route in relation to the total number of vehicles. After all the rows and cells are complete with the right values, the sum of each row is calculated and the sum of each column is calculated. These two sums should be equal, but rarely are in complex models. The adjustment factor is calculated by dividing the production sum (sum of all rows) with the sum of the attractions (sum of all columns). The new OD matrix is created by multiplying all the values of the first matrix with the adjustment factor. To check if this matrix is the right one with the right values for each route, the sum of all columns and the sum of all rows are calculated and they are equal. This are the values I used and inserted in Vissim for the analyses.

Traffic flows for the year 2035 where predicted/calculated by using Equation 15. All the individual flows of each route where calculated and the results gives a new OD matrix with new flows. These flows represent the future traffic in the area and their sum the future Attractions and Productions.

4. Results and analysis

Vissim runs 10 simulations of 5400s in the worst-case scenario. These simulations are different as to represent different cases and behaviours. The results about the queuing length and travel time in these situations are an average aggregate of the aggregate result of the 10 runs. Based on these results we can deduct if the system is capable and up to date with the current traffic situation and how it will react to the future one. As previously mentioned the two parameters that can be measured and that reflect the user experience based on L.O.S are queuing length, which if too long might affect the system or conjoined systems for worse and travel time between the main points of the system.

Travel time is measured for the route between the 3 main entry points, which also have the most vehicle flows. Travel time counters are set for the following:

1 – Vehicles entering from Frihamnen by Lundby Hamngatan and exiting in Polstjarnegatan (red line)

- Vehicles entering from Frihamnen by Lundby Hamngatan and exiting at Regnbågsgatan towards Lundbyleden.(yellow line)

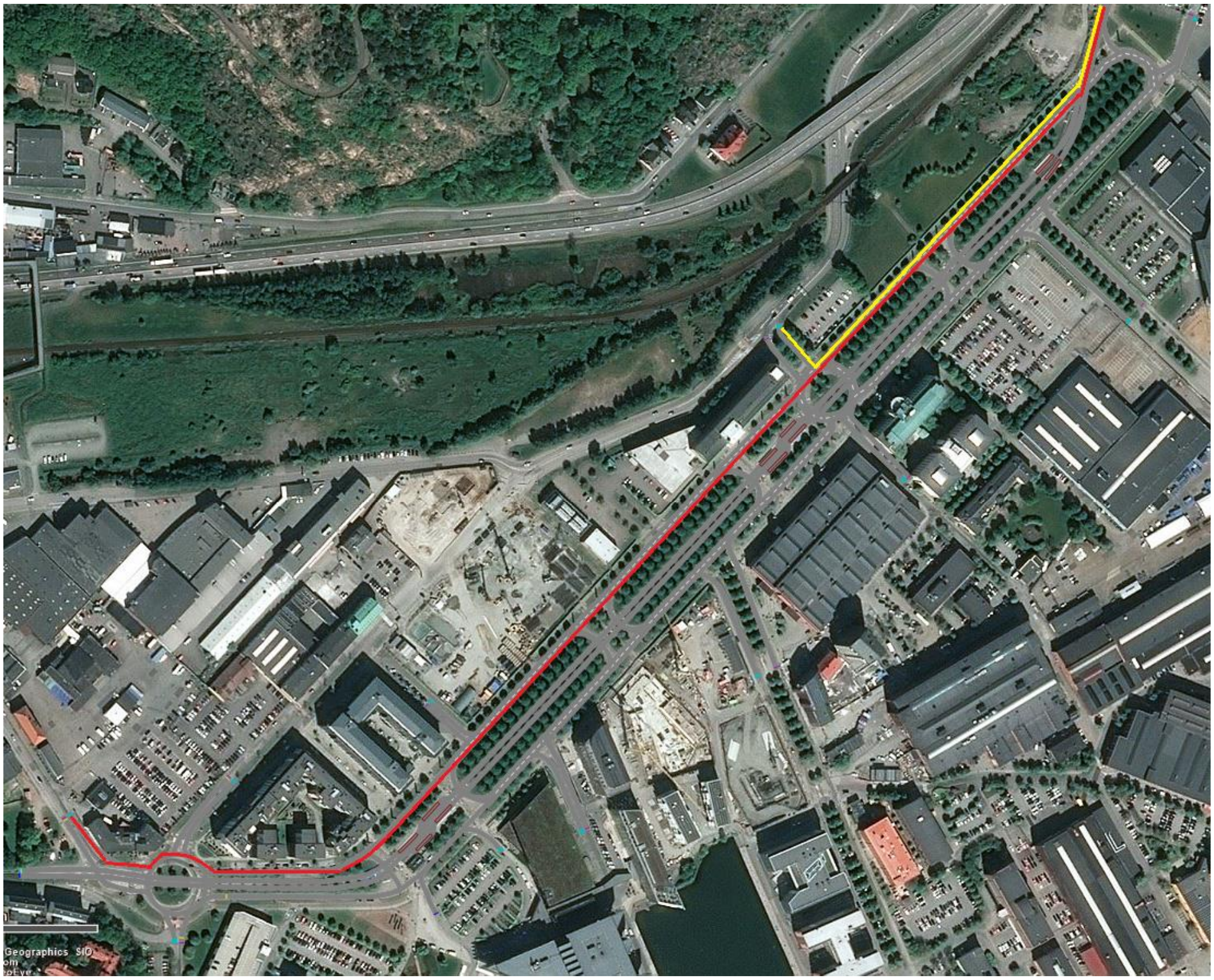


Figure 9: *Travel time measurement 1&2*

2 – Vehicles entering from Polstjarnegatan and exiting Towards Frihamnen by Lundby Hamngatan(red line)

- Vehicles entering from Polstjarnegatan and exiting towards Lundbyleden by Regnbågsgatan(yellow line)

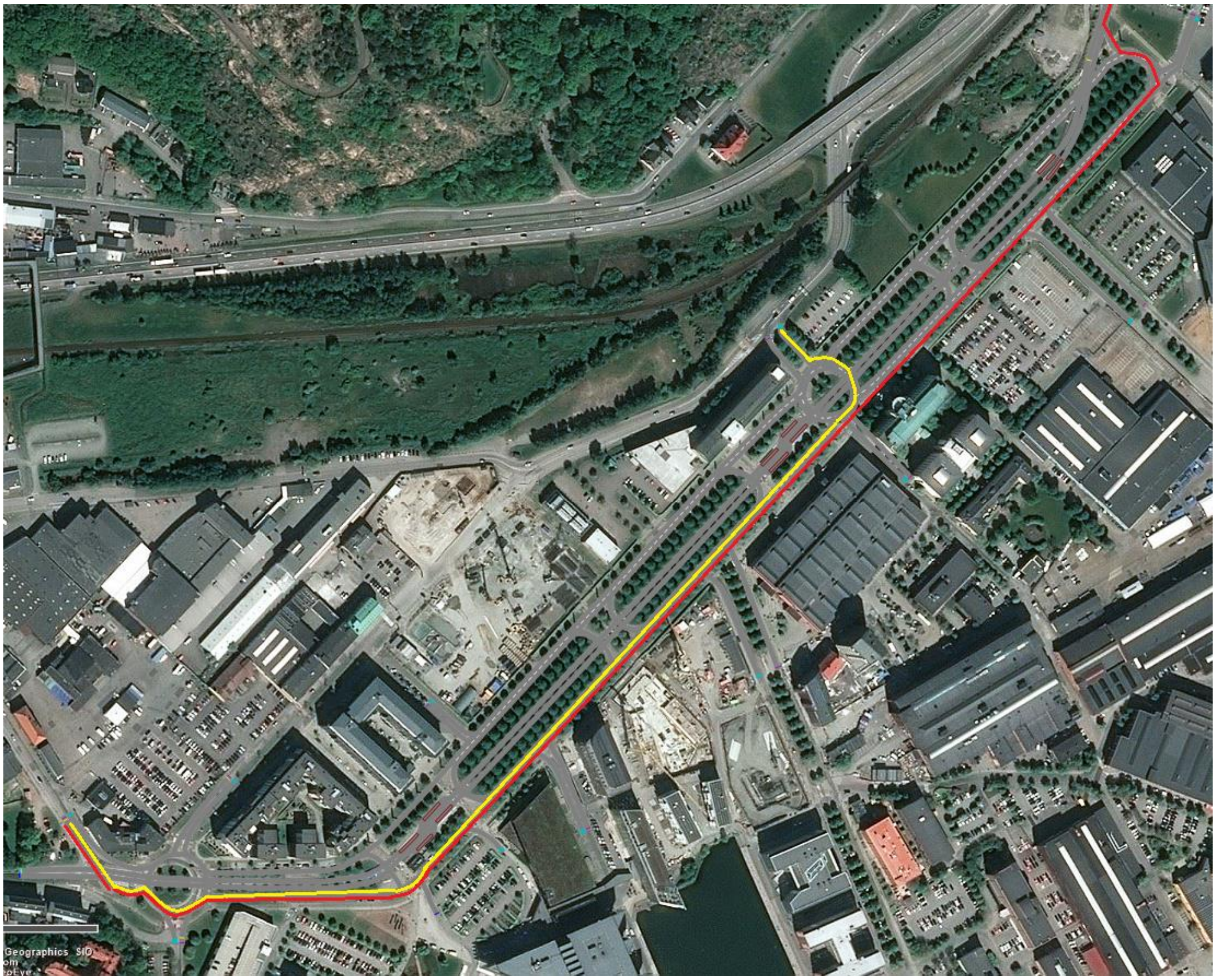


Figure 10: *Travel time measurement 3&4*

3 - Vehicles entering from Lundbyleden by Regnbågsgatan and exiting Towards Frihamnen by Lunby Hamngatan(red line)

- Vehicles entering from Lundbyleden by Regnbågsgatan and exiting at Polstjarnegatan(yellow line)

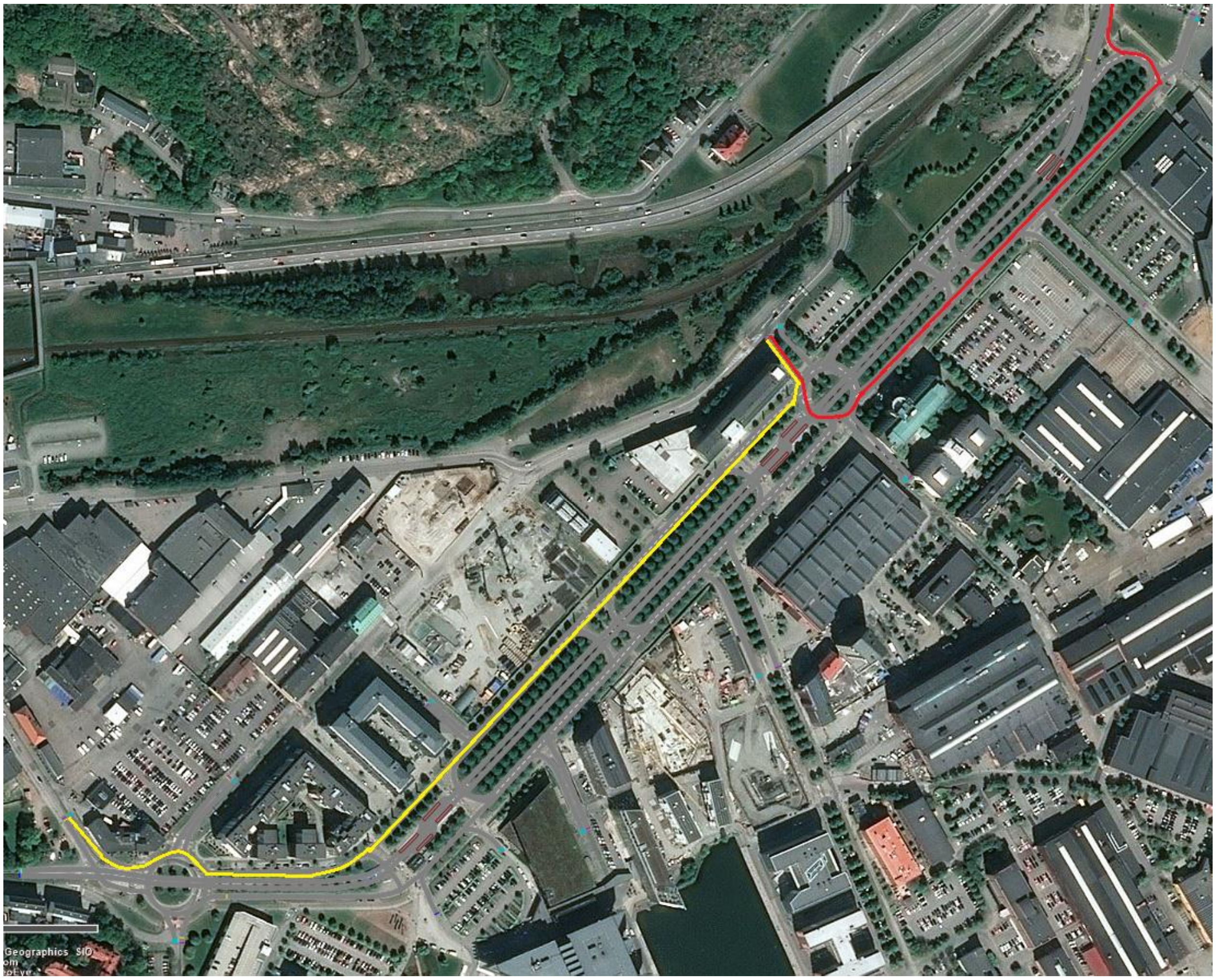


Figure 11: *Travel time measurement 5&6*

4.1 Current situation

The choice to measure these routes is made since they are the main entry and exit points. They lead to the most populated areas around Lindholmen, which as a result produces more traffic. The measurements are done for the worst-case scenario during the morning peak hour, 7:30 - 8:30(FM) and evening peak hour, 16:00 – 17:00 (EM). The time travel results are represented as the average aggregate of the 85% percentile of the selected time periods.

In order to evaluate the travel time of the worst-case scenario, we compare it with the time it takes the vehicles to cover the same distance in an as close to free flow conditions as possible, which according to Sebastian Hasselblom (expert in traffic analysis and simulations with WSP) 40% of the worst-case scenario flow, during the same peak hours. (as close to free flow)

- Worst case scenario morning peak hour, average aggregate 85% percentile

Table 3*. Travel time of worst case scenario morning peak hour in seconds.*

Travel time counter		
Nr.	**Name**	**Time, avg agg. 85% (seconds)**
1	Friham-Regnbågs	52
2	Friham-Polstjarn	139
3	Polstjarn-Regnbågs	239
4	Polstjarn-Friham	237
5	Regnbågs-Friham	125
6	Regnbågs-Polstjarn	129

Table 4*. Travel time of worst case scenario morning peak hour in minutes.*

Travel time counter		
Nr.	**Name**	**Time, avg agg. 85% (minutes)**
1	Friham-Regnbågs	1
2	Friham-Polstjarn	2
3	Polstjarn-Regnbågs	4
4	Polstjarn-Friham	4
5	Regnbågs-Friham	2,1
6	Regnbågs-Polstjarn	2,2

One thing that is to be noted is that the travel time from Regnbågsgatan is measured only by the point that the vehicles enter the route towards Lindholsmallén. This measurement sensor if moved further outside towards Lundby the vehicle time becomes even longer since there is visible presence of long queuing.

- 40% scenario morning, average aggregate 85% percentile

Table 5. *Travel time of close to free-flowing conditions morning peak hour in seconds.*

Travel time counter		
Nr.	**Name**	**Time, avg agg. 85% (seconds)**
1	Friham-Regnbågs	55
2	Friham-Polstjarn	133
3	Polstjarn-Regnbågs	159
4	Polstjarn-Friham	167
5	Regnbågs-Friham	123
6	Regnbågs-Polstjarn	115

Table 6. *Travel time of close to free-flowing conditions morning peak hour in minutes.*

Travel time counter		
Nr.	**Name**	**Time, avg agg. 85% (minutes)**
1	Friham-Regnbågs	1
2	Friham-Polstjarn	2
3	Polstjarn-Regnbågs	3
4	Polstjarn-Friham	3
5	Regnbågs-Friham	2
6	Regnbågs-Polstjarn	2

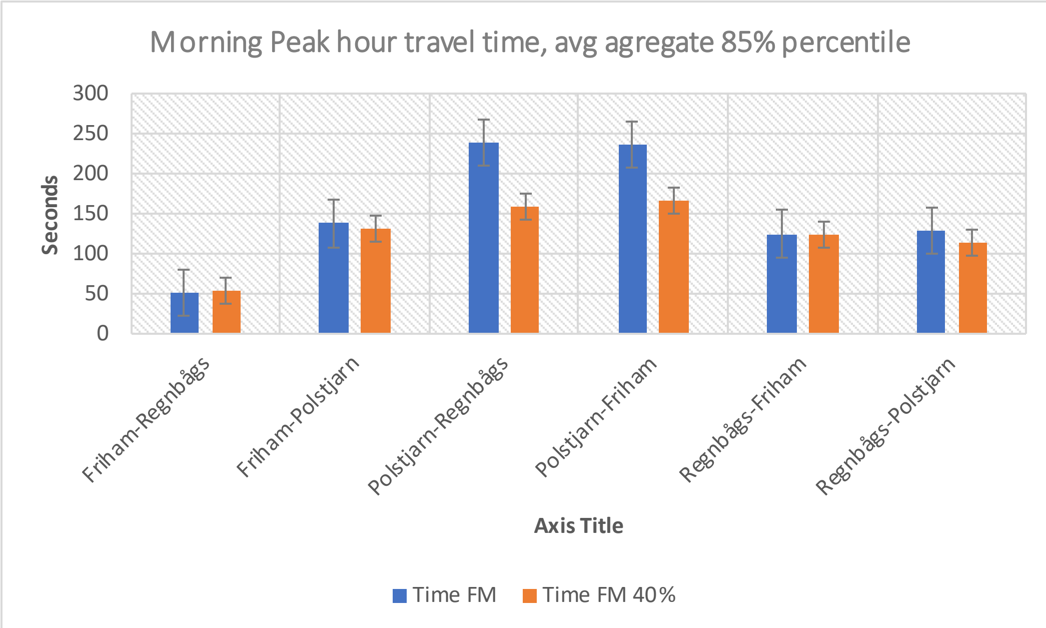


Figure 12: *Morning peak hour travel times, worst case scenario and 40% of the worst-case flow. In seconds.*

The comparison of the results shows that in the worst-case scenario, the time it takes to travel the same distances it's almost 60 s more for the main corridors. Which understandably causes dissatisfaction to users for such short distances. It causes queuing and lower level of service.

Figure 12 shows the visible difference in travel time. The biggest and most noticeable differences are seen in corridors that lead from residential areas towards more central parts of the city. This longer travel time is also an indication of queuing and lower travel speed. Lower travel speed means that the L.O.S is lower than what is predicted.

- Worst case scenario evening peak hour, average aggregate 85% percentile

Table 7. *Travel time of worst case scenario evening peak hour in seconds.*

Travel time counter		
Nr.	**Name**	**Time, avg agg. 85% (seconds)**
1	Friham-Regnbågs	61
2	Friham-Polstjarn	115
3	Polstjarn-Regnbågs	413
4	Polstjarn-Friham	461
5	Regnbågs-Friham	117
6	Regnbågs-Polstjarn	162

Table 8. *Travel time of worst case scenario evening peak hour in minutes.*

Travel time counter		
Nr.	**Name**	**Time, avg agg. 85% (minutes)**
1	Friham-Regnbågs	1
2	Friham-Polstjarn	2
3	Polstjarn-Regnbågs	7
4	Polstjarn-Friham	8
5	Regnbågs-Friham	2
6	Regnbågs-Polstjarn	2,7

By observing the travel times of the routes, it can be deducted as to which ones are mostly used and have heavier traffic. This traffic can cause lower travel speeds, and also which segments are less used and have a travel time close to free flow travel time.

- 40% evening scenario, average aggregate 85% percentile

Table 9. *Travel time of close to free-flowing conditions evening peak hour in seconds.*

Travel time counter		
Nr.	**Name**	**Time, avg agg. 85% (seconds)**
1	Friham-Regnbågs	55
2	Friham-Polstjarn	50
3	Polstjarn-Regnbågs	152
4	Polstjarn-Friham	158
5	Regnbågs-Friham	55
6	Regnbågs-Polstjarn	101

Table 10. *Travel time of close to free-flowing conditions evening peak hour in minutes.*

Travel time counter		
Nr.	**Name**	**Time, avg agg. 85% (minutes)**
1	Friham-Regnbågs	1
2	Friham-Polstjarn	1
3	Polstjarn-Regnbågs	3
4	Polstjarn-Friham	3
5	Regnbågs-Friham	1
6	Regnbågs-Polstjarn	2

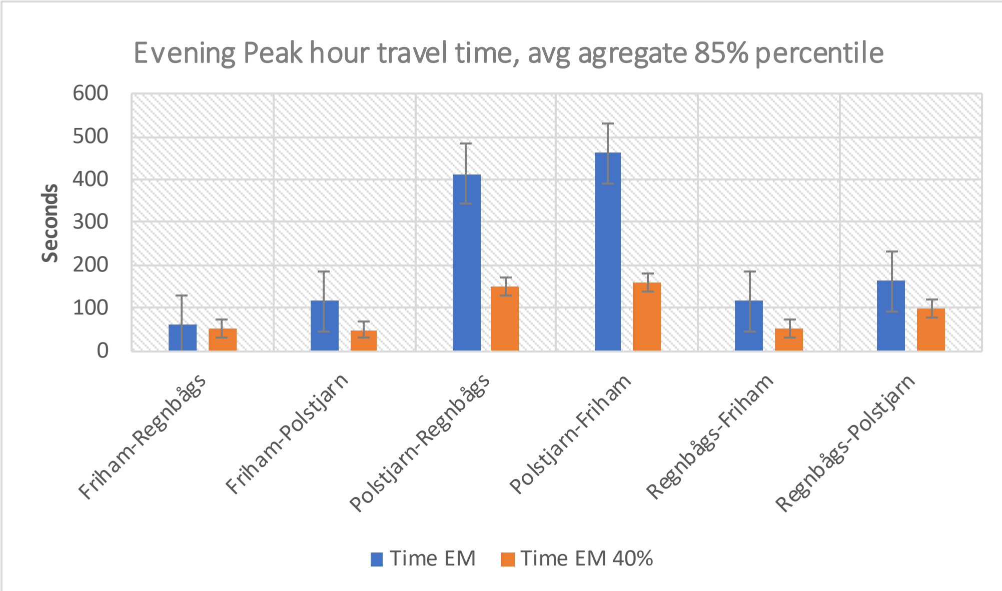


Figure 13: *Evening peak hour travel time, worst case scenario and 40% of the flow of the worst case, in seconds.*

Again, the results show a sharp decline on critical routes which shows again the bad ability of the current infrastructure system to handle heavy traffic. And that the evening traffic is more concentrated is certain areas. This areas are connected with roads that lead to residential areas or intersection/roundabout for multiple points that lead to residential areas.

The diagrams show clearly the step difference and between the most used roads with long travel times, which can be connected also to queuing and the difference between the heavy traffic worst case scenario and 40% traffic condition.

4.1.2 Queuing

Queuing counters are set near crossing points and points of signalized traffic control or points of interest like pedestrian crossing near the school. Queue counters measure queue formation form the specified point and backwards. The figure below demonstrates where the queuing counters are set for this analysis.

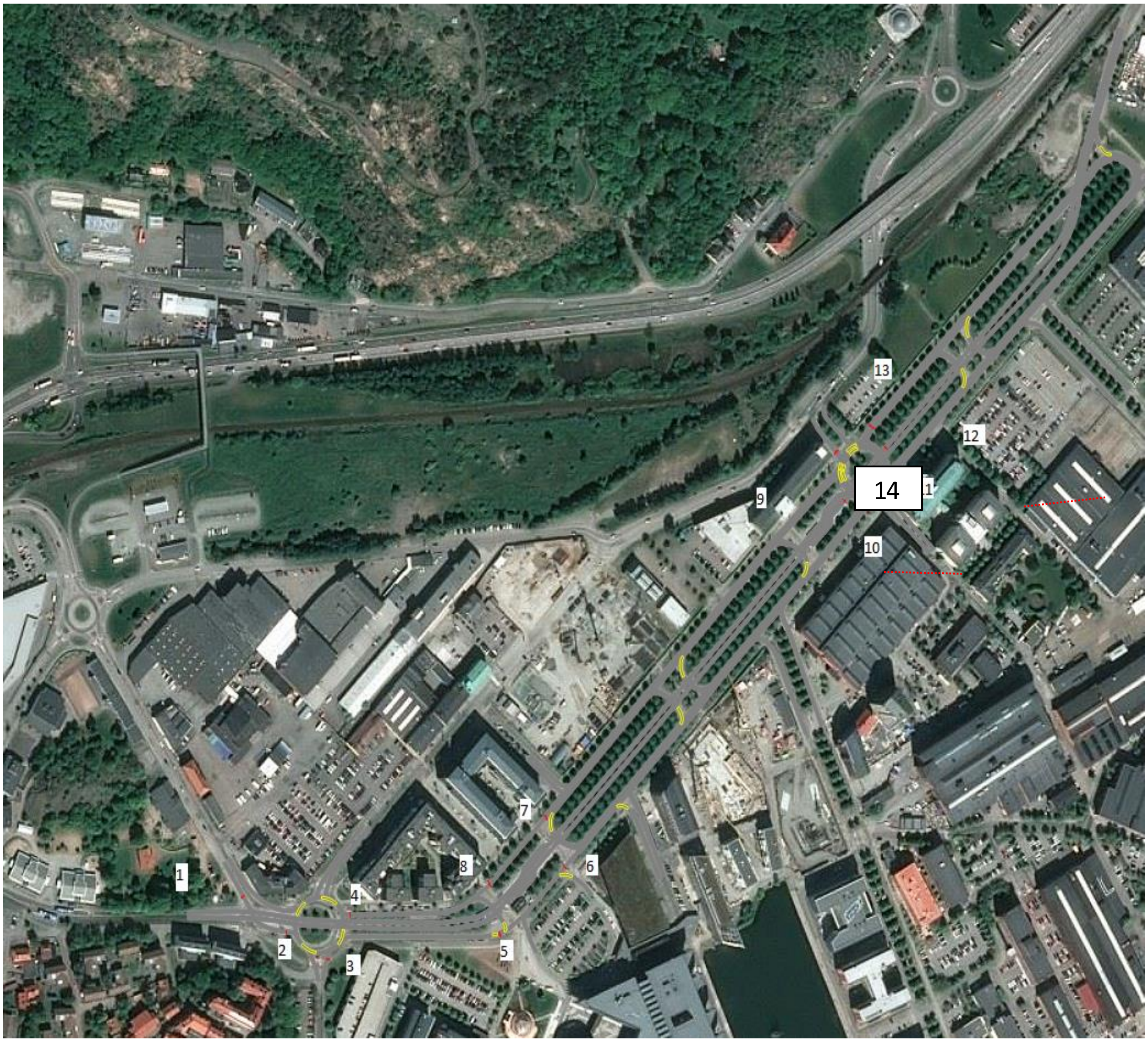


***Figure 14**: Queue measurement sensors location*

- Worst case scenario morning peak hour

Table 11. *Queue length of worst case scenario on morning peak hour.*

Queue counters		
Nr.	**Position**	**Length (meters, m)**
1	1	504,6
2	2	48,6
3	3	504,6
4	4	0,0
5	5	47,9
6	6	41,3
7	7	0,0
8	8	0,0
9	9	15,6
10	10	12,1
11	11	0,0
12	12	0,0
13	13	0,0
14	14	504,8

Queue counters measure the queue formation from the point where the counter is set towards the back of the first vehicle. The queue counters have measured that at point 4, 6, and 14 queuing is the worst. With the queue line stretching to nearly 500 meters. At point 14 this poses a big problem since the distance between Regnbagsgatan to the roundabout in the Vågmestareplatsen direction is 450 meters. So, the queuing caused in the entrance in Lindholmen causes problems for the system and roundabout effecting the nearby infrastructure. Another thing worth noticing is that the 3 major points where queues are formed are points where different lines and modes intersect and there are major pedestrian crossings. Point 7 and 11 have also queues which can be formed as a result of the queues by the previous points.

- Worst case scenario evening peak hour

Table 12. *Queue length of worst case scenario on evening peak hour.*

Queue counters		
Nr.	**Position**	**Length (meters, m)**
1	1	0,0
2	2	0,0
3	3	300,3
4	4	0,0
5	5	0,0
6	6	7,9
7	7	0,0
8	8	0,0
9	9	15,8
10	10	336,3
11	11	472,7
12	12	0,0
13	13	0,0
14	14	0,0

During the evening peak hour there is queue formation at points 3 and 6. Point 3 is near the roundabout where there is intersection between many modes and routes and point 6 where there is a main pedestrian crossing and bus stop. Points 9 and 10 are also points near at roundabout where many lanes and modes intersect. Point 9 is a dedicated bus lane which means that the traffic is so heavy inside the roundabout that the dedicated lane is affected and creates a queue, even if it is a short queue.

As above mentioned the queue are formed in the main entry routes to Lindholmsallén where multiple lanes intersect and also near pedestrian crossings. These queues are also responsible for longer travel times.

4.2 Dynamic simulation results

The results of the dynamic situation where the software runs and analysis the best possible route itself. The queue counters and vehicle travel times are the same as for the static simulation.

- Morning peak hour travel time, average aggregate 85% percentile

Table 13. *Dynamic simulation morning peak hours travel time, in seconds.*

Travel time counter		
Nr.	**Name**	**Time, avg agg. 85% (seconds)**
1	Friham-Regnbågs	51
2	Friham-Polstjarn	135
3	Polstjarn-Regnbågs	242
4	Polstjarn-Friham	206
5	Regnbågs-Friham	121
6	Regnbågs-Polstjarn	123

Table 14. *Dynamic simulation morning peak hour travel time, in minutes.*

Travel time counter		
Nr.	**Name**	**Time, avg agg. 85% (minutes)**
1	Friham-Regnbågs	1
2	Friham-Polstjarn	2
3	Polstjarn-Regnbågs	4
4	Polstjarn-Friham	3
5	Regnbågs-Friham	2,
6	Regnbågs-Polstjarn	2,1

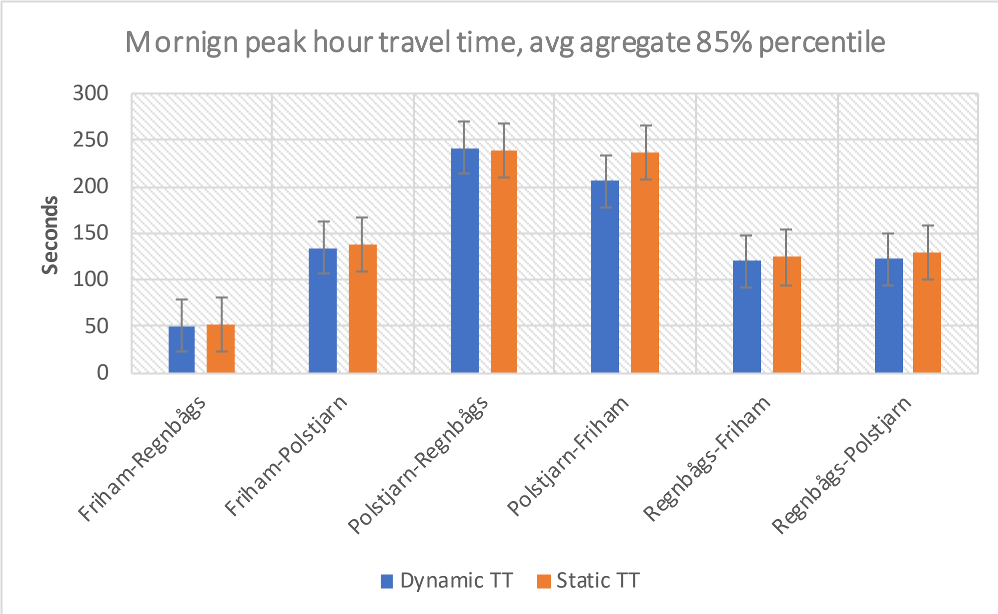


Figure 15: *Morning peak hour travel time, dynamic simulation and static simulation, in seconds.*

The results of the dynamic simulation show similar results to the static simulation. This proves that the model build for static simulation stands correct. Although some small changes in some segments can be noticed. In some segments the dynamic simulation has around 10-20 seconds less of travel time.

- Evening peak hour travel time, average aggregate 85% percentile

Table 15. *Dynamic simulation evening peak hour travel time, in seconds.*

Travel time counter		
Nr.	**Name**	**Time, avg agg. 85% (seconds)**
1	Friham-Regnbågs	60
2	Friham-Polstjarn	115
3	Polstjarn-Regnbågs	456
4	Polstjarn-Friham	455
5	Regnbågs-Friham	111
6	Regnbågs-Polstjarn	162

Table 16. *Dynamic simulation evening peak hour travel time, in minutes.*

Travel time counter		
Nr.	**Name**	**Time, avg agg. 85% (minutes)**
1	Friham-Regnbågs	1
2	Friham-Polstjarn	2
3	Polstjarn-Regnbågs	8
4	Polstjarn-Friham	8
5	Regnbågs-Friham	2
6	Regnbågs-Polstjarn	2,7

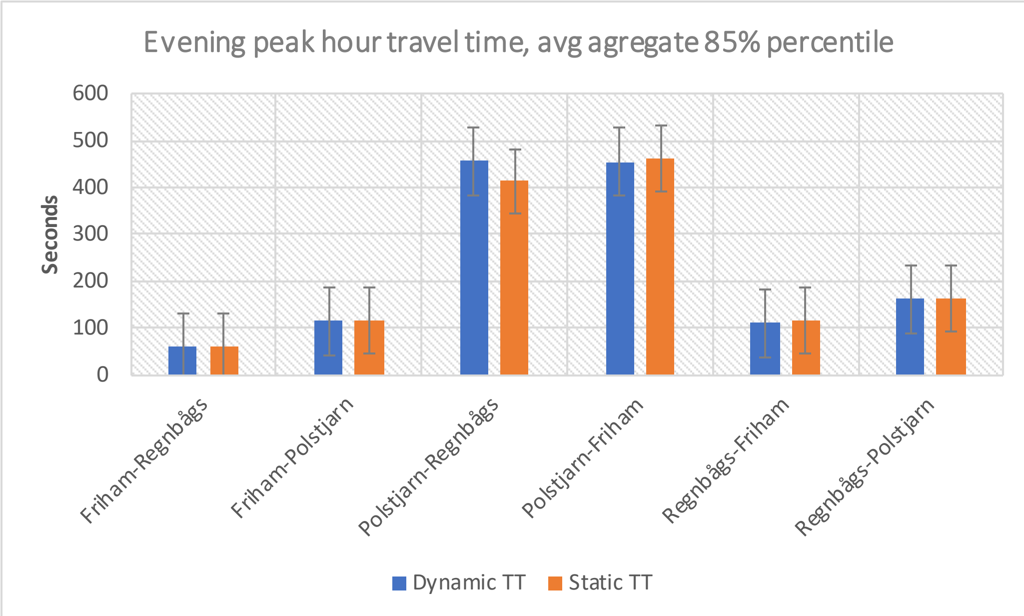


Figure 16: *Evening peak hour travel time, dynamic simulation and static simulation, in seconds.*

By evaluating both the morning peak hour and evening peak hour dynamic simulations and comparing them to the static ones, they show no big difference. The similarity shows that the static model was correct and in both cases the model shows the same problems in the same segments.

- <u>Morning peak hour queue lengths</u>

Table 17. *Dynamic simulation morning peak hour queue lengths.*

Queue counters		
Nr.	**Position**	**Length (meters, m)**
1	1	8,2
2	2	41,8
3	3	48,0
4	4	0,0
5	5	15,4
6	6	25,0
7	7	0,0
8	8	0,0
9	9	15,6
10	10	12,0
11	11	0,0
12	12	0,0
13	13	0,0
14	14	504,7

- Evening peak hour queue lengths

Table 18. *Dynamic simulation evening peak hour queue lengths*.

Queue counters		
Nr.	**Position**	**Length (meters, m)**
1	1	0,0
2	2	0,0
3	3	175,1
4	4	0,0
5	5	0,0
6	6	0,0?
7	7	0,0
8	8	0,0
9	9	50,4
10	10	504,2
11	11	292,0
12	12	0,0
13	13	0,0
14	14	15,1

The dynamic simulation gives the same results as the static simulations. The queues are created in the same segments and travel times vary a bit but still show problem in the same travel path. An interesting difference to be noticed is the long queue formed at counter 9, dedicated bus lane near the roundabout at Regnbågsgatan. Which might be as a result of a big congestion at the roundabout and irregular bus arrival patterns, as predicted by the software itself. A slight change which should be accounted for is the blocked path due to works. This road is Karlavagnsgatan.

4.3 Google maps typically traffic situation in the area

As another verification reference to check the results the situation of the traffic in the area during peak morning hour and peak evening hour are retrieved from Google maps to compare.

-Typical traffic morning peak hour according to Google maps satellite traffic data

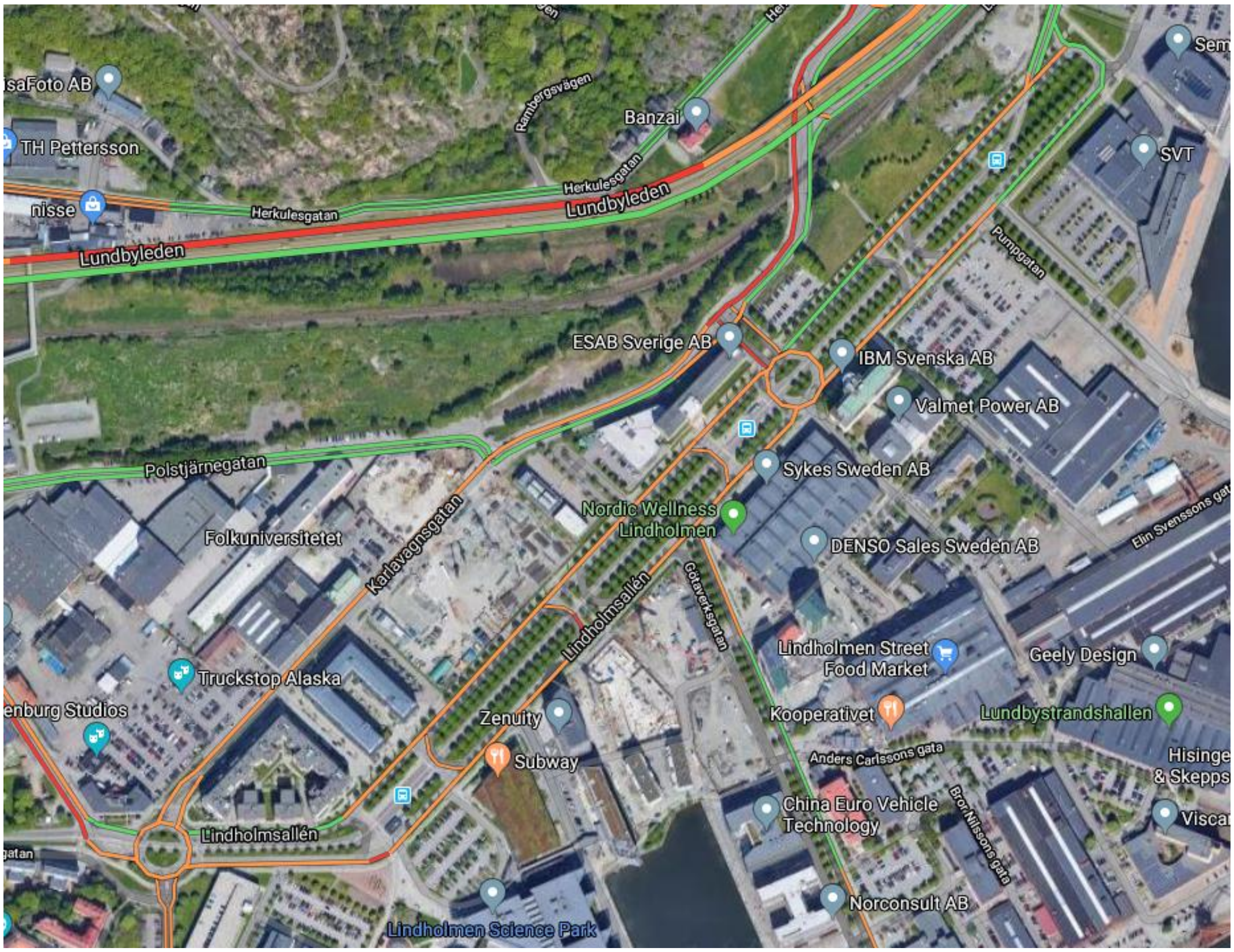


***Figure 17**: Google traffic view of the morning peak hour in Lindholmen*

-Typical traffic evening peak hour according to Google maps satellite traffic data

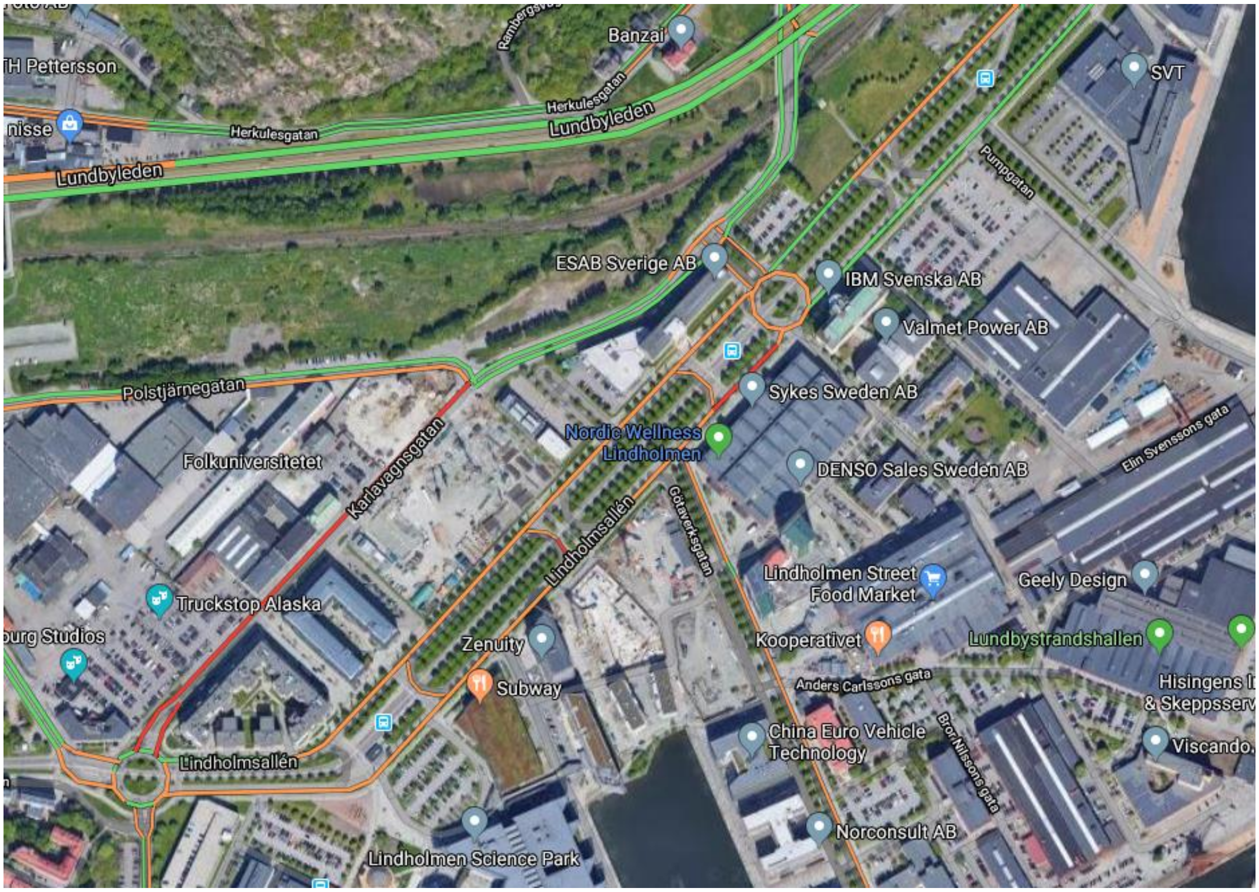


***Figure 18**: Google traffic view of evening peak hour in Lindholmen*

The data from Google maps verify the results of the study that the area needs an intervention in the infrastructure system since it shows clear problems in the current traffic situation and a worst-case scenario based on the present, with prolonged travel times and queue formation. In the case of Regnbågsgatan is so severe that reaches the nearest roundabout and effects traffic in the nearby roads creating a problem that surpasses the micro system of Lindholmen.

4.4 Future situation

Considering the change of land use and If the infrastructure system remains the same and it is not intervened upon the future situation of the traffic in the area

- Future predicted morning peak hour worst case scenario, average aggregate 85% percentile

Table 19. *Future (2035) morning peak hour travel time, in seconds.*

Travel time counter		
Nr.	**Name**	**Time, avg agg. 85% (seconds)**
1	Friham-Regnbågs	53
2	Friham-Polstjarn	140
3	Polstjarn-Regnbågs	249
4	Polstjarn-Friham	288
5	Regnbågs-Friham	133
6	Regnbågs-Polstjarn	136

Table 20. *Future (2035) morning peak hour travel time, in minutes.*

Travel time counter		
Nr.	**Name**	**Time, avg agg. 85% (minutes)**
1	Friham-Regnbågs	1
2	Friham-Polstjarn	2
3	Polstjarn-Regnbågs	4
4	Polstjarn-Friham	5
5	Regnbågs-Friham	2,2
6	Regnbågs-Polstjarn	2,3

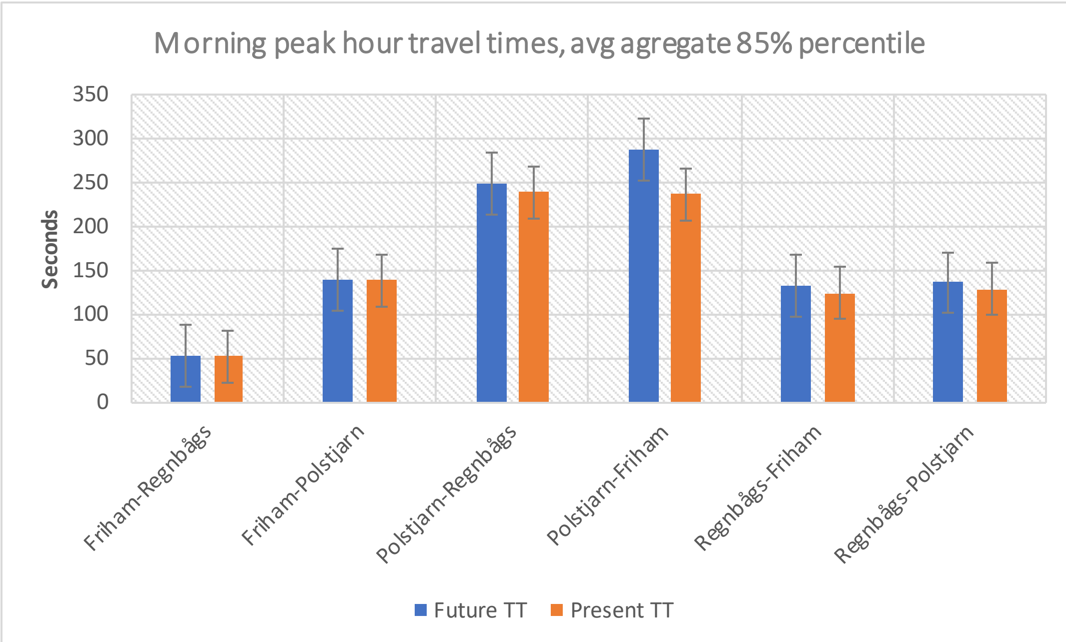


Figure 19: *Morning peak hour travel time, future (2035) and present situations.*

The heavier traffic during morning peak hours shows the effect by increasing the travel time in almost all the main measured roadways and segments which in the present situation are not as congested.

- Future predicted evening peak hour, average aggregate 85% percentile.

Table 21. *Future (2035) evening peak hour travel time, in seconds.*

Travel time counter		
Nr.	**Name**	**Time, avg agg. 85% (seconds)**
1	Friham-Regnbågs	61
2	Friham-Polstjarn	126
3	Polstjarn-Regnbågs	545
4	Polstjarn-Friham	533
5	Regnbågs-Friham	136
6	Regnbågs-Polstjarn	175

Table 22. *Future (2035) evening peak hour travel time, in minutes.*

Travel time counter		
Nr.	**Name**	**Time, avg agg. 85% (minutes)**
1	Friham-Regnbågs	1
2	Friham-Polstjarn	2
3	Polstjarn-Regnbågs	9
4	Polstjarn-Friham	9
5	Regnbågs-Friham	2,3
6	Regnbågs-Polstjarn	3

The heavier future evening peak hour traffic also show an increase in travel time which causes user dissatisfaction queuing and congestion in the area.

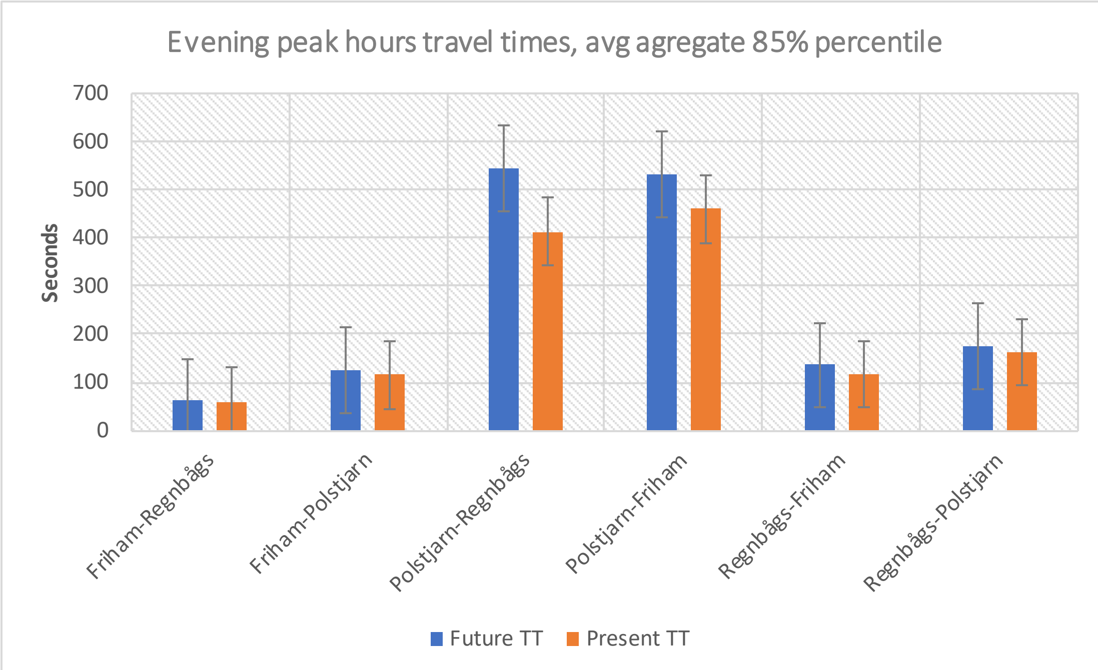


Figure 20: *Evening travel time, future (2035) and present situation.*

The future simulations show even more worrying results about travel time and queuing results. If the system remains as it is then the increase of traffic cannot be supported by it. The travel times become longer and also queues become longer which has a negative effect on the user experience of the system and a negative effect on the conjoined systems to Lindholmen.

- <u>Future queue lengths</u>

Table 23. *Future (2035) morning peak hour queue lengths.*

Queue counters		
Nr.	**Position**	**Length (meters, m)**
1	1	504,6
2	2	52,6
3	3	504,7
4	4	0,0
5	5	47,3
6	6	59,6
7	7	0,0
8	8	0,0
9	9	15,9
10	10	12,3
11	11	10,9
12	12	0,0
13	13	0,0
14	14	504,8

Table 24. *Future (2035) evening peak hour queue lengths.*

Queue counters		
Nr.	**Position**	**Length (meters, m)**
1	1	0,0
2	2	0,0
3	3	504,4
4	4	0,0
5	5	4,8
6	6	9,6
7	7	0,0
8	8	0,0
9	9	0,0
10	10	504,7
11	11	15,8
12	12	0,0
13	13	0,0
14	14	0,0

It is noticeable an increase of the queue lengths in the already effected areas and some queue forming is parts that were vulnerable. Which shows that the system is not adapted for an increase of traffic flow.

5. Discussions

Current situation and temporary solutions:

The current situation shows problems in the entry points to the area from roads that connected heavily populated areas of the city with Lindholmen. The major queues are formed in the area near the roundabouts where multiple lines intersect and also there is presence of bus lanes and traffic signals. A reason for these queues is the restriction of movement for vehicles that need to turn. All vehicles, independently if they are going straight or turning right, use the same lane. This blocks the freedom of movement for some vehicles. Also, the busses have priority and the signals show this. During the peak hours when the flow of the vehicles is bigger this priority for the busses in points where they intersect causes congestions.

Dedicated left/right turn lanes offer a significant advantage in the system. According to the US Department of Transportation dedicated right turns at intersections offer increased capacity and have an exponential effect on through passing vehicles and effected.

Table 25. *Impact of dedicated turn lanes on through passing vehicles* (US Department of Transportation, u.d.)

Right-Turning Vehicles Per Hour	**Through Vehicles Impacted (%)**
Under 30	2,4
31 to 61	7,5
61 to 90	12,2
90 and up	21,8

Dedicated turning lanes help reduce queuing and delays at intersections, help improve the traffic flow, increase intersection capacity and improve the overall road and intersection safety. (Department of Transport and Main Roads, Queensland Government)

Current situation signalized crossing in some parts with traffic lights like at Chalmers entry and removal of a pedestrian crossing area since there is another one next to it very closely and Lundyleden a dedicated right turn lane. And or try to separate bus and vehicle lane so they have no contact at all.

A signalized pedestrian cross at this point will benefit both pedestrian traffic and vehicle traffic. (Irvine, 2020) Signalized pedestrian crossings lower the risk for accidents, help slow the approaching traffic velocity and the disruption of traffic flow is relatively low. According to research from traffic specialists by the City of Irvine, USA, properly timed traffic signals actually increase the traffic capacity of an intersection. Of course, signal traffic is not an all fixing solution and in the future, something more has to be done.

Recommendations for the future:

Future a restructuring of the area and a new system that connects Lunbyleden with Lindholmen and under or over passes for pedestrians. And there are plans for tram lines and new vehicle ways by Gothenburg municipality (online).

In acknowledgment of the big growth, the city will have and the importance and huge change of Lindholmen itself a complete intervention in the infrastructure would be, expensive in the beginning solution, but valuable and worth the investment in the long term. As reported by CECA for every £ 1 billion of infrastructure investment the overall economic activity increases by £ 2.842 billion, plus other social benefits. Some solutions offered by the new infrastructure would be separation of the public transport and private vehicle lanes, underpasses or overpasses for pedestrians. So, in overall should be a complete separation of lanes so there is almost no crossing points between modes. This would clearly increase the flow and capacity of the system, but also make it more effective and safe. The reconstruction of the whole are is an ideal solution but it's not a realistic one. A practical and realistic solution which is also being looked upon by the government authorities is to reduce the number of vehicles that come in the area. This goal will be reached by the reconstruction of the adjacent corridor, Lundbyleden, with a high capacity. The second measure is to make the area more accessible through public transport. Optimize the bus lines that operate in the area and adding tram lines in the area. This measure will make the area more accessible with a high capacity public transport.

Trafikverket and Gothenburg's Municipality have already started looking in possible projects for Lundbyleden. A ne corridor with higher capacity and flow rates. This will enable vehicles that just went through Lindholmsallén to use this corridor.

Figure 21: *Concept of the new infrastructure system in Lundbyleden.*

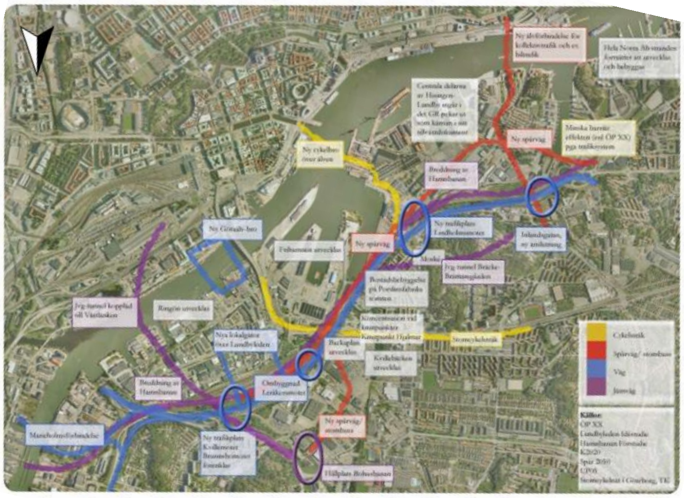


Figure 22*: Lindholmens analyze from Trafikverket.*

The analyse of Trafikverket (Swedish Road Administration) of the area for future development with new lane, re-routing and new transportation modes.

6. Conclusions

Relist the problems. Better planning and adaptation for a fast-growing city, which problems are present and will be in the future and future approach, what to keep in mind

The Lindholmen area is a very important part of Gothenburg both economically and residentially. The area has had changes during the years with the last major one in infrastructure happening in the early 2000s'. This change has not been able to accommodate the increase of in population, economic growth and traffic growth that goes through the area and its main artery, Lindholmsallén. The growth of traffic and inability of the system to adapt and support it have caused problems. These problems are longer travel times between the main entry/exit points. Travel times have increase a few seconds to a double or three times the free flow travel time. Another dominant problem in the area are queue that are created near intersections/roundabouts where a number of lanes and modes meet in the main points.

The current situation of the traffic in the area presents a longer travel time for users and queue formation in the main roads connected to Lindholmsallén. In the main directions the travel time is an average of 35-40 seconds more than the planned travel time for the desired L.O.S for the road. Queuing also effect the level of service and vehicle density in the area. Which can be a danger since there is a tendency from users not to respect the headway and gap in high density scenarios. The same problems are noticed even in the future prediction for the traffic in the area with longer travel times and more queuing. The increase of traffic in the future also presents delay and queuing problems in corridors and roads in the area that don't show this problems in the present.

This problems and conflicts manifest themselves and are more visible in pedestrian crossing points, which are not signalized in the area. And also around the roundabouts where multiple lanes for different vehicles from different directions connect. These connections cause many conflict zones and also limit the freedom of movement of the vehicles since all vehicles independent from their direction move in the same lane. The traffic flow and demand in the area is high and only increasing so measures to facilitate this high traffic need to be considered and implemented. Signals to control the intersections and minimize the flow interruptions and dedicated turn lanes will help control the current flow. While the construction of a new infrastructure system with dedicated lanes for each mode with the minimum intersections is an optimal solution but not realistic. The future solutions must focus on better traffic management and control like the present ones and in minimizing the vehicle flow in the area by making it more accessible through more public transport means and corridors in the near systems, like Lundbyleden expansion, which will take a huge load of the area. This solution can be supported by the knowledge that investment in infrastructure is proven to bring economic growth.

Bibliography

Association, C. E. (2018). *The social benefits of infrastructure investment.*

Eniro. (n.d.). *Eniro*. Retrieved from https://kartor.eniro.se/?c=57.705202,11.938593&z=14&q="Lindholmen, GÖTEBORG";207907530;geo

Government, O. (2018). Analysis Procedure Manual Version 2., (pp. 6-3 -- 6-7). Oregon.

Göteborg, T. (n.d.). *Trafiken.nu*. Retrieved from https://trafiken.nu/goteborg/#57.710152,11.939011,11

Highway Capacity Manula. (n.d.).

Ioannou, P. A. (n.d.). Dedicated Lanes. In P. A. Ioannou, *Automated Highway Systems* (pp. 76-79). New York: Springer Science+Business Media LLC.

Irvine, C. o. (2020). *Advantages of Traffic Signals*. Retrieved from https://www.cityofirvine.org/signal-operations-maintenance/advantages-traffic-signals

Kalte Lyman, R. L. (2008). *Using Travel Time Reliability Measures to Improve Regional Transportation Planning and Operations.* Florida: Transportation Research Record Journal of the Transportation Research Board .

L., E. (2013). *An Introduction to Tra c Flow Theory, Vol. 84.* Springer New York Heidelberg Dordrecht London: Springer.

Miriam Brill, W. (2019). *Mikrosimulering Lindholmsallen.* Gothenburg: WSP.

Park, L. S. (2020). Retrieved from Lindholmen Science Park: https://www.lindholmen.se/omradet/utveckling-pa-omradet

Roads, D. o. (n.d.). *Dedicated turning lanes.* Queensland: Queensland Government.

Stad, G. (2018). *Statistil, Resekalkyl*. Retrieved from https://resekalkyl.tkgbg.se/statistik/resekalkyl

Stad, G. (2019§). *Götebors Stad, Gator och vägar*. Retrieved from https://goteborg.se/wps/portal/start/gator-vagar-och-torg/gator-och-vagar/!ut/p/z1/04_Sj9CPykssy0xPLMnMz0vMAfIjo8ziAwy9Ai2cDB0N_N0t3Qw8Q7wD3Py8ffxDLI31w8EKDFCAo4FTkJGTsYGBu7-RfhQx-vEoiMIwHtki_YLc0FAAIaKNXg!!/dz/d5/L2dBISEvZ0FBIS9nQSEh/

Styrelsen, T. (2020, 01 28). *Statistik Trängselskatt Göteborg*. Retrieved from https://www.transportstyrelsen.se/sv/vagtrafik/statistik/trangselskatt11/goteborg/

SvenskKollektivtrafik. (2018). *Årsrapport 2018 Kollektivtrafikbarometern.* origo Group.

SvenskKollektivtrafik. (2019). *Kollektivtrafikens samhäälsnytta*. Retrieved from https://www.svenskkollektivtrafik.se/fakta/kollektivtrafikens-samhallsnytta/

SverigesRadio. (2020). *P4 Göteborg*. Retrieved from https://sverigesradio.se/sida/artikel.aspx?programid=104&artikel=6317857

Toolkit, R. S. (2010). *Pedestrian Crossings*. Retrieved from http://toolkit.irap.org/default.asp?page=treatment&id=19

Trafikverket. (2018). *Trafiktillväxt för väganalyser i Samkalk.* Borlänge: Trafikverket.

Urban, S. S. (n.d.). *Solutions Factsheet 2.1.* Retrieved from http://www.uemi.net/uploads/4/8/9/5/48950199/solutions-factsheet-2-1-dedicated_bus_lanes_041216.pdf

US Department of Transportation, F. H. (n.d.). *Benefits of Access Management*. Retrieved from https://safety.fhwa.dot.gov/geometric/pubs/accessmgmtbrochure/turning.htm

Vägverket. (2008). *Vad Planeras för Lundbyleden?* Gothenburg: Vägverket,Swedish Road Administration.

Appendix :

A. Zones of Lindholmen

Figure A.1: Frihamnen-center(zone 1)

Figure A.2: SVT-entrance(3-5)(zone 2)

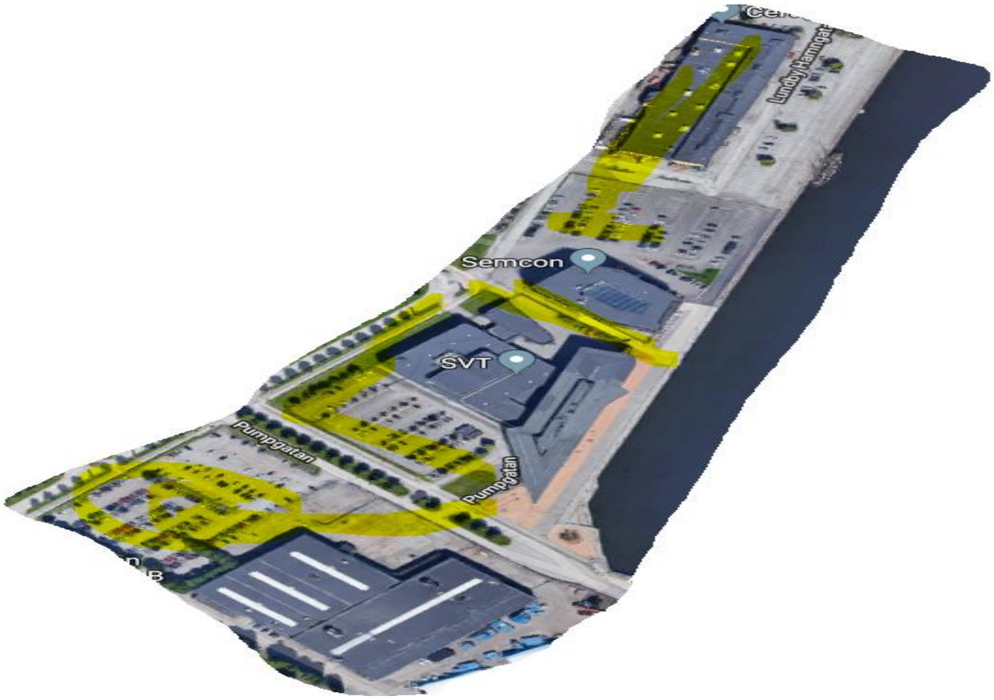


Figure A.3: Rengbågatan(7-9)(zone 3)

Figure A.4: Lindholmen -radison-construction(11-13)(zone 4)

Figure A.5: Chalmers-lower resident area(15)(zone 5)

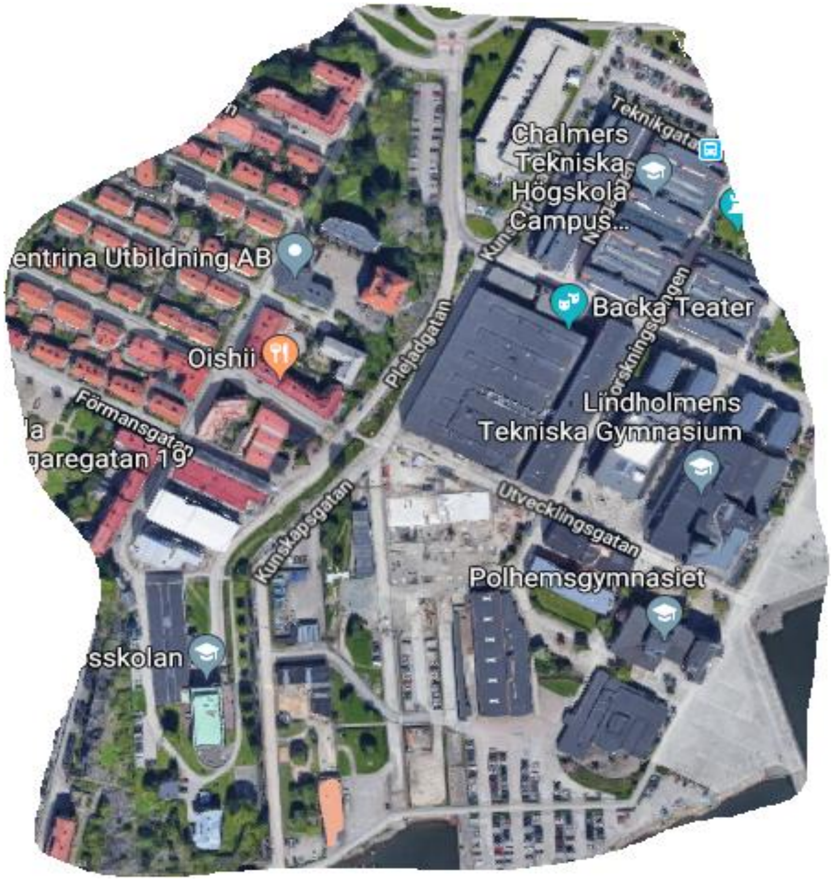


Figure A.6: Western residetial area,neighborhood(17-21)(zone 6)

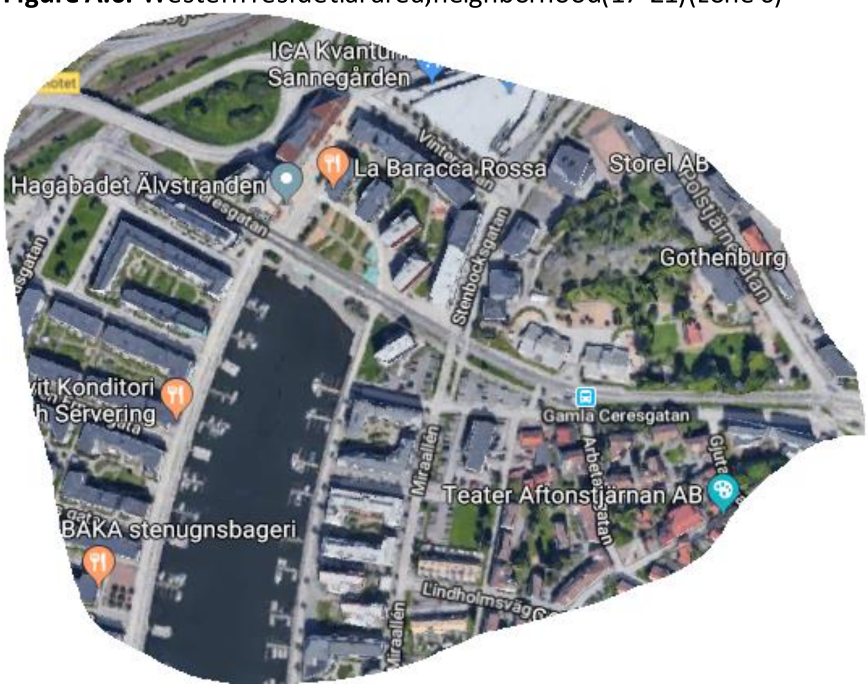


Figure A.7: 2 residential buildings (23)(zone 7)

Figure A.8: Karlatornet and the school(23-25)(zone 8)

Figure A.9: Lundby road (25)(zone 9)

B. Tables and Matrices

Figure B.1: L.O.S and free flow speed

vp, service flow rate (pc/hr/ln)
V, Traffic Volume = 4,000 vph
PHF, Peak Hour Factor = 1
N, Number of Lanes = 2
Fp, Population Factor = 1
Pt, Percentage of Trucks = 5%
Et, Passenger Cars Equivalent = 1.5
Fhv, Heavy Vehicle Factor

FREE-FLOW SPEED	CRITERIA	LOS				
		A	B	C	D	E
60 mph	Maximum Density (pc/mi/ln)	11	18	26	35	40
	Average Speed (mph)	60.0	60.0	59.4	56.7	55.0
	Maximum Volume to Capacity Ratio (v/c)	0.30	0.49	0.70	0.90	1.00
	Maximum Service Flow Rate (pc/h/ln)	660	1,080	1,550	1,980	2,200
55 mph	Maximum Density (pc/mi/ln)	11	18	26	35	41
	Average Speed (mph)	55.0	55.0	54.9	52.9	51.2
	Maximum Volume to Capacity Ratio (v/c)	0.29	0.47	0.68	0.88	1.00
	Maximum Service Flow Rate (pc/h/ln)	600	990	1,430	1,850	2,100
50 mph	Maximum Density (pc/mi/ln)	11	18	26	35	43
	Average Speed (mph)	50.0	50.0	50.0	48.9	47.5
	Maximum Volume to Capacity Ratio (v/c)	0.28	0.45	0.65	0.86	1.00
	Maximum Service Flow Rate (pc/h/ln)	550	900	1,300	1,710	2,000
45 mph	Maximum Density (pc/mi/ln)	11	18	26	35	45
	Average Speed (mph)	45.0	45.0	45.0	44.4	42.2
	Maximum Volume to Capacity Ratio (v/c)	0.26	0.43	0.62	0.82	1.00
	Maximum Service Flow Rate (pc/h/ln)	490	810	1,170	1,550	1,900

Matrices:

Table B.1: OD matrix for static simulation morning peak hour

FM 2

	1	2	3	4	5	6	7	8	9	10	11	12			summa	räknad
1	0	54,3186	2,1988	2,396	41,264	0	0	32,199	21,073	0	156,55	0			310	310
2	28,352179	0	10,07	10,973	188,98	0	0	147,47	96,509	172	130,44	21,425			403,11	854
3	0	0	0	0,1263	2,1758	0	0	1,6978	0	0	0	0			4	4
4	0	0	0,4913	0	22	6	1,5871	0	0	0	0	0			30,078	30
5	4,6366903	25,4372	0,4823	5,9429	0	294	54,971	217,11	93,45	1,7944	21,121	3,4691			722,42	762
6	1,6006334	8,69649	0,1649	30	86	0	18,794	74,226	31,949	0,6135	8,9376	1,2352			262,22	276
7	0,6378378	3,49923	0,0663	0,0759	1,2451	0	0	29,867	12,855	0,2929	2,9054	0,4772			51,922	56
8	1,8061223	9,90852	0,1879	0,2047	3,5257	0	0	0	36,401	0,699	8,2271	1,3513			62,312	74
9	5,489167	30,114	0,4005	0,4364	7,5162	0	0	5,865	0	2,1243	25,004	0,0005			76,95	94
10	0,7535711	42	0	0	0	0	0	0	0	0	3,4326	0,5638			46,75	48
11	13,933333	2,4969	0,1011	0,1101	1,8968	0	0	1,4801	0,9687	0,9178	0	10,425			32,33	38
12	6,9213483	1,24033	0,0502	0,0547	0,9422	0	0	0,7353	0,4812	0	3,5747	0			14	14
														Σ	2016,1	2560
Σ	64,130883	177,711	14,214	50,32	355,55	300	75,352	510,65	293,69	178,44	360,19	38,947	2419,2			
	88	306	16	48	418	300	74	448	306	180	314	62	2560			

Adj. Fac 1,058

New Tij	1	2	3	4	5	6	7	8	9	10	11	12		summa	räknad
1	0	57,48	2,3268	2,5354	43,666	0	0	34,074	22,299	0	165,66	0		328,04	310
2	30,002	0	10,656	11,612	199,98	0	0	156,05	102,13	182,01	138,03	22,672		853,14	854
3	0	0	0	0,1337	2,3025	0	0	1,7967	0	0	0	0		4,2328	4
4	0	0	0,5199	0	23,281	6,3492	1,6795	0	0	0	0	0		31,829	30
5	4,9066	26,918	0,5104	6,2888	0	311,11	58,171	229,75	98,889	1,8988	22,35	3,671		764,46	762
6	1,6938	9,2027	0,1745	31,746	91,006	0	19,888	78,547	33,808	0,6492	9,4578	1,3071		277,48	276
7	0,675	3,7029	0,0702	0,0803	1,3176	0	0	31,605	13,603	0,3099	3,0745	0,505		54,944	56
8	1,9112	10,485	0,1988	0,2166	3,7309	0	0	0	38,52	0,7396	8,706	1,43		65,938	74
9	5,8087	31,867	0,4238	0,4618	7,9536	0	0	6,2064	0	2,2479	26,459	0,0006		81,429	94
10	0,7974	44,445	0	0	0	0	0	0	0	0	3,6324	0,5966		49,471	48
11	14,744	2,6422	0,107	0,1165	2,0072	0	0	1,5663	1,0251	0,9712	0	11,032		34,211	38
12	7,3242	1,3125	0,0531	0,0579	0,9971	0	0	0,778	0,5092	0	3,7828	0		14,815	14
														2560	2560
Σ	67,864	188,05	15,041	53,249	376,24	317,46	79,738	540,37	310,78	188,83	381,16	41,214	2560		
	88	306	16	48	418	300	74	448	306	180	314	62	2560		
	20,136	117,95	0,9592	-5,2491	41,758	-17,461	-5,738	-92,372	-4,7804	-8,8279	-67,156	20,786			

Table B.2: OD matrix for static simulation evening peak hour

EM

	1	2	3	4	5	6	7	8	9	10	11	12		summa	räknat
1	0	33,67742	0	0	0	0	0	0	0	0	0,60704	0,02958		34,314	36
2	43,8235428	0	2,22419	4,89887	94,4579	0	0	10,8628	3,7579	42	20,1881	0,98368		223,197	282
3	0	0	0	0,48688	9,32023	0	0	1,07961	0,51258	0,01759	0,31074	0,01568		11,7433	14
4	0	0	0	0	40	8	0	0	0	0	0	0		48	48
5	17,6850842	32,28417	0,44811	0	0	82	16,2856	28,3048	13,4386	0,4612	8,14695	0,39697		199,452	212
6	2,61479822	14,1005	0,26197	26	146	0	9,52083	16,5474	7,85642	0,26963	1,21515	0,05869		224,445	248
7	1,70099505	9,172747	0,17042	0,37536	7,18544	0	0	10,7645	5,11081	0,1754	0,78359	0,03818		35,4775	48
8	15,6077589	65,60001	1,21879	2,68443	51,3876	0	0	0	36,5506	1,25439	5,60396	0,27306		180,181	222
9	30,2300784	163,018	0,6211	1,368	26,1874	0	0	0	0	3,11719	13,926	0,67855		239,146	266
10	53,8692472	94	0	0	0	0	0	0	0	0	23,721	1,15582		172,746	188
11	167,449275	44,38233	0	0	0	0	0	0	0	0	0	3,75862		215,59	218
12	51,4411765	13,63445	0	0	0	0	0	0	0	0	0,27311	0		65,3487	66
														1649,64	1848
∑	384,421956	469,8697	4,94458	35,8135	374,539	90	25,8065	67,5592	67,2269	47,2954	74,7757	7,38882	1649,64		
	318	638	6	40	454	90	32	86	84	48	46	6	1848		
	-66,421956	168,1303	1,05542	4,18647	79,4615	0	6,19355	18,4408	16,7731	0,70461	-28,7757	-1,38882			

Adj. Factor 1,12024

New Tij	1	2	3	4	5	6	7	8	9	10	11	12		summa	räknad
1	0	37,72693	0	0	0	0	0	0	0	0	0,68003	0,03313		38,4401	36
2	49,093061	0	2,49163	5,48793	105,816	0	0	12,169	4,20977	47,0502	22,6156	1,10196		250,035	282
3	0	0	0	0,54542	10,4409	0	0	1,20942	0,57421	0,01971	0,34811	0,01756		13,1554	14
4	0	0	0	0	44,8098	8,96195	0	0	0	0	0	0		53,7717	48
5	19,8116095	36,16615	0,502	0	0	91,86	18,2439	31,7083	15,0545	0,51666	9,12657	0,4447		223,434	212
6	2,92921203	15,796	0,29347	29,1263	163,556	0	10,6656	18,5372	8,80111	0,30205	1,36126	0,06575		251,434	248
7	1,90552951	10,27572	0,19091	0,42049	8,04945	0	0	12,0589	5,72535	0,19649	0,87782	0,04277		39,7434	48
8	17,4844983	73,48801	1,36534	3,00721	57,5666	0	0	0	40,9455	1,40522	6,27781	0,30589		201,846	222
9	33,865064	182,62	0,69578	1,53249	29,3363	0	0	0	0	3,49201	15,6005	0,76015		267,902	266
10	60,3467011	105,3029	0	0	0	0	0	0	0	0	26,5733	1,2948		193,518	188
11	187,584046	49,71904	0	0	0	0	0	0	0	0	0	4,21057		241,514	218
12	57,6266694	15,27392	0	0	0	0	0	0	0	0	0,30595	0		73,2065	66
														1848	1848
∑	430,646391	526,3687	5,53914	40,1199	419,575	100,822	28,9095	75,6828	75,3105	52,9824	83,767	8,27728	1848		
	318	638	6	40	454	90	32	86	84	48	46	6	1848		

Table B.3: Free flow matrix morning

FM

0,4

New Tij	1	2	3	4	5	6	7	8	9	10	11	12		summa
1	0	22,99207	0,930726	1,01418	17,46643	0	0	13,62945	8,919754	0	66,26478	0		131,2174
2	12,00096	0	4,262521	4,644719	79,99238	0	0	62,41986	40,85051	72,80449	55,21256	9,06879		341,2568
3	0	0	0	0,053477	0,920985	0	0	0,718666	0	0	0	0		1,693128
4	0	0	0,207955	0	9,312202	2,539691	0,671791	0	0	0	0	0		12,73164
5	1,962627	10,76712	0,204154	2,515504	0	124,4449	23,26841	91,89974	39,55554	0,759532	8,940013	1,468418		305,7859
6	0,677519	3,681065	0,069796	12,69846	36,40224	0	7,955012	31,41872	13,52326	0,259669	3,783115	0,522854		110,9917
7	0,269985	1,481159	0,028084	0,032132	0,527038	0	0	12,64202	5,441385	0,123964	1,229817	0,202		21,97758
8	0,764499	4,194097	0,079524	0,086654	1,492377	0	0	0	15,408	0,295859	3,482389	0,57199		26,37539
9	2,323465	12,7467	0,169529	0,18473	3,181459	0	0	2,482564	0	0,899175	10,58368	0,000221		32,57152
10	0,318973	17,77784	0	0	0	0	0	0	0	0	1,452962	0,238652		19,78843
11	5,897728	1,056894	0,042783	0,04662	0,802892	0	0	0,626515	0,410021	0,388477	0	4,41262		13,68455
12	2,929681	0,525009	0,021253	0,023158	0,398835	0	0	0,31122	0,203677	0	1,513114	0		5,925947
∑	27,14544	75,22195	6,016324	21,29963	150,4968	126,9846	31,89521	216,1487	124,3121	75,53116	152,4624	16,48555	1024	1024

Table B.4: Free flow matrix evening

EM

New Tij	1	2	3	4	5	6	7	8	9	10	11	12		summa
1	0	15,09077	0	0	0	0	0	0	0	0	0,272012	0,013254		15,37604
2	19,63722	0	0,996653	2,19517	42,32634	0	0	4,867593	1,683908	18,8201	9,046234	0,440784		100,014
3	0	0	0	0,218169	4,176372	0	0	0,483769	0,229685	0,007883	0,139243	0,007024		5,262145
4	0	0	0	0	17,9239	3,584781	0	0	0	0	0	0		21,50868
5	7,924644	14,46646	0,200798	0	0	36,744	7,297549	12,68332	6,021811	0,206664	3,650627	0,177879		89,37375
6	1,171685	6,318401	0,11739	11,65054	65,42225	0	4,26626	7,414861	3,520443	0,120819	0,544506	0,0263		100,5735
7	0,762212	4,110286	0,076365	0,168197	3,21978	0	0	4,823563	2,290141	0,078596	0,351126	0,017109		15,89737
8	6,993799	29,39521	0,546135	1,202884	23,02664	0	0	0	16,37822	0,562087	2,511122	0,122356		80,73845
9	13,54603	73,04799	0,278313	0,612997	11,73452	0	0	0	0	1,396804	6,240216	0,304058		107,1609
10	24,13868	42,12117	0	0	0	0	0	0	0	0	10,62932	0,517921		77,4071
11	75,03362	19,88762	0	0	0	0	0	0	0	0	0	1,684229		96,60546
12	23,05067	6,109566	0	0	0	0	0	0	0	0	0,12238	0		29,28261
∑	172,2586	210,5475	2,215655	16,04796	167,8298	40,32878	11,56381	30,2731	30,12421	21,19295	33,50679	3,310914	739,2	739,2

Table B.5: Future matrix morning peak hour

FM

New Tij	1	2	3	4	5	6	7	8	9	10	11	12	
1	0	67,29334	2,724055	2,968307	51,12085	0	0	39,89075	26,10639	0	193,9442	0	384,0479
2	35,1245	0	12,47557	13,59419	234,1222	0	0	182,6908	119,5615	213,0846	161,5965	26,54259	998,7925
3	0	0	0	0,156516	2,695546	0	0	2,103395	0	0	0	0	4,955456
4	0	0	0,608644	0	27,25501	7,433185	1,966203	0	0	0	0	0	37,26304
5	5,744229	31,51326	0,597518	7,362392	0	364,226	68,10213	268,9727	115,7714	2,223002	26,16569	4,297774	894,9762
6	1,982967	10,77377	0,20428	37,16592	106,5423	0	23,28278	91,95649	39,57996	0,760001	11,07244	1,530292	324,8512
7	0,790194	4,335064	0,082197	0,094045	1,542537	0	0	37,00074	15,92588	0,362817	3,599435	0,591215	64,32412
8	2,23754	12,27531	0,23275	0,25362	4,367899	0	0	0	45,09624	0,865922	10,19228	1,674105	77,19566
9	6,800332	37,30712	0,496179	0,540668	9,311512	0	0	7,265983	0	2,631711	30,97637	0,000646	95,33052
10	0,933572	52,03229	0	0	0	0	0	0	0	0	4,252539	0,698489	57,91689
11	17,26151	3,093323	0,125219	0,136446	2,34991	0	0	1,833688	1,200052	1,136995	0	12,91488	40,05202
12	8,57461	1,5366	0,062202	0,067779	1,167312	0	0	0,91088	0,596123	0	4,428591	0	17,3441

Table B.6: Future matrix evening peak hour

EM

New Tij	1	2	3	4	5	6	7	8	9	10	11	12	
1	0	44,16776	0	0	0	0	0	0	0	0	0,796127	0,038792	45,00268
2	57,47435	0	2,917011	6,424839	123,881	0	0	14,2465	4,928472	55,08278	26,47657	1,290088	292,7216
3	0	0	0	0,638537	12,22343	0	0	1,415899	0,672244	0,023071	0,407537	0,020558	15,40128
4	0	0	0	0	52,45979	10,49196	0	0	0	0	0	0	62,95175
5	23,1939	42,34052	0,587698	0	0	107,5426	21,35851	37,12161	17,62467	0,604865	10,68468	0,520618	261,5796
6	3,429294	18,49273	0,343577	34,09887	191,4782	0	12,48652	21,70186	10,30365	0,353613	1,593663	0,076975	294,359
7	2,230846	12,03001	0,223506	0,492281	9,423672	0	0	14,11763	6,702799	0,230035	1,027679	0,050074	46,52854
8	20,4695	86,03407	1,59843	3,52061	67,39453	0	0	0	47,93587	1,645121	7,349568	0,358112	236,3058
9	39,64659	213,7973	0,81457	1,794124	34,34465	0	0	0	0	4,088175	18,2639	0,88992	313,6392
10	70,64924	123,2805	0	0	0	0	0	0	0	0	31,10997	1,515853	226,5556
11	219,6089	58,2072	0	0	0	0	0	0	0	0	0	4,929412	282,7455
12	67,46484	17,88152	0	0	0	0	0	0	0	0	0,358181	0	85,70453

Excel formulas

```
=(427*200/(200+227)*114/(114+86)*150/(150+14)*94/(157+94)*31/(31+82))*2
```

Individual route flow determination example

Q	R
	Σ
2419,19	
2560	
Adj. Factc	1,0582

Adjustment factor derived by the division of the sum of attraction by the sum of the counted attractions.

```
=M6*$R$23
```

$$\text{Adj.Factor} \quad = \frac{\sum Att}{\sum Att\ counted} \qquad \textit{Equation 15}$$

Adjusted flow for each route is calculated by multiplying the Adjustment factor with the flow value

Future flow calculation

= worst case scenario flow * (1+growth rate)^(future year-base year)

```
=E6*((1+0,0099)^(2035-2019))
```

Equation 16

C. Simulation parameters

Figure C.1: Simulation Parameters

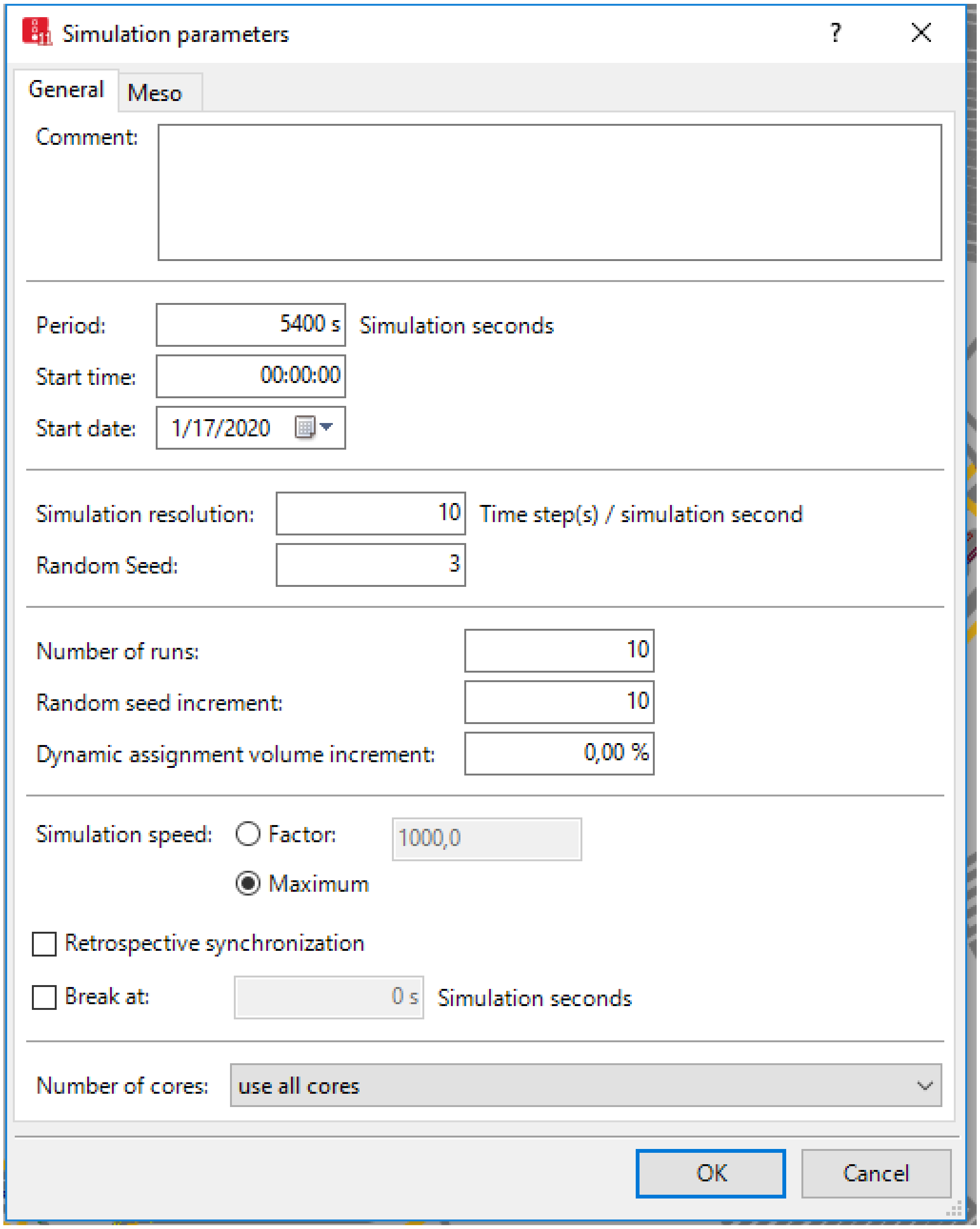


Figure C.2: Vehicle behaviour

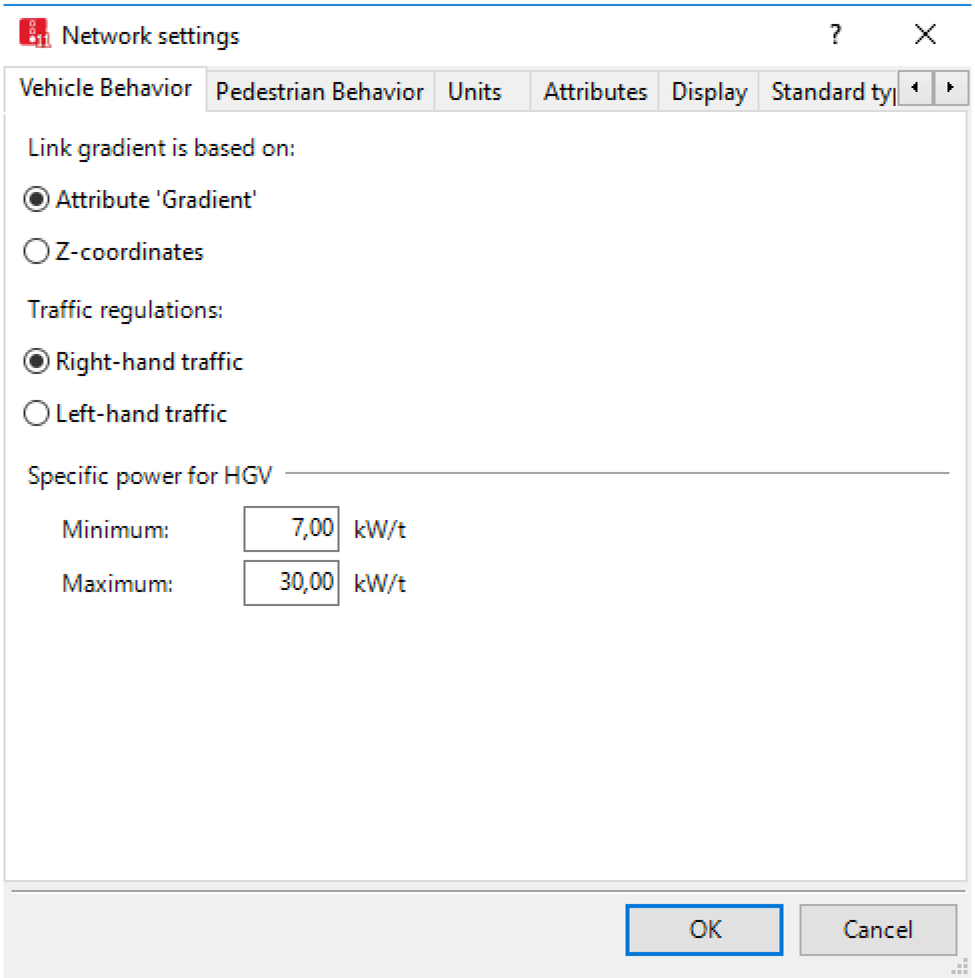


Figure C.3: Driving behaviours based on facility type

Driving Behaviors

Select layout... <Single List>

Count: 8	No	Name	NumInteractObj	StandDistIsFix	StandDist	CarFollowModType	W74bxAdd	W74bxMult	LnChgRule	AdvMerg	DesLatPos	OvtLDef	OvtRDef	LatDistDrivDef	LatDistStandDef
1	1	Urban (motorized)	4	☐	0,50	Wiedemann 74	2,00	3,00	Free lane selection	☑	Middle of lane	☐	☐	1,00	1,00
2	2	Right-side rule (motorized)	2	☐	0,50	Wiedemann 99	2,00	3,00	Slow lane rule	☑	Middle of lane	☐	☐	1,00	1,00
3	3	Freeway (free lane selection)	2	☐	0,50	Wiedemann 99	2,00	3,00	Free lane selection	☑	Middle of lane	☐	☐	1,00	1,00
4	4	Footpath (no interaction)	2	☐	0,50	No interaction	2,00	3,00	Free lane selection	☑	Any	☐	☐	1,00	1,00
5	5	Cycle-Track (free overtaking)	2	☐	0,50	Wiedemann 99	2,00	3,00	Free lane selection	☑	Right	☑	☑	0,30	0,10
6	11	Urban (mototized)	4	☐	0,50	Wiedemann 74	2,50	3,00	Free lane selection	☑	Middle of lane	☐	☐	1,00	1,00
7	12	Right-side rule (motorized)	2	☐	0,50	Wiedemann 99	2,00	3,00	Free lane selection	☑	Middle of lane	☐	☐	1,00	1,00
8	13	Freeway (free lane selection)	2	☐	0,50	Wiedemann 99	2,00	3,00	Free lane selection	☑	Middle of lane	☐	☐	1,00	1,00

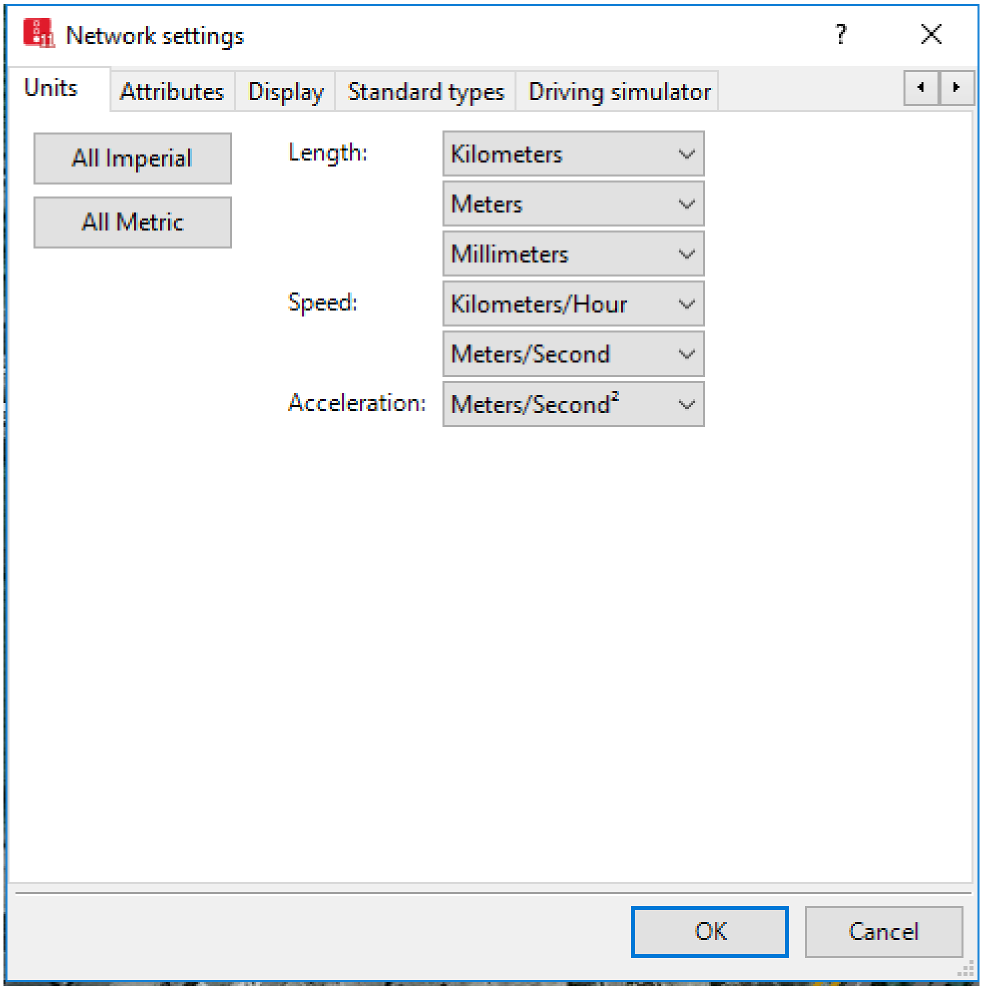
Figure C.4: Link Based Behaviour by vehicle class

Link Behavior Types / Driving Behaviors By Vehicle Class

Select layout... Driving behaviors

Count: 10	No	Name	DrivBehavDef
1	1	Urban (motorized)	11: Urban (mototized)
2	2	Right-side rule (motorized)	12: Right-side rule (motorized)
3	3	Freeway (free lane selection)	13: Freeway (free lane selectio...
4	4	Footpath (no interaction)	4: Footpath (no interaction)
5	5	Cycle-Track (free overtaking)	5: Cycle-Track (free overtaking)
6	6		1: Urban (motorized)
7	7		1: Urban (motorized)
8	8		1: Urban (motorized)
9	9		1: Urban (motorized)
10	10		1: Urban (motorized)

Figure C.5: Network setting units


Network settings
Units
Attributes
Display
Standard types
Driving simulator
All Imperial
All Metric
Length:
Kilometers
Meters
Millimeters
Speed:
Kilometers/Hour
Meters/Second
Acceleration:
Meters/Second²
OK
Cancel