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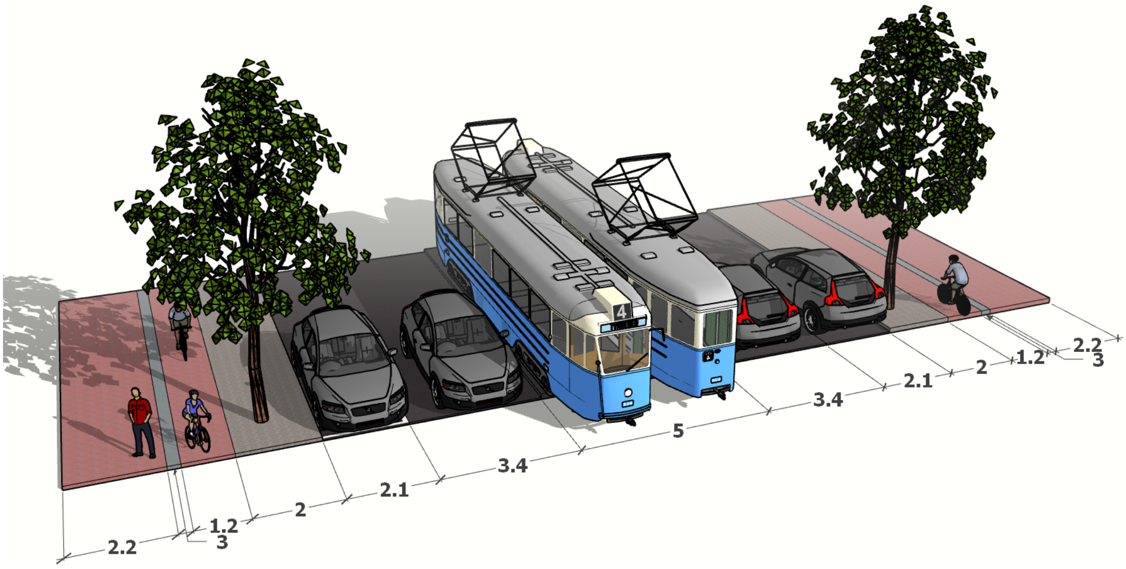

Sustainable traffic planning in an urban area

Microsimulation modeling of bicycle lane design alternatives for Linnegatan in Gothenburg

Master's thesis in Infrastructure and Environmental Engineering

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Cover: Sketch of the current design of Linnégatan made in Google sketchup.

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Abstract

Cities consistently try to make their transportation sector more sustainable. For instance does Gothenburg have goals to triple their bicycle trips. In order to encourage people to choose a sustainable mode of transportation, the infrastructure needs to be optimized. This thesis is a case study, which examines current traffic conditions on Linnégatan, Gothenburg, Sweden and evaluates the effects of improving the infrastructure for cycling. At Linnégatan, the pedestrians and cyclists do not have a clear separation, resulting in multiple conflicts between the two modes. The analysis was conducted with microscopic-simulation software, Vissim and Viswalk.

In this thesis, an alternative design is presented where the parking space on one side of the street has been converted into a two-way bicycle lane to improve the separation between the pedestrians and cyclists. The data collection was gotten from Gothenburg city and from prerecorded footage. To capture bike-pedestrian interaction more realistically, static routes were added for the cyclists. While modelling the pedestrians and the cyclists with Viswalk, the walking behaviour parameters were continuously adjusted.

The results showed an increase in the speed of the bicyclists, when applying the new design, without negatively influencing pedestrians' and vehicles' speed. The future travel demand volumes had an negative influence on the speed but mainly for the cyclists. In conclusion, the new design is considered to have increased safety, accessibility and mobility. The limitation of the study was that the data collection was conducted in the winter period so the authors used estimated growth factors to adjust cycling demand to be more representative of the real traffic situation.

Keywords: urban traffic, microscopic simulation, pedestrian, cyclist, vissim, viswalk, interaction, shared space, urban multimodal streets, bike lane design.

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Niklas Dimakis and Bára Guðmundsdóttir, Gothenburg, June 2018

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1 Introduction

Transport networks connect people and places together and help the society function more efficiently. Nevertheless, there are many negative effects of traffic that need to be taken into consideration in order to provide for social, economic and environmental improvements (European Environment Agency (EEA), 2016). Approximately one-third of the total energy consumption in the European Union countries (Eurostat, 2015) is caused by transportation, where the larger part is derived from passenger traffic. The transportation sector is also responsible for more than 20% of greenhouse gas (GHG) emissions (Sims, 2014), which affect the climate change (European Environment Agency (EEA), 2017). Other side effects from motorized traffic include pollution which influences people's health, congestion that results in people generally spending more time in traffic, noise, and land consumption (Behrends, 2017).

According to the United Nations Human Settlements Programme (2013), not everybody has access to a car but most people can walk or cycle, considering that bicycles can be a more affordable alternative than cars. Given that all individuals are considered equal, their opportunities to travel with their chosen mode of transportation should also be valued accordingly. However, cities can encourage its citizens to choose one mode of transportation over the other, in a way that people will reduce their use of private motorized cars and rather choose to use public transportation, bicycle or walking (United Nations Human Settlements Programme, 2013). The influence of these types of changes can cause transportation to become more sustainable, by increasing the accessibility for people to commute by foot or bicycle. Therefore, improvements in non-motorized transportation infrastructures (e.g.,sidewalks and cycle paths) are essential for achieving more sustainable transport networks (Trafikkontoret, 2015).

1.1 Background

In 2015, the United Nations (UN) developed 17 sustainable goals for countries to adopt and accomplish over the following 15 years, called 2030 Agenda. Sweden wants to lead the way in implementing the 2030 Agenda and published their first report of the implementation in June 2017, where their goals and implementations are explained and described in more detail. The goals that relate to traffic in urban areas are, for example, the following:

- Implement the Vision Zero Strategy
- Provide economically efficient transportation
- Improve the quality of the air
- Reach zero net emission of green house gases by 2045

To achieve these goals, many sectors need to participate, e.g. the municipalities (Government of Sweden, 2017). The city of Gothenburg has created a program to carry out their sustainable vision (Göteborg stad Miljö- och klimatnämnden, 2013). The specific factors which are targeted within the program are e.g.: Lowering the speed for vehicles, parking space strategy, reduce the traffic's climate impact, actively increase mobility for cyclists and make a plan for pedestrians paths (Göteborg stad Miljö- och klimatnämnden, 2013). Their goal is to triple the number of cycling trips from 2011 to 2025 (Trafikkontoret, 2015).

The parliament accepted two new transport goals in 2009. The former discusses improvements in functionality, where the transportation system should increase their accessibility, security, and comfort. The transportation system should be designed for everybody, including children and the disabled, in such a way that the conditions of choosing the more sustainable alternative should be better. The latter goal focuses on decreasing the number of fatal and severe accidents. It also states that the transport sector should contribute to the national environmental goals as well as improving the public health (Trafikverket and SKL, 2010).

Göteborgs stad (2014) states in the 2035 strategy for the city of Gothenburg that the bicycle shall be considered it's own mode and shall be well separated from other modes. This also includes the separation between pedestrians and bicycles. Göteborgs stad (2014) also states that within the city where bicycle and motorized traffic need to be mixed, the bicycles shall be prioritized and speeds should be set by the bicycle. In the strategy, it is stated that a commuting network for cyclists need to tie together important nodes in the city. Between these nodes, mobility shall be high and few or no conflicts shall occur with other modes (Göteborgs stad, 2014).

1.2 Study Area

In the cycle program for Gothenburg, it is stated that roads in Gothenburg have often been designed in such a way that the pedestrians and the cyclist are mixed together. In that case, conflicts are created between the cyclists and the pedestrians. In future designs, the separation between cyclists and pedestrians should be more clear in order to decrease the conflict, increase accessibility and flow, as well as reduce the number of crashes and, thus, improve road and traffic safety. In the program, a demonstration of a bad example and a good example is presented, where Linnégatan is a bad example, see figure 1.1 (Trafikkontoret, 2015).

Figure 1.1: Linnégatan on the left side in the figure, showing a lack of proper separation, while on Odinsgatan (right side picture), a clear separation can be seen (Trafikkontoret, 2015)

Based on the aforementioned example and the city's goals, Linnégatan was chosen as a study area in this project. Linnégatan is located in the central area of Gothenburg, which connects a public park, Slottskogen, and a public square, Järntorget. Restaurants and services can be found on the ground floor in the surrounding buildings and apartments above them. The location of the stretch can be seen figure 1.2.

Figure 1.2: Location of the stretch at Linnégatan, highlighted in orange color (map from www.map.google.com)

The street is relatively symmetric about the middle, where the pedestrian lanes and cycle lanes lie at the edges and trams and busses occupy the middle of the road. The safety zone divides the motorized traffic with non-motorized traffic, where the car traffic is between the parking spaces and the tram. The general cross-section of the street, is presented below, see figure 1.3.

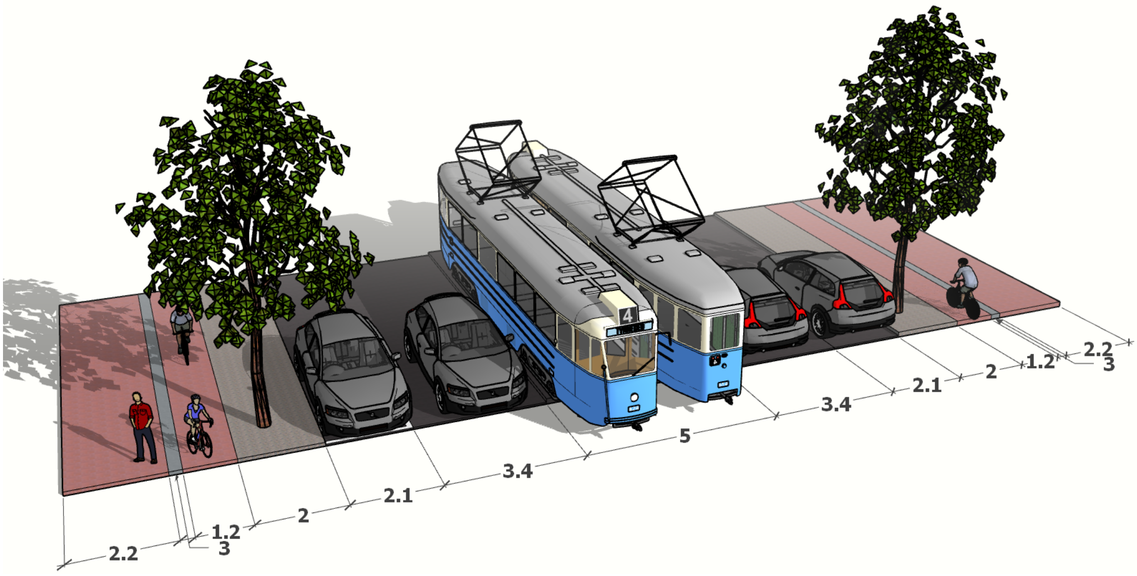

Figure 1.3: Demonstration of the current cross section of Linnégatan, dimensions in [m]. From left: pedestrian path, separation strip (is 0.3 m), bicycle path, safety zone, parallel parking, car lane and, public transportation's lane. The section is mirrored about the middle public transport's lane

There is one tram stop and one safe crossing in the study area. The safe crossing allows pedestrians to stop halfway on a traffic island, if there is not enough time to cross the entire corridor at once. The design speed, for vehicles, at Linnégatan is 50 km/h. In 2013 the speed was measured on the street, where the median speed was between 24-33 km/h and the 85- percentile 33-40 km/h. The data also shows that the measured speed on the street has been lowering (Göteborg stad, n.d.*b*). 32 parking spaces are on each side of the road, which are owned by Gothenburg city (Göteborg stad, n.d.*a*).

Accidents on the street have been documented and are presented in figure 1.4. The accidents are categorized according to their severity, where the non-severe accidents can, e.g., represent a fracture on the ribs, moderate accidents can be, e.g., a concussion with loss of consciousness and severe accidents can be, e.g., brain damage (Transportstyrelsen, n.d.). As seen in the figure there are more non-severe accidents and moderate accidents than severe accidents. The non-severe accidents often do not include motorized vehicles.

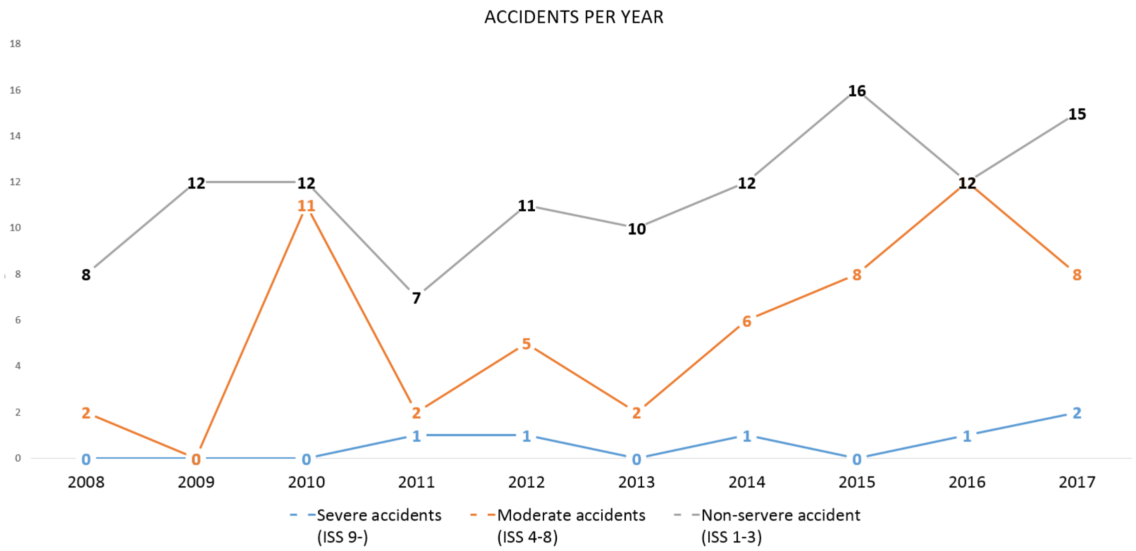

Figure 1.4: Registered accidents at Linnégatan in Strada (Swedish Traffic Accident Data Acquisition)

1.3 Aim and Objectives

The aim of this thesis is to study the traffic system of Linnégatan in the city of Gothenburg. The main focus will be on the interaction between bicycles and pedestrians as well as their interaction with motorized vehicles and public transportation.

In the thesis, the applicability of the traffic simulation software Vissim and Viswalk is assessed by creating and validating a model of Linnégatan. This is carried out with focus on evaluating an alternative street cross-section design, improving bike lanes, and meeting future demands for the city's mobility and sustainability strategies. The thesis also aims to conclude in a recommendation regarding what design is best suited for the area in accordance with those aspects.

1.4 Study Limitations

When starting this project, the goal was to be able to produce relatively accurate traffic models as well as conduct evaluations with little or no expert knowledge in scripting and software modifications (which can be used to do customized changes in the software) but rather be able to use "out-of-the-box" features to resemble what many consultants have access to. This lead to a restriction to use some of the developed "workarounds" with COM-scripting solutions for shared space behavior in Vissim and Viswalk.

The scope of this study does not include presenting a detailed plan over suggested designs. The designs are rather used to exemplify how different approaches can be used in planning the network in an urban area.

2 Literature Review

Theory relating to traffic, micro simulation and design guidelines will be presented in this chapter, to give more insight into why and how the work was conducted during thesis.

2.1 Traffic characteristics

The main function of streets is to provide mobility from one place to another and access to opportunities along the streetscape which often influence city-wide economic growth. Moreover, the streets need to be designed for every mode with good safety specifications while retaining a good level of performance (Mannering and Washburn, 2013). This section provides description of the most common traffic modes and their characteristics.

2.1.1 Traffic Modes

The definition of different modes, that are used in the thesis, is presented in table 2.1.

Table 2.1: Definition of different traffic modes

Pedestrians	**Cyclist**	**Motorized vehicles**	**Public transport**
Walkers	Bicycles	Private cars	Busses
	Electric bikes	Freight	Trams
	Cargo bikes	Motorcycles	

2.1.2 Motorized Vehicles

According to Mannering and Washburn (2013) the fundamental parameters in traffic are flow, speed, and density. In this thesis, these parameters are defined in the same manner as in their work but explicitly outlined for clarification. The definition of traffic modes and mobility will be described afterwards.

Traffic flow, defined as the number of vehicle per unit time, is presented in equation 2.1 and expanded in equation 2.2. The flow is often measured for one hour period with the unit veh/h. When measuring the flow of interest, the peak 15 minute of the hour is often used (Mannering and Washburn, 2013).

$$q = \frac{n}{t} \tag{2.1}$$

$$q = \frac{n}{\sum_{i=1}^{n} h_i} \tag{2.2}$$

Where

q: traffic flow
n: amount of vehicles going trough the specific section,
t: defined time interval, and
h_i: time headway of the i'th vehicle.

The speed will be defined as space-mean speed and is often expressed in as km/hour and is given as

$$\overline{u_s} = \frac{l}{t} \tag{2.3}$$

Where
$\overline{u_s}$: space-mean speed in unit distance per unit time,
l: length of roadway used for travel time measurement of vehicles, and
$\bar{t}$: average vehicle travel time.

Traffic density is defined as

$$k = \frac{n}{l}. \tag{2.4}$$

The above mentioned equations 2.1, 2.3, 2.4, form a relationship that can be express as

$$q = \overline{u_s} \cdot k \tag{2.5}$$

From equation 2.5, assuming a linear speed-density model, the relationship can be presented graphically, see figure 2.1.

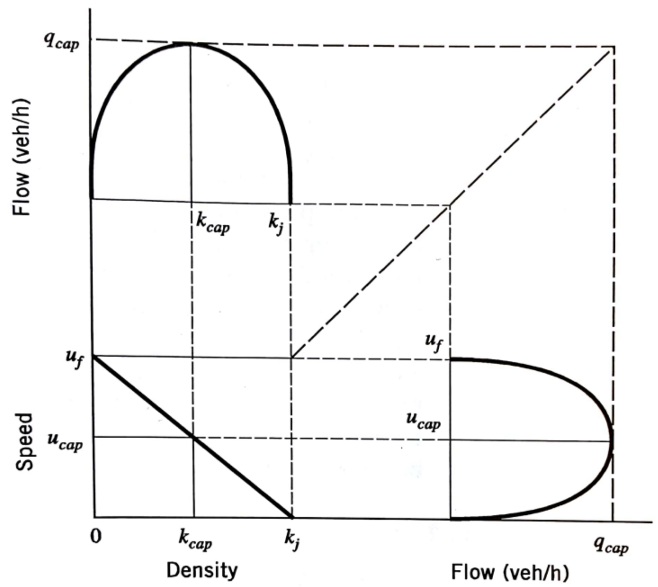

Figure 2.1: Fundamental traffic flow theory diagram (Mannering and Washburn, 2013)

2.1.3 Pedestrians

Pedestrians do not move like vehicles, since pedestrians have more freedom and flexibility to move and pass other pedestrians, which results in higher speed variations among them. Therefore, the fundamental traffic flow diagrams in 2.1 cannot be directly applied to the pedestrian mode. The speed-density-flow relationship for pedestrians is more complex than for vehicles and still is a research area in very early stages of development. The relationships are imprecise and can be subjective (Transportation Research Board, 2000). A simple relationship between speed, density, and flow is explained in figure 2.2.

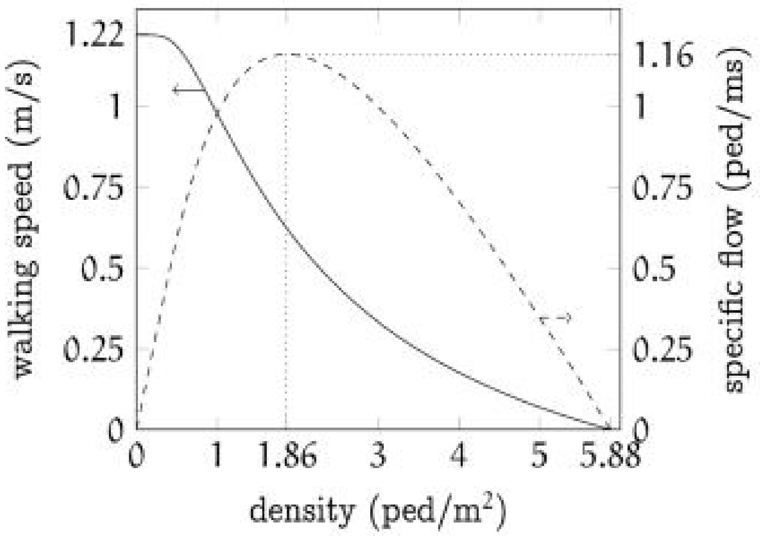

Figure 2.2: Fundamental diagram for pedestrians, the solid curve represent the relationship between density and the walking speed and the dashed curve represents the relationship between density and flow (Transportation Research Board, 2000)

As can be seen in the diagram, the maximum flow of pedestrians is when the density does not reach over 1.86 ped/m^2. As seen in the diagram, the speed is uninterrupted when the density is lower than 0.5 ped/m^2. However, this number can vary between methods but will be used as the base values in this work.

2.1.4 Mobility

Mobility is defined as the competence to move in the physical, psychological and virtual sense (Mayinger, 2001). By increasing mobility in an area, in a transportation sense, the ability to travel to a specific destination improves. Therefore, accessibility is the key to good mobility, where quality, affordability and the design is for all the city's residents (United Nations Human Settlements Programme, 2013).

2.1.4.1 Level of Service

The Transportation Research Board have made a concept, called Level of service, to quantify transportation facilities. Where it is expressed as: *"The level of service represent a qualitative ranking of the traffic operational conditions experienced by users of a facility under specified roadway, traffic, and traffic control (if present) conditions."* (Mannering and Washburn, 2013). Techniques for measuring the level of service (LOS) for a road's performance are diverse. LOS can be measured by different factors, e.g. speed, travel time, hindrances (interruptions) and conditions. However, safety is not included in the LOS system. The system is divided into six different LOS levels, from A to F, from A being the best conditions and F being the worst (Transportation Research Board, 2000).

Since the main focus in the thesis is on pedestrians and cyclists, only the definitions of measuring LOS for pedestrians and cyclists is described. The LOS criteria are based on the density, the LOS for pedestrians (PLOS) are listed in table 2.2.

Table 2.2: Pedestrian walkway LOS (Transportation Research Board, 2000)

Level of service	**Pedestrian Space** m^2/ped	**Flow rate** p/min/m
LOS A	$>$ 5.6	$\leq$ 16
LOS B	$>$ 3.7-5-6	$>$ 16-23
LOS C	$>$ 2-2-3.7	$>$ 23-33
LOS D	$>$1.4-2.2	$>$ 33-49
LOS E	$>$ 0.75-1.4	$>$ 49-75
LOS F	$\leq$ 0.75	Varies

As seen in table 2.2, in order to have the best service, each pedestrian needs to have at least 5.6 m^2. The denser the area is, the more likely it is that the pedestrian needs to slow down or stop to cross a pedestrian stream, see the probability in figure 2.3.

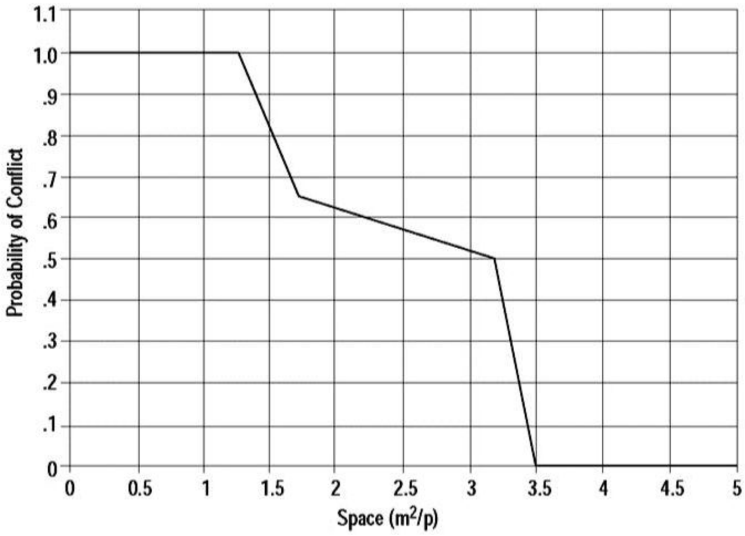

Figure 2.3: Probability of a pedestrian conflict (Transportation Research Board, 2000)

Comparing table 2.2 and figure 2.3, LOS A, and LOS B have no probability of a conflict. Therefore, they can move without reducing their speed or stopping. In LOS C-F, the density has an influence on the pedestrians so that their speed decreases.

Cyclists do not travel as organized as vehicles do and bicycle lanes are not always designed the same, which makes it harder to evaluate the performance of the bicycle facilities. To value LOS of bicycle facilities (BLOS), the percent of hindrance is evaluated. The hindrance value is evaluated for a 1 km section of a path, where the number of hindrances cyclists experience, from other cyclists or pedestrians in both directions, are measured (Transportation Research Board, 2000). The LOS for bicycle facilities is listed in table 2.3.

Table 2.3: LOS for bicycle facilities (Transportation Research Board, 2000)

Level of service	**Hindrance (%)**
LOS A	$\leq$ 10
LOS B	$>$ 10-20
LOS C	$>$ 20-40
LOS D	$>$ 40-70
LOS E	$>$ 70-100
LOS F	100

Some researchers, such as Schantz (2012), have taken some additional factors into consideration when assessing how users choose to use pedestrian and bicycle facilities. Schantz (2012) states that the factor that influences bicyclists to use a facility more or less frequently does, indeed, depend on the route environment. Schantz

(2012) divides the route environment into 5 categories that play a role in how it is perceived:

- Physical environment (non moving objects)
- Traffic environment (moving objects)
- Social environment (interaction between people)
- Light environment (natural and constructed)
- Weather

The factors above contain many sub-categories and are individually scored on a chart where an environment is more or less stimulating or inhibiting on one axis. Schantz (2012) could conclude that for new cyclists the stimulating/inhibiting factors were more important to new riders than to seasoned riders when it comes to choosing a specific route. On the other axis is safe/unsafe which is an important factor for all users. The two axes determine how a specific route environment affects the choice of a route. The safety and perceived safety is closer described in section 2.1.5.

2.1.5 Safety and Security

As a complement to the level of service (LOS), the safety and security factors of an infrastructure design is included in this study. Differentiating between safety and security can be challenging. In this study, the definition by Merriam-Webster stating safety to be "the condition of being free from harm or risk" and security to be "the quality or state of being free from danger" will be used. The two will be described in the sections that follow.

Streets serve to provide people with better mobility. However, crashes occur, leading to economic cost, injuries or worse, fatality. The speed of the vehicles has a big impact on the likelihood of surviving a crash. The slower the vehicles are, the more likely it is that there will not be a fatal accident, as seen in figure 2.4 (Organisation for Economic Co-Operation Development (OECD), 2008).

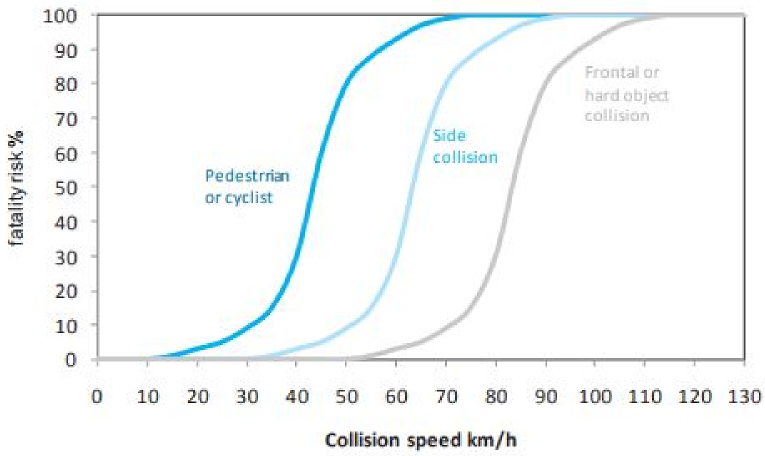

Figure 2.4: Fatality risk in the traffic (Organisation for Economic Co-Operation Development (OECD), 2008)

The factors that influence road and traffic crashes result from human factors, vehicle characteristics, and roadway design. Fatal crashes are likelier to happen on rural roads, due to higher speeds and less consistent traffic flows (e.g., no platooning). However, severe injury crashes happen more often on urban roads. This is because of more conflict and diversity in the road users with different speeds. To prevent the crashes from happening, a good road design is needed and must be provided for all the road users, especially the vulnerable users such as elderly and young pedestrians (Organisation for Economic Co-Operation Development (OECD), 2008). Municipalities, in Sweden, have a goal to decrease the number of nonfatal accidents by 25% per year, from 2010 to 2020. This is with the main focus on accidents in terms of single vehicle, single pedestrian accidents and collision between pedestrian or cyclist and vehicles. The municipalities can do that by taking various measures, e.g. that the desired speed would not go over 30 km/h in mixed traffic and prioritize maintenance for cycling paths and sidewalks, by increasing the funds (Trafikverket, 2013). Many reasons for accidents among pedestrians and cyclists are because of the road surface. The road surface should have good friction, even (i.e., no holes and cracks) and not slippery (Vägverket, 2004). Individuals experience a situation in different ways and some can experience more risk of an accident than others. Therefore, it is necessary to consider how vulnerable the user feels when carrying out the design (Trafikverket, 2015).

2.1.5.1 Impaired Vision in Traffic

People with impaired vision need to be kept in mind when designing sidewalks and paths in public spaces. Walking paths should be continuous, with no obstacles and clear warnings and the paths should not be interrupted by vehicles or bicyclist. The contrast between two surfaces should be more than 0.4 according to the NCS system, see an example of NCS contrast measurement in figure 2.5. In addition, the contrast should be good enough in wet situations and in shadows (Trafikverket, 2016).

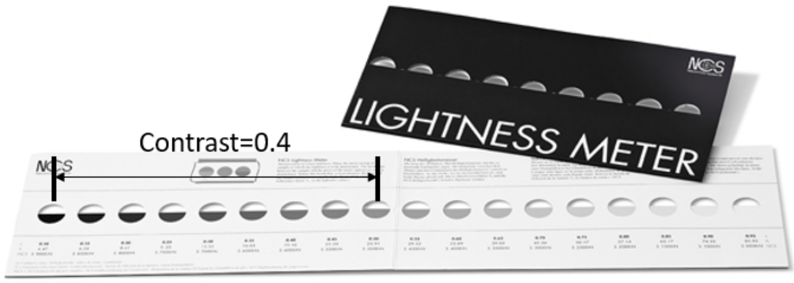

Figure 2.5: NCS measurement, with 0.4 contrast as an example (Natural Colour system (NCS), n.d.)

2.1.5.2 Security

Security mainly has an impact on vulnerable road users, such as pedestrians and cyclists but can also affect public transportation and private motorized vehicle users. Road design can protect against intentional mishaps and provide better security. When designing the roads, such protections can be implemented by making more space for pedestrians, segregate bicycle lanes, provide good lighting conditions and prioritized signal control for pedestrians. By implementing these changes, the security is improved at a relatively low expense (Worldbank.org, 2002) and (Trafikverket, 2015).

2.2 Street Design Guidelines

In Sweden, road designs are regulated in the document "Vägar och gators utformning" (VGU) which translates in to "roads' and streets' design" (Trafikverket and SKL, 2015*a*). This is a design-guide/regulation document. The municipalities of Sweden are advised to use the guidelines in VGU but the state-regulated traffic administration, Trafikverket, are required to use it when "normal" conditions apply (Trafikverket and SKL, 2015*a*). In VGU, details on the most parts of the road design are covered. In the following sections, some of the most important ones in relation to this project will be described.

In the sections below regarding design guidelines, different modes will be touched upon depending on their space requirement. In table 2.4 below the different uses of space will be listed.

Table 2.4: Different use of space in a traffic corridor (Trafikverket and SKL, 2010)

Usage	Placement	User
Pedestrian path	City center, city district	P
Walking street	City center	PB
Walking speed area	Housing area/ City center	PBM+MV
Pedestrian and Bicycle lane	In or between districts/city center also between urban areas	PBM
Mixed traffic lane	In or between districts/city center	BM+MV
Bicycle priority street	City Center	BM+MV
Main street	Between districts	MV
Local street	Within districts	MV
P=pedestrians B=bicyclist	*M=mopedist MV=motor vehicle*	

In the Swedish system, traffic corridors are classified A through C, depending on how different modes interact with each other. **Class A** - cars have their own lanes, with no intrusion on the street shoulder, pedestrian paths, bicycle lanes, traffic separating islands or lines, or opposite traffic. Pedestrians and bicyclists have enough space so that they do not have to adjust to one and other. This class ensures good comfort and is considered safe. **Class B** - cars could require the use of the road shoulder and, when overtaking a bicycle, also use the opposing car lane (maximum 1m). When a car is approaching on the opposite lane, a speed reduction is needed. On pedestrian and bicycle lanes, some adjustment is required among the modes. Comfort on class B is lower than class A but safety is considered good if speed is reduced. **Class C** - Cars intrude on the opposite lane when overtaking a bicycle. When approaching another car, a very low speed is required. The class gives a low comfort but is considered safe, if a low enough speed is applied (Trafikverket, 2015).

2.2.1 Pedestrian Paths and Walking Streets

The design of a pedestrian path does differ to some degree from the design of a car lane. Not only is capacity and speed important factors but also, as mentioned in section 1.1, the accessibility, and safety are important aspects. The pedestrians are a homogeneous user group and therefore, the design should be in such way that all can use the path without being hindered (Trafikverket and SKL, 2010). Trafikverket and SKL (2010) also state that traffic safety consists in both subjective and the objective safety, i.e. the path should both be and feel safe.

Trafikverket and SKL (2010) give specific design guidelines relating to pedestrian paths to meet the above-stated goals and requirements. In the design guidelines, recommended widths and minimum requirements are stated depending on the location and status on the surroundings, see table 2.5 below.

Table 2.5: Recommended and acceptable minimum width on pedestrian path (Trafikverket and SKL, 2010)

	Recommended (m)	**Accepted (m)**
New facility	2.0	1.8 with turning zone
Build environment	1.75	1.2
Short tapering	1.3	0.9

Walking streets are common in city centers and are streets intended for pedestrians but can also be shared with bicycles, with the requirement that bicycles give way for pedestrians (Trafikverket and SKL, 2010). They are commonly built in urban shopping districts and aim to increase the accessibility for pedestrians and cyclists. On these types of streets, motorized vehicles are prohibited with the exception of transports or deliveries to and from shops or restaurants in the area, as well as transportation for disabled people, the motorized vehicles are required to keep a walking speed.

On the walking street, there are, according to Trafikverket and SKL (2010), recommendations on how the mix of pedestrians and cyclists should be combined on a walking street depending on the width and volume of pedestrians see table 2.6 below.

Table 2.6: Recommended mix on a walking street (Trafikverket and SKL, 2010)

P / hour and meter walking width	**Recommended combination**
<100	P, B mixed
100-160	Separated lanes but same level
160-200	Separated lanes on different levels
>200	No B

P=pedestrians, B=bicyclists

The "walking speed area" is an area where pedestrians are the main mode in terms of traffic regulations. The vehicles, motorized and non-motorized are required to keep a walking speed when entering the area. This type of area is common in housing areas, as well as some parts of city centers. It is important that the design of this type of area is not separated into lanes, since it has been shown that the motorized vehicles then tend to increase their speed to dangerous speeds (Trafikverket and SKL, 2010).

2.2.2 Bicycle Lane

In VGU from Trafikverket and SKL (2015*a*), bike lanes and pedestrian paths are written under the same section which according to the specialized version of VGU for urban areas, Trafikverket and SKL (2015*b*) require different attention and instead refer to the guidelines specialized for bicycles, pedestrians and mopeds (GCM guidelines) (Trafikverket and SKL, 2010) when assessing pedestrian or bicycle lane design.

As mentioned before, municipalities are only recommended to follow the VGU guidelines and do not require to do so. Therefore, the city of Gothenburg has developed an additional document describing the design guidelines that the city are using (Trafikkontoret, 2015). In this document not only are design guidelines available but also the overall future development plan for the city described in section 1.1.

The designs in the GCM guideline does not differ much from the City's design guidelines in terms of pedestrians. However, when bicycle lanes are described the Gothenburg specific design guiding documents differ some from Trafikverket and SKL (2010) in some important aspects. Trafikkontoret (2015) has differentiated the bicycle lanes as the commuters network lanes, the general network, and the local network. In table 2.7 below, the different designs are presented.

Table 2.7: Recommended widths of bicycle paths (Trafikverket and SKL, 2010) (Trafikkontoret, 2015)

Commuter	**One way path (m)**	**Two way path (m)**
<500 B/maxh	2.0	3.0
501-1000 B/maxh	2.4	3.6
>1000 B/maxh	3.0	4.8
General		
<500 B/maxh	1.6	2.4
501-1500 B/maxh	2.0	3.6
>1500 B/maxh	4.2	4.8
GCM		
Small flow	1.6 (<200 B/maxh)	2.25 (<300 B/maxh)
Large flow	2.0 (>200 B/maxh)	>2.5 (>300 B/maxh)

maxh=peak flow hour *B=bicycles*

In the GCM guidelines, the bicycle speed should be estimated to be from 15-20 km/h but can vary between users, e.g. between children and racing cyclists (Trafikverket and SKL, 2010).

2.2.3 Car Lane

In VGU tätort (urban area) Trafikverket and SKL (2015*b*) the designs for car traffic is mainly separated into 3 categories. There are the main streets, the local streets, bicycle priority streets and the mixed traffic streets. The main and local streets are usually determined by the flow on the link. In the section below, the three of them will briefly be described.

Main road is the name used for highways, multiple lane roads or two-lane road or street (Trafikverket and SKL, 2015*b*). Roads with daily traffic above 3500 vehicles are considered by the traffic office, Göteborgs stad, Trafikkontoret (2018), a part of the main road's network. On the main roads, the traffic safety is to have a good standard at the same time the road should offer a high level of service. In these streets, public transportation should have good accessibility even when car traffic is limited. Larger vehicles should be able to fit and both fast and slow driving users shall be able to drive here. Bicycle paths, as well as pedestrian paths, are separated from the motorized vehicles and the road should be designed such as the cars are forced to slow down where pedestrians or bicyclists cross the road. Parallel parking is in general not allowed on the main roads/streets and is only allowed where it is specifically designed for it (Trafikverket and SKL, 2015*b*).

Local roads/streets are just like the main roads/streets in the city's network defined by the flow of cars per day. The local parts of the network are where the flow is less than 3500 vehicles per day. The streets of this standard should be designed for high safety standard, especially concerning non-motorized vehicles such as pedestrians and bicyclists. A lower level of service with lower mobility is acceptable for cars, and vehicle types that do not occur often on the road can be allowed low mobility. Buses and public transportation should have a high mobility in the streets during normal traffic conditions. The accessibility should be good for cars with a possibility for deliveries as well as emergency vehicles. Slow users are especially prioritized in the local network and pedestrians and bicyclists are separated from the motorized traffic if there is a need. When non-motorized vehicles and pedestrians cross the local network street, cars are forced by the design of the road to keep a low speed (Vägverket and Svenska Kommunförbundet, 2004).

Some parts of the local network can use "**narrow streets**". Here buses and trucks cannot pass each other in a good way, and all types of separations can occur between motorized and non-motorized traffic, depending on the speed. The narrow street can be either one or two-laned streets and the lanes do vary from 3 to 5.8m (Vägverket and Svenska Kommunförbundet, 2004).

Bicycle priority street (BPS) is a street where bicycles and motorized vehicles share the same lane. Trafikverket and SKL (2010) state recommendations for these streets and the first is that the ratio between bicycles and motorized vehicles should be 2:1 with a minimum absolute amount of bicycles of 1000 per day and maximum 500 motorized vehicles per day. The maximum number of cars allowed on German BPS are however 3000 vehicles per day. The speeds of the BPS should not exceed 30km/h and no parking should be allowed on these streets. Smooth surfaces such as asphalt concrete should preferably be used (Trafikverket and SKL, 2010).

2.2.4 Parking

Parking in an urban area can be designed in different ways in regard to geometry and location. However, here the focus will rather be on the goals and policies set up by the city of Gothenburg regarding the parking spaces for motorized vehicles and how they have an effect on the usage of motorized vehicles.

In the "parking policy" by Göteborgs stad et al. (2009) it is stated that to be able to reach the public transportation goals for 2020 in Gothenburg, not only does the public transportation it self need to be improved. Along with an improved public transportation, actions for reduced demand for personal car usage need to be implemented. An example that is mentioned in the policy report is various changes in the supply of car parking.

One of the actions discussed is to relocate residential parking spaces from the streets in order to provide more space for cyclists, public transit and pedestrians, which would also increase the attractiveness of urban environment (Göteborgs stad et al., 2009).

To increase the trips by bicycle and public transportation shall the demand of "all day parking" from work commuters by car decrease. This can be accomplished by raising the parking fees, changing the time limitation of the parking spaces, and lowering the number of available parking spaces. Accessibility should not be negatively affected for users that have to use a car (Göteborgs stad et al., 2009).

2.2.5 Mode Separation

Every year, around 10% of all fatal accidents involve bicyclists, and the same number of severe accidents are 40% (Trafikverket, 2014). The majority of these are accidents including motorized vehicles and only 1% of the accidents involving both pedestrians and bicyclists are between the two groups (Trafikverket and SKL, 2015*b*). The separation between motorized vehicles are thus of great importance and mixed traffic should only be used when speeds and volumes are low e.g. city central (Trafikverket and SKL, 2015*b*).

The separation between bicyclists and pedestrians does not show the same safety advantages as with motorized vehicle separation (Trafikverket and SKL, 2015*b*). However, a sufficient separation between pedestrians and bicyclists increases the perceived safety as well as an increased mobility (Trafikverket and SKL, 2015*b*). This type of separation can also help decrease single accidents where yielding due to conflict is the cause of the accident (Trafikverket, 2014). Trafikverket and SKL (2015*b*) states that today's most common separation method (painted line) is perceived as unclear and not sufficient and that this in conjunction with a narrow or uneven pedestrian path can lead to spillover effects from pedestrian paths.

2.3 Data Collection

To be able to give relevant and accurate prognoses on demand on different modes, reliable data has to be collected and used. To collect data on different types of traffic, different methods can be used and depend on the use of the data different level of accuracy is needed and thus some methods are preferred over others. In the traffic system in the scope of this report, different modes are present and are described in section 2.1.1. This requires a strategy individually assigned to each traffic mode.

Motorized traffic data can be collected with relatively well established techniques

(Federal Highway Administration, 2013). The motorized traffic also varies less with weather conditions and seasons (Nordback, 2014). Nordback (2014) also shows in a report that motorized vehicles use a traffic network for less variable purposes. This implies that motorized vehicle movements can be measured with greater accuracy and based on based on shorter measurement duration when compared to non-motorized road users.

A variety of options for data collection are available shown in figure 2.6 below.

Presence Sensing Technologies	Axle Sensing Technologies
Inductive loops	Infrared
Magnetic	Laser (most)
Video detection system	Piezo-electric
Acoustic	Quartz sensor
Ultrasonic	Fiber optic
Microwave radar	Capacitance mats
Laser radar	Bending plates
Passive infrared	Load cells
	Inductive Signatures
	Contact switch closures (e.g., road tubes)

Figure 2.6: Methods for collecting vehicle data (Federal Highway Administration, 2013)

Many of the methods in figure 2.6 above does work very well for measuring vehicle flow and passing axles. This is something that is very useful for assessing the traffic of motorized vehicles with relatively limited freedom of movement (they follow the roads). The same methods are, due to the different definitions of the level of service (LOS, BLOS, and PLOS) mentioned in section 2.1.4.1, difficult to use to asses non-motorized vehicles.

To decide on what methods are required to collect sufficient and accurate data, it is important to realize what the main differences between the different modes from a data collecting perspective are. Pedestrians and bicyclists, in general, make shorter trips than motorized vehicles, making them more variable in their patterns than motorized vehicles. The non-motorized vehicles are especially sensitive to variations in weather conditions and land use in the area (Ryus et al., 2014).

Methods to use to collect data on non-motorized vehicles are summarized in short in table 2.8 bellow.

Table 2.8: Methods for collecting data on non-motorized vehicles (Ryus et al., 2014)

Method	Advantages	Challenges
Bluetooth and WiFi	Accuracy and not limited to lanes	Not possible to determine percentage of users with this signal active, nor how many devices each person have.
GPS	Accuracy and not limited to lanes	Require that user participate. User sample is difficult to determine
Bike sharing data	Good for determining origin-destination data	Does not represent the cyclist population as a whole
Pedestrian signal buttons	Good for checking amount of crossings	Does not measure volume of pedestrians
Surveys	Good for origin-destination and demand	Does not measure absolute volumes or flows
Sensors	Can measure volumes and flow	Difficult to detect some objects, some system does not register volume
Trip generator	Good for origin destination and prognoses	Does not assess current situation

A difference between data collection of motorized and non-motorized vehicles is the duration that is acceptable to still provide an accurate sample. As mentioned above, motorized traffic is less variable over time and therefore, shorter collecting times are acceptable. With non-motorized vehicles, different methods to compensate for short collection times have been developed. El Esawey (2016) did research on how accurate different methods for this are. The most accurate is day of year factors (DYF) developed by Hankey et al. (2014) with a mean absolute percent error (MAPE) of 17,5% compared to the monthly-weather factor method with a MAPE of 24.5%.

$$day\ of\ year\ factor = \frac{traffic\ of\ specific\ day}{AADT} \tag{2.6}$$

The method does require that data from a whole year is available to be able to calculate the annual average daily traffic (AADT). When this has been calculated an estimate of AADT can be calculated with shorter counts. This estimation can be seen in equation 2.7 below (Hankey et al., 2016).

$$estimated\ AADT = \frac{1}{n}\sum_{i=1}^{n}\frac{AdjC_i}{SF_i} \tag{2.7}$$

Where,
$AdjC_i = adjusted\ counted\ bicycles\ e.g\ from\ axles\ counted$
$n = number\ of\ days\ counted$
$i = individual\ day$
$SF_i = scaling\ factor$

2.4 Modelling

By using theory, data, and assumptions, any system (e.g., transportation network) can be described in a simplified model. The purpose of models is to understand, analyze and predict changes in the system. Before building the model, few aspects needed to be specified:

- How the system works
- The boundaries
- How the components interact
- The inputs into the system
- The outputs of the system

A framework of building up models can be seen in figure 2.7 (Barceló, 2010)

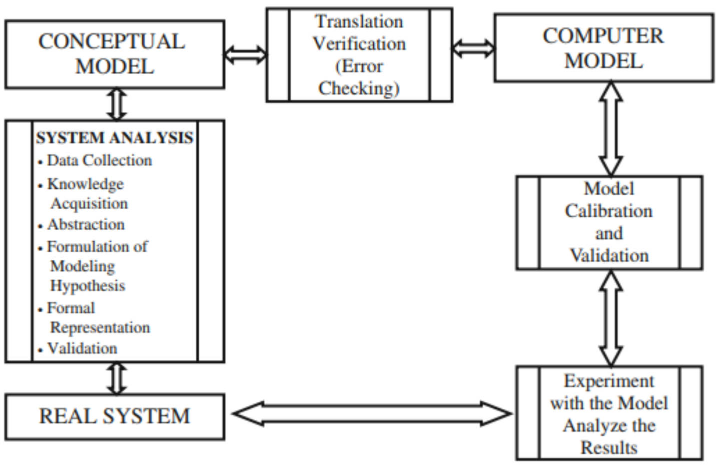

Figure 2.7: Method for building up models (Barceló, 2010)

In the process of building up the model, revisions of these aspects need to be performed so the model will be more realistic.

2.4.1 Traffic Modelling

As said in 2.4, models are used to understand the system better and its changes. The purpose of modeling traffic is to estimate the effects of newly implemented design solutions of future increase in travel demands.

After knowing the fundamental parameters, as described in section 2.1, a microscopic, mesoscopic or macroscopic study can be conducted of the traffic flow. The arrival of vehicles to the system can be modeled in different ways. The simplest model is considered to be one where the vehicles are assumed to arrive evenly distributed into the system, having a uniform space between each other. This kind of arrival is called deterministic arrival. When surveying traffic, this type of traffic flow is not likely to be the reality so uniformity is often assumed (Mannering and Washburn, 2013).

2.4.2 Microsimulation

Models that do not have a uniform traffic pattern, a so-called stochastic distribution where the arrivals and speeds are random, are more reasonable to be representative of real-world situations (Mannering and Washburn, 2013). For limited areas, e.g. intersections and urban streets, a microscopic approach is normally used to simulate the traffic. In that kind of approach, the model shows more precisely how each vehicle behaves and how its interacts with other road users.

One methodology to model how the vehicles move in the system is in a Psycho-physical way, a queuing model, where the method aims to combine physical and human factors that influence driving behaviour in real-world traffic situations. The fundamental input is to determine the vehicle reaction and the vehicle state (Schulze and Fliess, 1997).

2.4.3 Vissim (Car Following Model)

The software Vissim, developed by PVT, simulates traffic in a microscopic resolution. The software uses the psycho-physical method in the car-following logic and this model was developed by Widemann. An illustration of Wiedemann's model is presented in figure 2.8 (PTV AG, 2017).

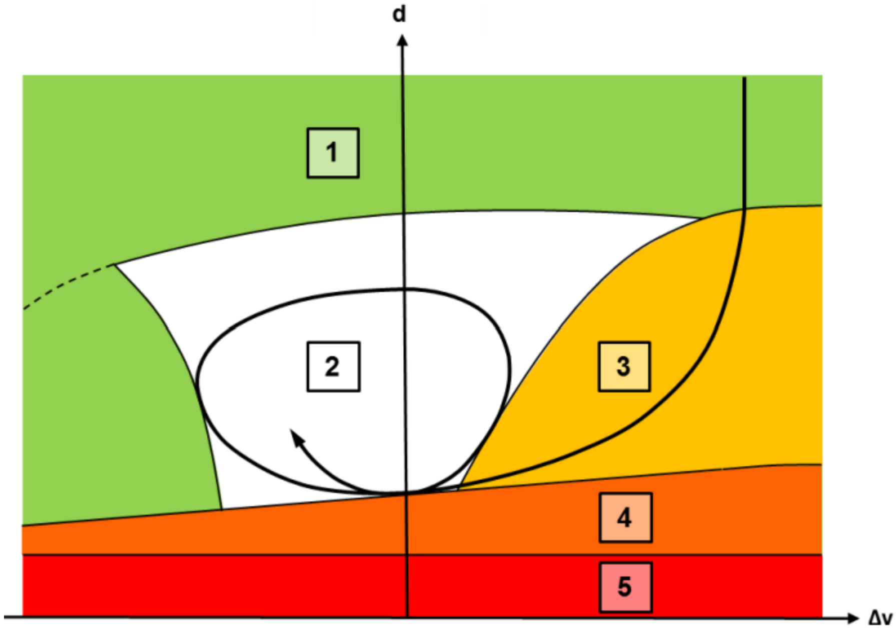

Figure 2.8: Car following model by Wiedemann, zone 1 represent no reaction, zone 2 represent unconscious reaction, zone 3 represent reaction, zone 4 represent deceleration and zone 5 represent collision (PTV AG, 2017)

In figure 2.8, the black line represents the different stages of the car following. The more distance there is between cars (zone 1), the cars do not have any reaction to each other. When the cars get closer together (zone 3) the driver will react to the car in front and will decelerate. The speed of the car is still more than the car's in front, so the distance between them gets smaller. So the car has to decrease its speed until the car have a similar speed as the car in-front, leading to the unconscious reaction condition to the car in front (zone 2). After a while of lowering the relative speed towards the car in front, the distance will again increase, leading to an increase in relative speed in the following car. This pattern repeats itself to maintain a good distance to the car ahead. The speed and the distancing behavior has a stochastic distribution in the model (PTV AG, 2017).

In Vissim the pedestrians and cyclist are modeled based on Wiedemann's model, with vehicle behavior by default. Therefore, the pedestrians are not able to walk in two different directions on one lane. To model pedestrians in two directions, the pedestrians need to have two lanes with separate directions. In that case, no interaction between the pedestrians from other directions will occur, since they can not cross over to the other link (PTV AG, 2017).

2.4.3.1 Gap Acceptance

Road users often need to cross streets, enter roundabouts, motorways, etc., which is not controlled by signalized control. To enter, they use gaps, space or time between users, in the traffic. Gap acceptance is called the minimum gap that the user will use to cross over. This gap can vary greatly between users, vehicles and roads

(Hoogendoorn and Knoop, 2012).

2.4.4 Viswalk (Social Force Model)

Viswalk is an add-on to Vissim as well as a stand-alone software developed by PTV. It is used to model pedestrian movement in a more realistic way and accounts for the sometimes more random way of pedestrian movement in comparison to vehicle movement. The software is based on the Social Force Model described by Helbing and Molnár (1995) where so-called "social forces" are the driver for the pedestrians movements. A desired destination, as well as a desired speed, is appointed to the pedestrian, this will be called the driving force. The pedestrian route is also dependant on the surrounding obstacles and other pedestrian's movement, this can be called repulsive forces, see figure 2.9 below for a visualization of these forces. The model also includes a randomization factor "noise" which is used as a way to make the model slightly less "mechanical".

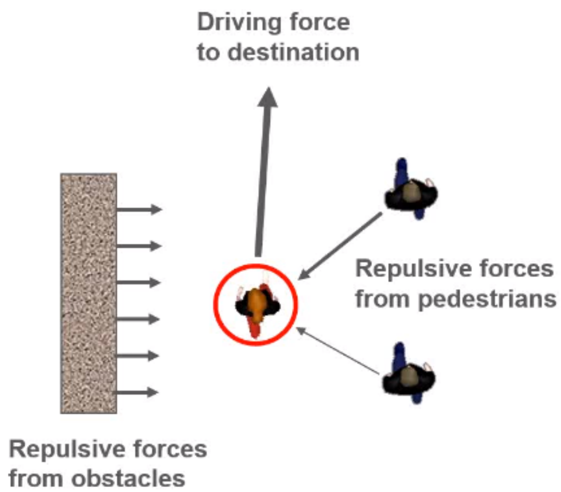

Figure 2.9: Visualization of the driving and repulsive force in the social force model (PTV Vision, 2017)

The model is based on three levels of detail.

- A strategic that operates on the level of minutes to hours where the pedestrian plans his or her route. In this level, predefined inputs from the user are needed such as origin, destination and desired speed.
- A tactical on the seconds to minutes level that decides on where the pedestrian choose the route between the destinations. This is where the pedestrians route is calculated depending on the routing conditions and the network is taken into account.
- An operational level where the pedestrian on a millisecond to second resolution avoid obstacles and other pedestrians. This is during simulation recalculated

by every interaction with other pedestrians or obstacles. How the operational level is calculated thus how the pedestrians will move, is defined by several parameters which will be described in section 2.4.4.1 below.

2.4.4.1 Parameters of the Social Force Model

As mentioned above, the operational level is calculated in the model during simulation (PTV AG, 2017). The different parameters are used for being able to in a realistic way change the behavior of the pedestrians depending on the situation and surroundings of that pedestrians e.g. pedestrians tend to behave differently in an escalator, staircase or in a park. The following section will describe how the different parameters affect the model and the behavior of the pedestrians. The parameters are divided into local and global parameters and will be presented in that order. The global parameters do affect all pedestrian types, whilst the local parameters can be set individually do the different types of pedestrians e.g a wheelchair user might not behave in the same way as a regular pedestrian and should, therefore, have different settings.

Tau (τ) defines the "relaxation time" between the current speed, after for instance an interaction with another pedestrian, and the desired speed. A higher tau value thus results in a less "nervous" behavior. However, if the value is set too high, the pedestrian will almost never reach it's desired speed (PTV AG, 2017).

Lambda (λ) states the anisotropy of the forces acting on the pedestrians i.e. how the pedestrian will react to a force in front of that pedestrian respectively behind the pedestrian. A low lambda value lowers the pedestrians "awareness" behind him/her and with a high value the pedestrian responds in the same way to a force from behind and one from the front see figure 2.10.

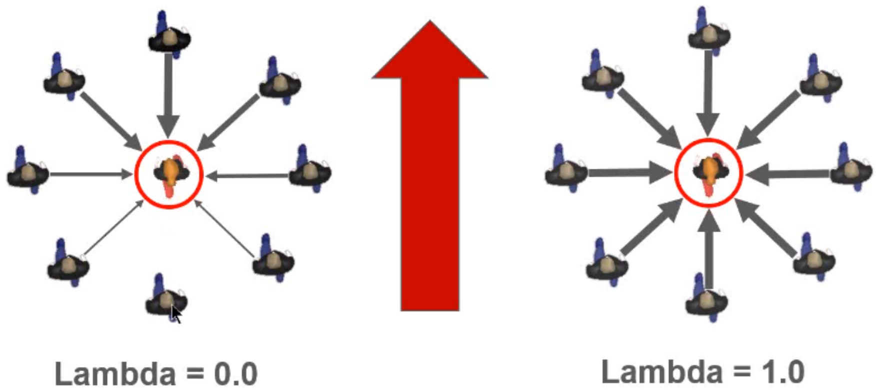

Figure 2.10: Visualization of the impact of the lambda value in the social force model (PTV Vision, 2017)

A Social Isotropic and **B Social Isotropic** does together with the lambda value determine the force between pedestrians A and B.

A Social Mean does determine the strength of this above-stated force and **B Social Mean** governs the range of the force.

As mentioned above there is also a "**Noise**" term included in the calculations of the forces. This term creates a certain degree of randomness in the forces. The noise is good for creating a more realistic movement and does help preventing deadlocks for pedestrians.

The parameter **Side preference** states if the pedestrian type will have a preferred side that he/she yield towards. This can be set to left, right or none.

VD is a parameter that impacts how early the pedestrian will react to an obstacle or pedestrian, the relative speed is taken into account and the distance.

React to n states how many pedestrians one pedestrian does take into consideration when calculating it's route.

In the model in Viswalk, there are also a set of "Global" parameters, meaning they determine the overall pedestrian behavior in the model disregarding what pedestrian type is considered. Below, a brief description of the different global parameters will be presented.

In conjunction with the VD and "React to n" parameters, a global parameter "**Grid size**" defines how large the individual cell is that a pedestrian is situated in which thus also affect how early an interaction will start. In Viswalk, the model does take in to account the following 8 cells, the four joining cell, and the four cells which also contain a pedestrian and is joined in one of the corners.

Cell size defines the distances of the control points where the route calculation from the origin to the destination will be based upon.

Never walk back is an option to prohibit pedestrians to continue if the desired direction and the current direction differ with more than 90°.

Dynamic potential allows the model to recalculate the pedestrians route according to the path that has the shortest traveling time rather than the default setting where the shortest path is chosen. In figure 2.11 below a visualization of the differences between the two ways of calculating the route is shown.

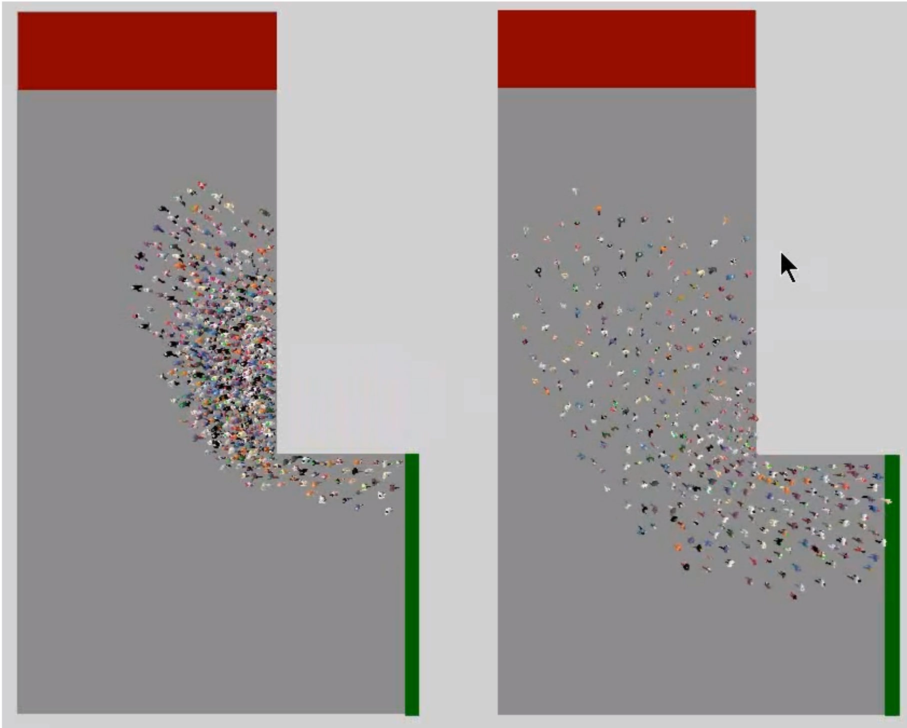

Figure 2.11: Visualization of the dynamic potential in the social force model (PTV Vision, 2017)

2.4.5 Model for Pedestrians

In the Vissim manual PTV AG (2017), PTV states that the Helbing (social force model) way of modeling pedestrian is more detailed and realistic. This is due to the fact that it is based on destinations routes but are during simulation recalculating the direction and speed based on surrounding objects and other pedestrians. The Wiedemann model (car following model) does in a more car-like way follow lanes and destinations pre-defined by the user and does only recalculate it's behavior at cross-sections. The Wiedemann model does, however, work well when the pedestrian's purpose is mainly to act as a traffic disturbance at for instance a crossing (PTV AG, 2017).

3 Methodology

In this chapter, a description of how the project was conducted will be presented. The methodology chapter will also connect back to relevant sections of the literature review chapter and elaborate on how the theoretical findings have been translated into being used in the project.

3.1 Designing the Model

When designing a model, a reference model is needed to be able to see how well the setup of the model resembles the reality. In the project, this reference model will be called the "Baseline model" and will act as a way to be able to calibrate the model to a realistic behavior. When the baseline model has been created and calibrated, scenario models can be designed and compared to both the baseline and each other.

3.1.1 Baseline Model

When setting up the model, different references were used to increase it's accuracy. As described in the literature review there are many ways to collect data and one of the first measures to be conducted was to make an ocular assessment to get a sense of how where and when certain situations occurred in the system.

It stood clear that there is indeed an issue in the interaction between pedestrians and bicyclists and the area where the pedestrians path and the bicycle path are situated is almost used as a shared space. The personal motorized vehicles do have their own lane and do therefore have little or no interaction with the pedestrians or bikes with the exception of the oncoming traffic and the pedestrian crossings.

3.1.2 Geometry

When adding roads for vehicles, bicycle, and pedestrians, into the model, both maps and field measurements were used. Maps were taken from various sources but a majority has been supplied by OpenStreetMap (openstreetmap.se) and google maps (maps.google.com). As a complement to available maps, manual mapping on site was required to get the accuracy needed to design a model that reassemble the reality as much as possible. This was done with measuring tape and mainly the cross sections of the corridor were measured this way.

3.1.3 Vissim Model

The main focus of this study has been, as stated in the scope, to evaluate the traffic corridor performance with respect to different designs of the bicycle and pedestrian paths. This, in conjunction with the fact that bicycle-pedestrian interaction has been less researched, has led to that the majority of both time and effort has been put into the realism of that specific interaction.

3.1.3.1 Bicyclists and Pedestrians

Pedestrians in Vissim can be modeled as modified vehicles shaped and 3d rendered as pedestrians, but still modeled with the car following theory. This way of modeling the pedestrians does, however, have some disadvantages, see section 2.4.5 in the literature review above. These disadvantages mainly consist of a vehicle-like behaviour such as platooning and strictly following the road user ahead.

To evaluate what type of pedestrian model should be used to model pedestrians in this study, a "test track" was designed to easier be able to see the isolated behavior of pedestrians and bicyclists. The first test that was run was pedestrians and bicycles modeled in the Wiedemann model (car following model) which is the default settings in Vissim in figure 3.1.

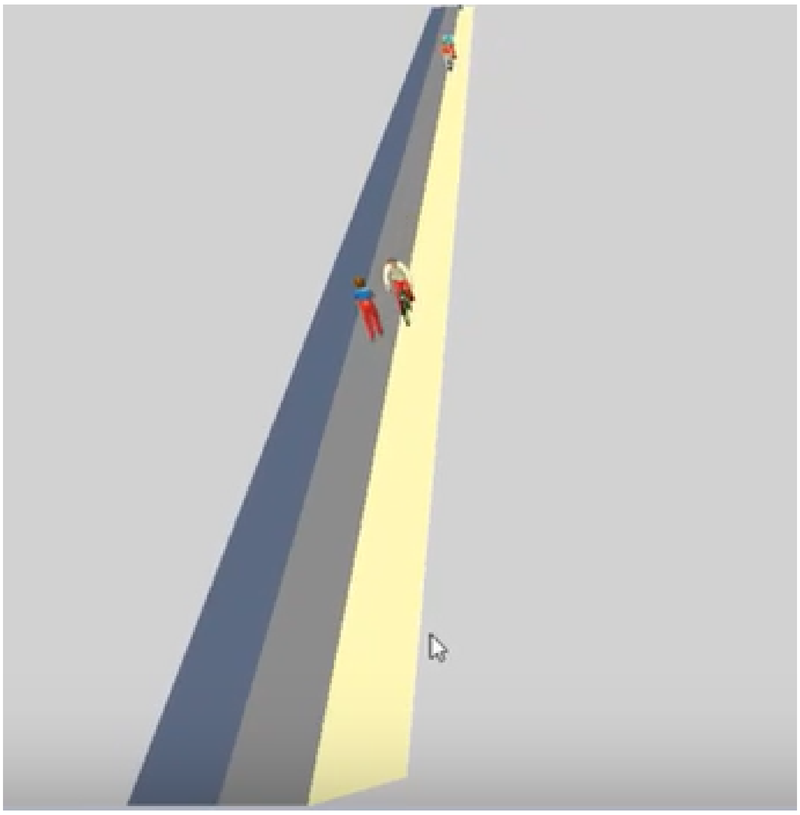

Figure 3.1: Test model to evaluate the use of Wiedemann's model for bicycles and pedestrians

This option of modeling pedestrians is sufficient in many applications where pedestrians are used as a visualizing tool at crossroads for cars or when the flows are more one directional and carlike e.g airport ques. Svensson and Friis (2013) do in their master's thesis compare the behavior of pedestrians in Vissim and Viswalk and conclude that both programs can be used successfully depending on the application.

As figure 3.1 shows, there is a clear separation between the different direction of flows (colored to make this more visually clear). This model did not resemble reality as no interaction between pedestrians from different direction occur due to the fact that traffic in the car following model can only flow in one direction.

The alternative to the Vissim pedestrian model is the Viswalk model (Helbing, social force model), described in section 2.4.4 in the literature review above. This model is specially designed to reassemble real pedestrian behavior. The flows are not limited to one direction and flows are therefore more realistic. The following step towards determining the appropriate way for modeling pedestrians and cyclists was to use Helbing's model for pedestrians and Wiedemann's models for cyclists, see figure 3.2 below.

Figure 3.2: Test model to evaluate the use of Wiedemann's model for bicycles and Helbing's model for pedestrians

When the test model in figure 3.2 was run, it was clear that the two models do not with the default settings work together, both the pedestrians and the bicycles use their lanes in a correct way. However, no interaction occurred at all and bicycles ran through pedestrians.

The next step was to model both pedestrians and bicycles using social force model on pedestrians. The bicyclists were put into the test model as pedestrians with default pedestrian settings with an exception for the desired speed.

This way of modeling the stretch worked with respect to that the pedestrians and the bicyclists now interact. However, this did not show the spillover effect that had been observed in the field but rather a complete mix of the two modes on the path. A solution for a bicycle lane was needed to resemble reality.

Different solutions for resolving this issue were explored. First, a change in the desired yielding side was implemented in the pedestrians as well as the bicyclists so that the bicyclists would stick to their side. A result of this change could be seen but compared to the observed current situation the degree of separation was not enough. Different routing alternatives were tried where bicyclists had a route with partial routing on the "preferred side" however, this alternative did not show results in the desired direction as a pedestrian who is on a route that is uninterrupted does not take into consideration new partial routes. A more rigid design was then implemented to account for the desired degree of separation where small areas acted as the "bicycle lane" and between these areas pedestrians can have the beginning and end of more strict routes see figure 3.3 below.

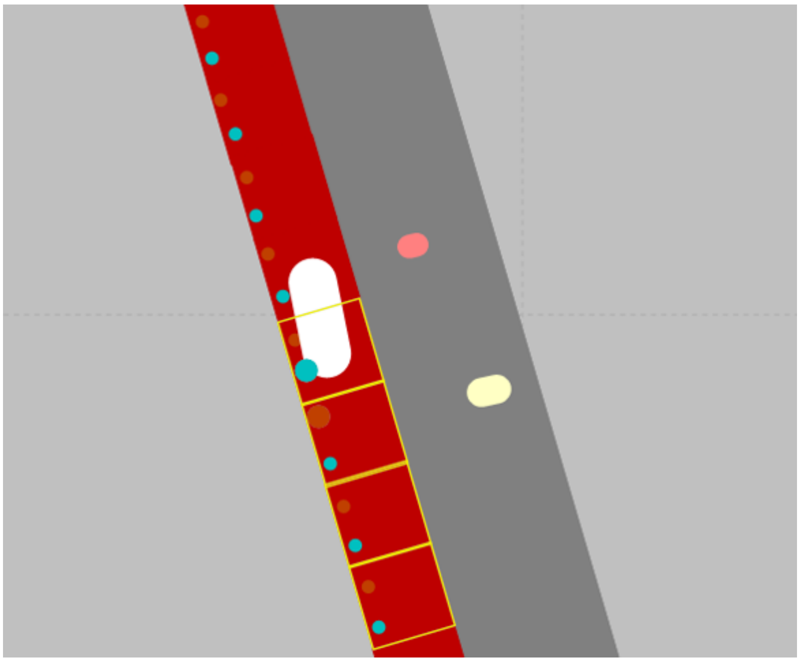

Figure 3.3: Illustration of static routes on bikelane areas where blue dots are destination and red dots are origin of the routes

With this "area solution", a desired level of separation was acquired, where bicycles were confined in their lane and pedestrians (who were not affected by the routing of bicycles) had the possibility to "spill over" to the bicycle lane. However bicycles still moved non-realistically and that was due to the fact that the parameters were still the same as the default pedestrian parameters. The bicyclists' parameters were adjusted according to table 3.1 below both through an ocular assessment in the test model as well with consultation from Fredrik Johansson[1].

[1]Fredrik Johansson - Researcher at The Swedish National Road and Transport Research Institute (VTI)

Table 3.1: Adjusted parameters for bicycle and pedestrian behaviour

Type	Pedestrians yield left	Bike behaviour	Pedestrians yield right
Tau	0.4	0.9	0.4
ReactToN	8	4	8
AsocISO	2.72	0.5	2.72
BsocISO	0.5	0.2	0.5
Lambda	1	0	1
AsocMean	0.4	0.2	0.4
BsocMean	4	2.8	4
VD	4	6	4
Noise	1.2	0.3	1.2
Sidepref	Left	None	Right

When the parameters and the behavior of the pedestrians and bicyclists were determined, they needed to be put into the model. Four main origins and destinations were established (north east, north-west, south-east and, south-west) as well as individual inputs for pedestrians crossing the street and walking towards the tram platform, see figure 3.4 for the input of the crossing pedestrians).

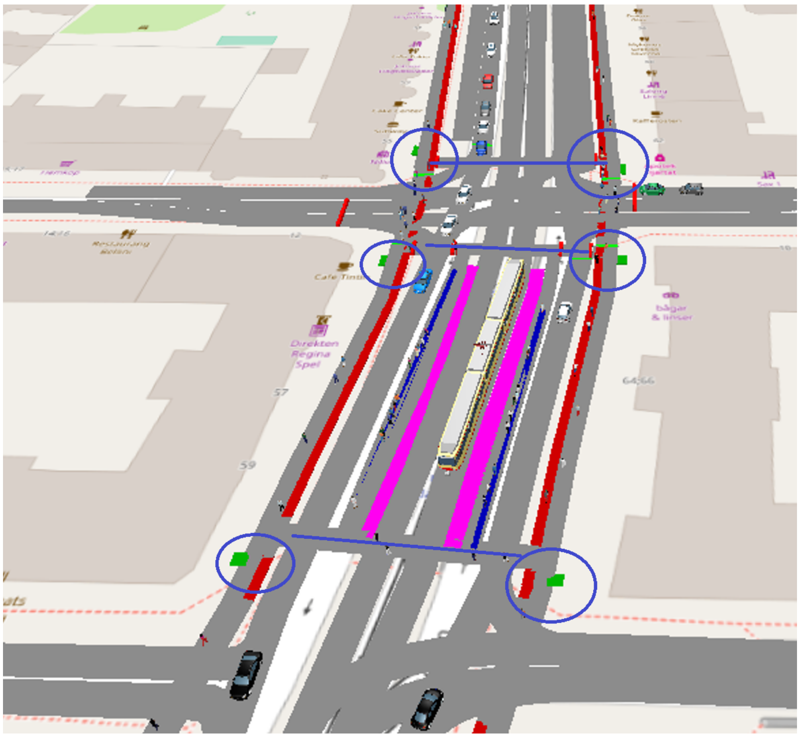

Figure 3.4: Illustration of the input of pedestrians crossing the Linnégatan street marked in blue

3.1.3.2 Private Motorized Vehicles

Private motorized vehicles are modeled with the composition 98% cars and 2% heavy goods vehicle (HGV) and with stochastic distribution of interval. The desired speed was put as 40 km/h for cars and 30 km/h for HGV even though the design speed for the street is 50 km/h. That was done because the speed, as described in section 1.2, was measured at a lower level on the street. Moreover, measurements were conducted for the travel time on the street and will be explained in chapter 3.2.1 as well the traffic volume.

3.1.3.3 Public Transportation

Trams 1 and 6 both pass through Linnégatan and stop at the station Olivedalsgatan. Blå Express drives on the same street but does not stop and is just passing. Line 2, drives from the south at Linnégatan but turns right, east to Olivedalsgatan and reverse. The tram number 2 was modeled and has priority for every other traffic mode, except for other trams and buses, see an illustration of the trams in figure 3.5. The speed for both the trams and buses was set to 20 km/h.

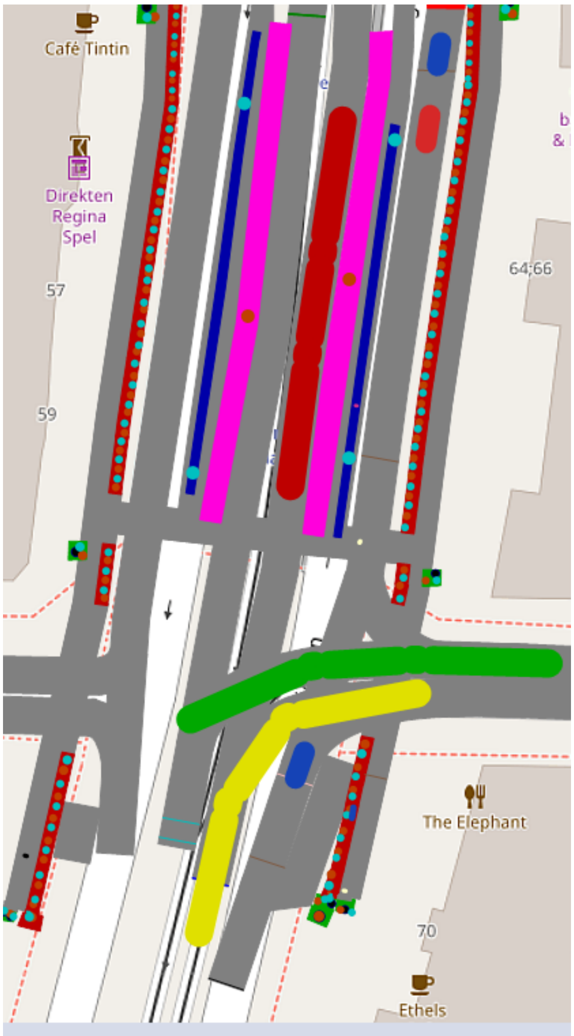

Figure 3.5: Illustration of the trams, where the yellow and green trams represent the line number 2, with the private motorized traffic waiting. The red tram is either 1 or 6, stopping at Olivedalsgatan stop station

3.1.3.4 Traffic Signals

In reality, there are 14 signal groups at the main cross-section (Linnégatan and Olivedalsgatan). However in the model, only 4 groups were made, two for pedestrians and two for the motorized traffic. There are detectors for the trams and buses on Linnégatan but in the model, they were set with no light but with priority rule, so the cars driving at Olivedalsgatan wait for the trams. There is no yellow time modeled since that was recommended from from Miriam Brill [2]. The green time for the pedestrians follow the motorized traffic but for the pedestrians going east-west. In the model, no bicycle radars, pedestrian's call buttons or vehicle detectors were inserted.

[2]Miriam Brill - Traffic analysis at the consultant firm WSP

3.2 Data Collection

After building the Vissim network using the design features of Linnégatan from Google, data collection was conducted to provide traffic input for the model.

3.2.1 Private Motorized Vehicles

Three ways of data collection were used to find fitting amount of volume for private motorized vehicles in the system: Data from Trafikkontoret, data from Gothenburg city and video recordings were used. The data from Trafikkontoret were only available at one cross section and the data from Göteborg stad was not updated, all older than 2017 and not available for the same year. Therefore, video recording with manual counting was conducted, to match the field data better.

The figure 3.6 below shows the location where Trafikkontoret has permanently placed cables that count passing vehicles.

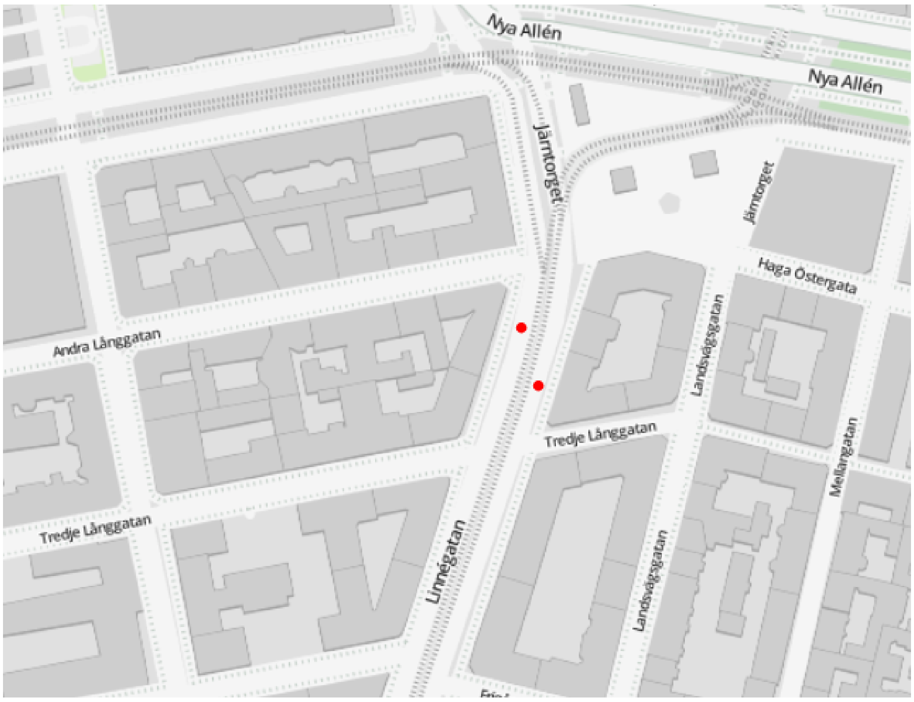

Figure 3.6: Map of data collection site (openstreetmap.se, 2017)

With a resolution of 15 minutes intervals, the graph shown in Figure 3.7 could be plotted. From this data, both what time on the day the peak hours occur as well as how intense it is e.g. how many vehicles pass the cross-section in this peak hour could be derived. When data is being collected in this project, the data in Figure 3.7 will be used as a reference value to make sure that the traffic volume represents the maximum flow as well as determining what times during the day the peaks occur to minimize the required time of manual counting in the field.

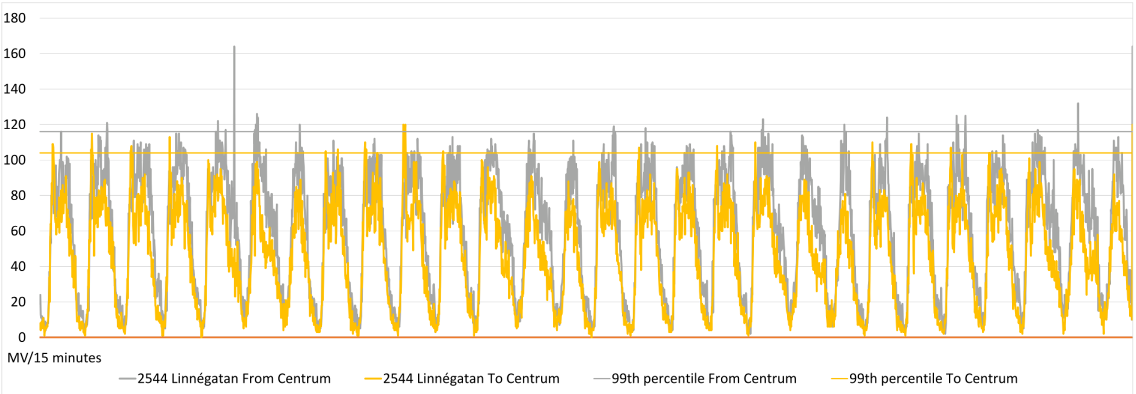

Figure 3.7: Plot from passing vehicles week 40-43 2017 on Linnégatan for consecutive 15-minute periods

From the data in figure 3.7 it was shown that the peak hour occurs between 07:00 and 09:00. This time interval was hence chosen as a representative data collection interval for motorized vehicles.

Gothenburg city keeps information of the traffic volume at their website. However, the data was not provided for consistent periods of time during the day, see Appendix B figure B.1. The intersection Linnégatan and Nordenskiöldsgatan and part of the intersection Linnégatan and Olivedalsgatan were video recorded for one hour between 7:30-8:30, 25 January 2018 and then manually counted afterward. The counting was dived into 15-minute periods and the two maximum periods used to estimate the peak volume occurrence, see figure B.2 in the appendix.

3.2.2 Bicycle and Pedestrian Traffic

When data for the pedestrians and bicycles were to be collected a few questions had to be answered to be able to populate the model. How large are today's volumes?, How does the traffic vary over the year? and, How do the speeds vary over the stretch?. These questions were answered in different ways for the pedestrians and bicycles and will be described in the section below.

To find how large the current volumes of the stretch of both the pedestrians and the bicycles, a video camera was set up in a fixed location over a cross-section of the stretch see figure 3.8 below for the specific location. The camera was recording for 48 hours, this to be able to determine both when the peak hour of pedestrians and bicycles actually occur as well as to determine how large that flow is.

Figure 3.8: Video capturing area where red markings show the measuring cross sections (maps.google.com)

To find what speeds the pedestrians traveled with, a predefined stretch with a known distance was walked and timed. An average of those walks was put together to later be able to evaluate which input desired speeds should be used as well as to be able to calibrate the model.

The bicycles' speed was determined by GPS tracking along the stretch in both directions see figure 3.9. These recordings were performed with 2 different riders, one experienced and one inexperienced to simulate the range of different speeds occurring see Appendix A for more detailed information on speeds and elevations. The speed range was used in the model as a linear distribution.

Figure 3.9: GPS measuring of the speeds in the bike path

When estimating the AADT on the street Linnégatan, measurements from two nearby streets were used to calculate the day of year factor according to equation 2.6. The measurements were collected with permanently installed measuring equipment and are therefore collected in the same place each year. From one of the streets (Sprängkullsgatan), measurements from 2012 to 2017 was available and from the other (Vasagatan), from 2014 to 2017. When the day of year factor was calculated, the values from all years and the specific day that we want to use was used as a reference. The average was then calculated to account for possible disturbances in the system that day, see equation 3.1 below. Not all years had measurements from that specific day, then the day measured closest to the specific day was chosen. To see more specific information on the calculations of AADT of bikes on the stretch, see Appendix C.

$$average\ day\ of\ year\ factor = \frac{1}{n}\sum_{i=1}^{n}\frac{Daily_i}{AADT_i} \tag{3.1}$$

Where,
$Daily_i$ = *is the recorded flow from the the specific day*
n = *number of years counted*
i = *individual year*
$AADT_i$ = *Average annual daily traffic from year i*

3.2.3 Public Transportation

The number of the trams that go through Olivedalsgatan for the maximum hour were obtained from the public transport operator's timetables (Västtrafik.se), the number of the trams, 13 in total, were equally distributed over one hour and added to the model with a stop on Olivedalsgatan. The number of people boarding the trams was obtained from Västtrafik's customer support. From that data, the maximum number was used in the model, even though the obtained data significantly underestimated the actual public transit utilization. There was no data of people alighting the trams, therefore the same amount of boarding and alighting was used as input data. The travel time collection for the trams was not conducted on Linnégatan due to default public transit priority in Gothenburg.

3.2.4 Traffic Signals

The green time was measured in the video, as described in section 3.2.1 and the average green time used. To make the model more realistic, the green time for the south-north traffic was set higher, 33 sec green time, than east-west, 23 sec green time, to compensate for the lack of detectors in the model. Pedestrians lights follow the vehicle traffic with green time, north-south as 27 sec and east-west as 20 sec.

3.2.5 Calibration of the Model

When input data such as volumes and speeds had been collected, the baseline model could be calibrated to make vehicles' parameters and general settings more accurate with respect to the measured values. Due to a lack of detailed evaluation methods such as video processing of vehicle, cycling and pedestrian behavior the main values that could be used for calibration were speed and travel times.

The travel time for the private motorized traffic was measured at 3 points for 10 vehicles, see Appendix B.3 for measured values. The average time was used as travel time to calibrate to. Additionally, "reduced speed areas" were added in the model at Linnégatan around Olivedalsgatan and Nordenskiöldsgatan cross section, to slow down the private motorized vehicles.

As described in section 3.2.2, the speed for cyclist and pedestrians were used as a reference value to calibrate the model with. The bicycles was first roughly calibrated with the desired speed from an initial 8-14 km/h linear speed distribution to 9-15 km/h and finally with a desired speed of 10-16 km/h as well as with the behaviour parameters shown in table 3.1 in the methodology above, see figure 4.1 in the result section for a graph of the calibration.

The pedestrians were supposed to be calibrated in a similar manner as the bicycles. However, the pedestrians speeds did change along with the calibration of the bicycles. As the bicycles got faster and the behavior parameters for the bicycles changed, the pedestrians' speed was lowered and within the accepted error range of $\pm 5\%$ thus no calibration of the default pedestrian speed or behavior parameters needed to be performed. See figure 4.2 in the result section for a visualization of the calibration.

3.2.6 Assumptions and Limitations

In this project the team had limited resources (e.g., number of people) for surveying the study area and collect data at multiple locations at the same time. The solution for this was to take the field measurements during different days but still at the same time. No access to measuring equipment such as pneumatic tubes or video processing software has lead to limitations in field measurements. In the model, pedestrians and bicyclists are assumed to travel from south to north and north to south without any destinations along the stretch. This assumption was due to a lack of specific origin-destination data. The pedestrian volumes were assumed to not vary over the year due to the number of shops, offices, and restaurants in the stretch and that they are assumed to be the main destinations for the pedestrians.

3.3 Scenario Design

Linnégatan's non-motorized lanes, as it is designed today, could be seen as a pedestrian path and a bike path parallel along each other. However, if the behavior of the users is assessed the non-motorized section could be argued to be used more as a walking street (see figure 3.10), where pedestrians use the bicycle lane as their space as well, leaving cyclists to yield and give way.

Figure 3.10: Visualization on how the non motorized section is used on Linnégatan, (maps.google.com, 2017)

A report from Trafikverket and SKL (2010) states that on a walking street bicyclist's speed should be restricted with uneven surface of objects. However, in the city of Gothenburg's program on cycling one of the main goals is to create a fast, even, and safe bicycle network (Trafikkontoret, 2015).

The classification system mentioned in the literature review suggest the corridor on Linnégatan to be considered as a Class B as it is used today. With a new design, the aim is to improve this section to be A classified. This would require the bicycle lane to be properly separated from the pedestrian lane as well as the motorized vehicles.

Koucky (2017) states in his lecture that in order to achieve a modal shift from motorized personal vehicles to a more sustainable option, a change is needed. To make this modal shift possible he says, not only do alternative options be available and well developed e.g. bike lanes and safe pedestrian paths but also the option that is used today must become more expensive. This cost can consist of monetary- time- or comfortability-conditions. Koucky (2017) means that those who can already afford to drive a personal motorized vehicle will not stop doing that because there is a good bicycle lane available. One way to achieve this is to decrease the number of available parking options or raise the price on the existing ones.

The design proposal does therefore use the space that previously was used as parallel parking (see right in figure 3.10) as a two way 2.5m wide bicycle path,. This does leave enough space for a car lane to still be wide enough and does also give more than what the city of Gothenburg require as a minimum 2 way bike lane see table 2.7 and and to see a sketch of the proposed alternative see figure 3.11. The proposed design can also help to better guide visually impaired road users.

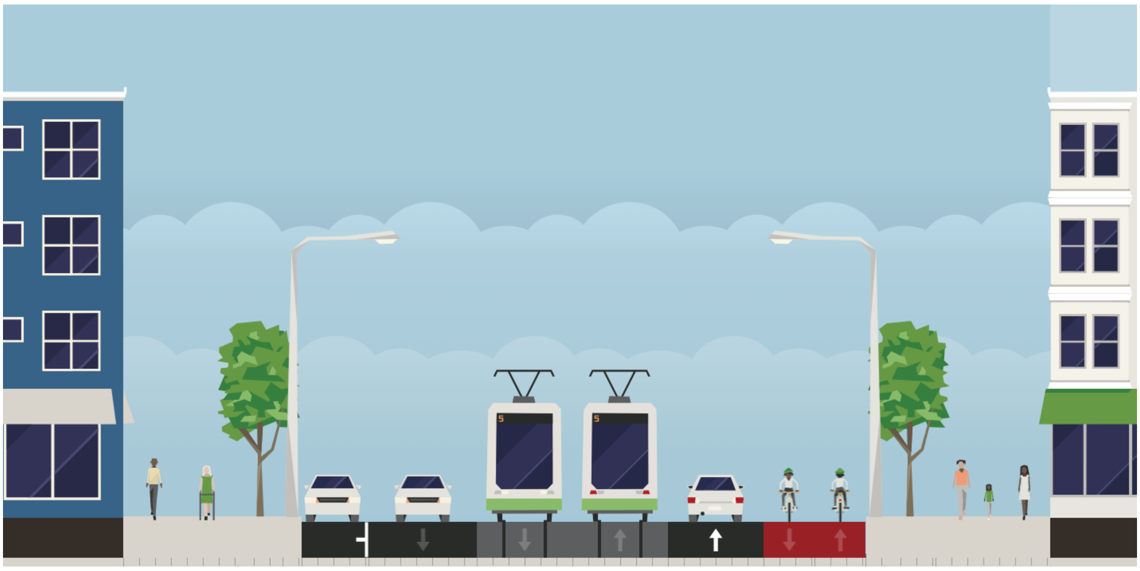

Figure 3.11: Sketch over alternative design

When designing the bicycle path in the scenario, there is no problem to model this as a default Vissim bicycle path since no parallel interaction with pedestrians is occurring. However, to be able to evaluate what impact the geometry does have on the bicycles speeds the bicycles are modeled with Viswalk and the social force model as well as the same desired speed.

Some changes were made to the bicycle paths in the scenario compared to the baseline apart from geometry. First, the new bicycle path design should make it possible for bicycles to overtake other slower bicycles, something that was not possible in the baseline model with the small area method described in paragraph 3.1.3.1 above. To resolve this issue static routes were put into the model in a similar manner but only in the curves of the bicycle path, figure 3.12. With this solution, bicycles remain in their lane following their assigned static route but still have enough time to overtake slower bicycles.

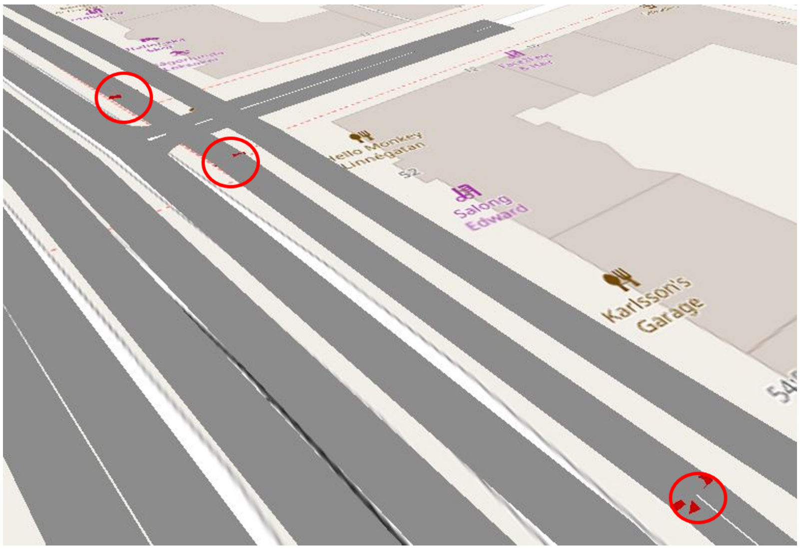

Figure 3.12: Illustration of the cycling path, where the red cycles represent where the static route was inserted

With the not so strict static routes, there was an issue with representing the bicyclists in the signalized intersection areas. Here bicyclists stacked up and formed a crowd during the red light. At the green signal crowds on both sides met in the middle of the intersection and congestion occurred. The solution for this was to slightly separate the two-way bicycle path in front of the signalized intersection and place a static route on each side, see figure 3.13. This way of modeling the bicycle path forces the cyclists to form a queue which resembles reality more closely.

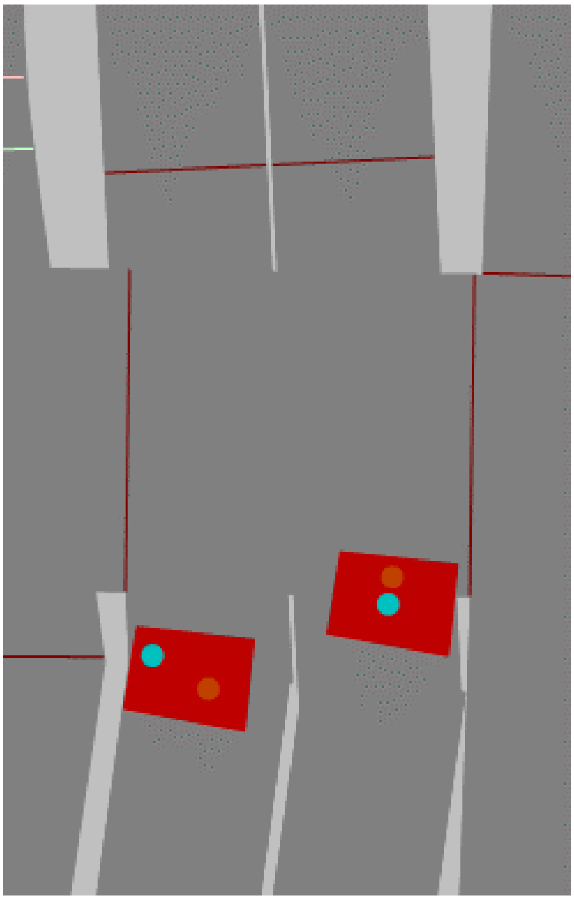

Figure 3.13: Bike path separation before the red lights, the red area with static route force the cyclist to go on the right track

3.3.1 Future Travel Demand

One part of this study is to evaluate how well different designs can hold up to future flows aimed at by the city of Gothenburg. The city states these relative flows in their traffic strategy Göteborgs stad (2014) and bicycle programme Trafikkontoret (2015) where the pedestrians and bicycle trips shall account for 35 % of all trips.

This translates to a change in the pedestrians traffic of 1.2% as a yearly average from 2011 to 2025 which according to Trafikkontoret (2018) has in reality been 0% from 2011 to 2017. In the model, the pedestrian input for future flows was set to the intended increase of flows to use a conservative approach and use the highest possible volumes.

A conservative approach with respect to volumes was used in terms of bicyclists as well. As of the year 2017, bicycle trips have increased with an annual average of 3.1%. To reach the goal set by the city, the annual increase should have been 8.2% (Trafikkontoret, 2018). In the future flow model, the volume of bicycles has been set to match the city's goal volume.

Personal motorized vehicle trips have been set to be decreased by 25% according to

Gothenburg's traffic strategy (Göteborgs stad, 2014). However, in order to keep a conservative approach to the volumes, the volumes of personal motorized vehicles were kept at the same levels.

According to Trafikkontoret (2018), the public transport traffic requires an increase of 2.5% per year (2011-2025). This goal has been met and exceeded as the latest measurings show an annual increase of 3.2%. Despite the trend of an increasing public transportation, in the model, today's volumes will be kept in the future flow scenarios. This is due to a lack of reliable data on the amount of passenger on each bus and each tram.

4 Results

In this chapter results from the calibration process and traffic simulations with respect to bicycles, pedestrians and private motorized vehicles will be presented. In conjunction with the results, short discussions will be included. References to the methods used can be found in the texts in the results.

4.1 Calibration

First, the process of calibrating the model was performed. Speed data was used to calibrate bicyclists' speeds in the model (figure 4.1). Travel time data was used to calibrate the travel times (figure 4.2).

4.1.1 Bicycles

With bicycling speed and behavioural parameters adjustments (described more in detailed in section 3.2.5), an error <5% was acquired and considered acceptable, see figure 4.2. The calibration for cyclist was conducted in regards of the north south side of Linnégatan.

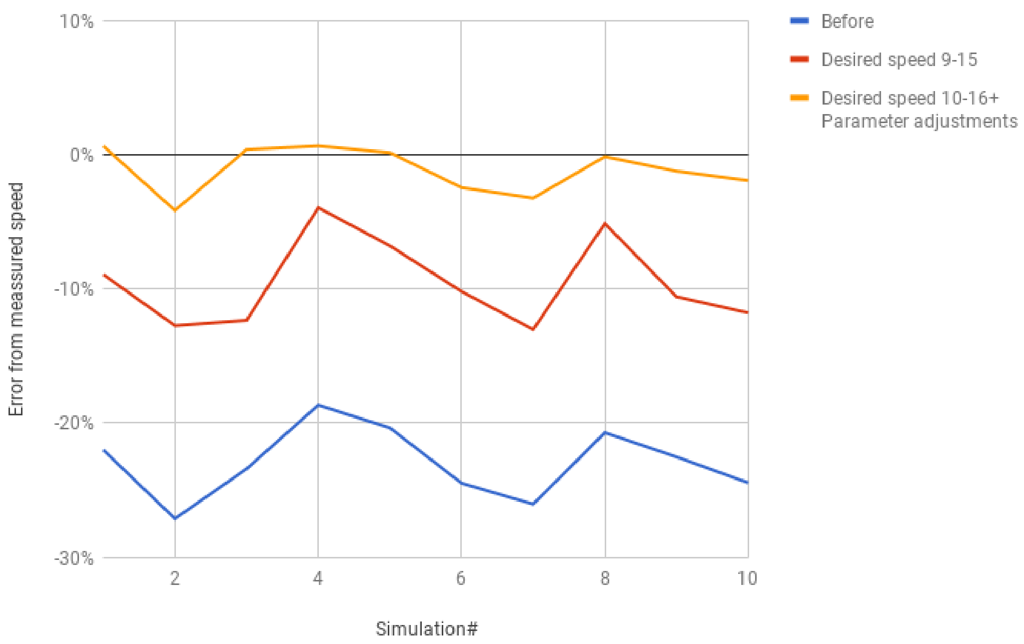

Figure 4.1: Graph showing calibration of bicycle speeds

4.1.2 Pedestrians

After the calibration of bicyclists' parameters and desired speed, the error of pedestrian speeds was within the error margin of ±5%, see figure 4.2 below.

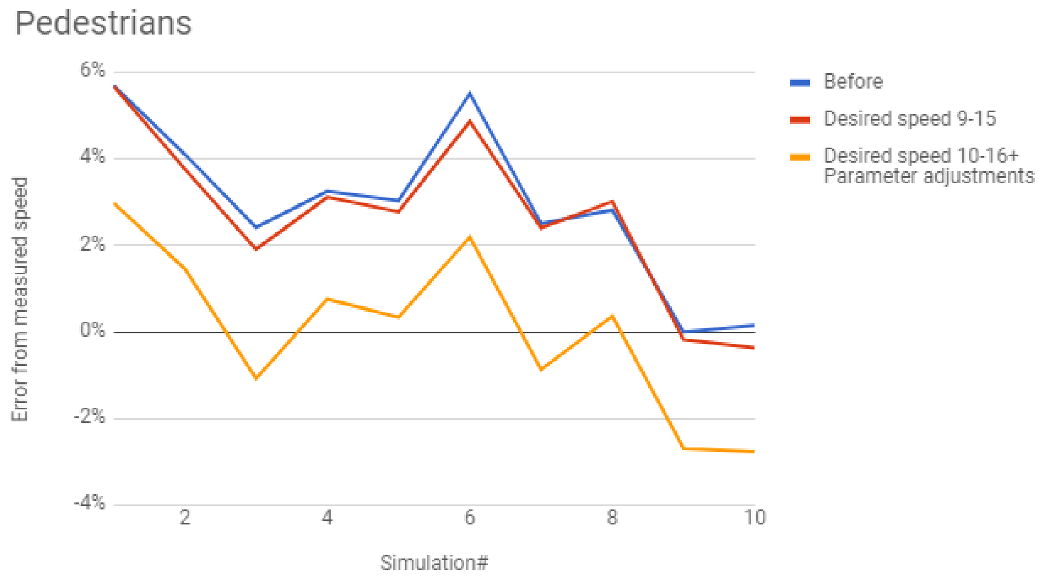

Figure 4.2: Graph showing calibration of pedestrian speeds

4.1.3 Private Motorized Vehicles

When calibrating the private motorized vehicles, one calibration cycle (described in more detail in section 3.2.5) was sufficient to fall within the range of the standard error of the measured data and was considered sufficient, see figure 4.3 below.

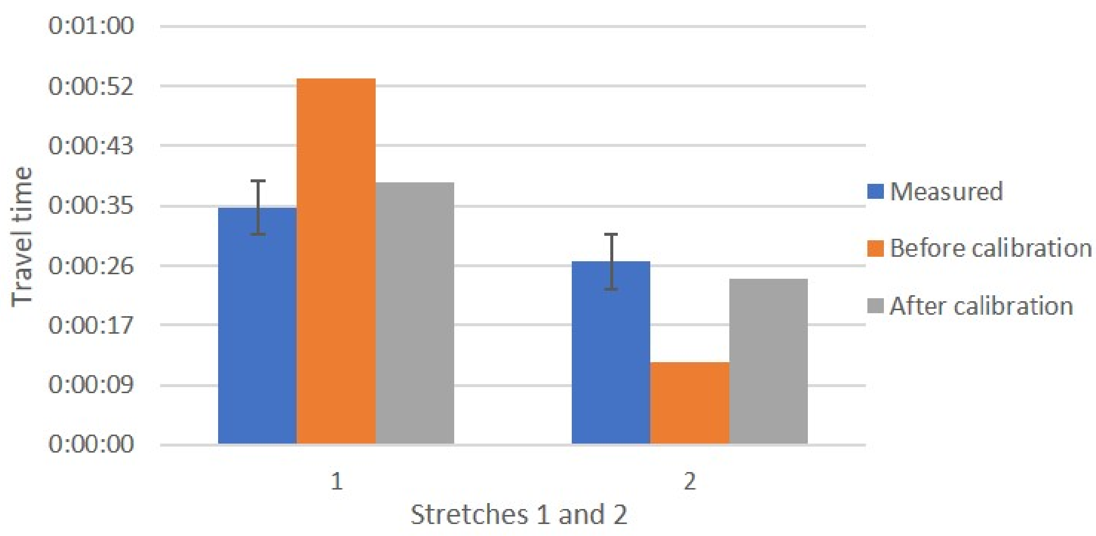

Figure 4.3: Graph showing calibration of motorized vehicle travel time over 2 stretches

4.2 Combined Non-motorized Traffic

When modeling the pedestrians and bicyclists in Vissim, the approach of modeling bicyclists as pedestrians was chosen due to the requirement of a parallel interaction along the stretch. This has led to combining pedestrians and bicyclists-related results when evaluating network performance for non-motorized modes.

4.2.1 Speed

Based on the network performance evaluation, the speed was the first parameter that was exported and checked since it is one of the key factors to a better flow. In contrast to what was expected, the "baseline model" was showing higher speeds than the alternative design in the scenario-based model, see figure 4.4 below.

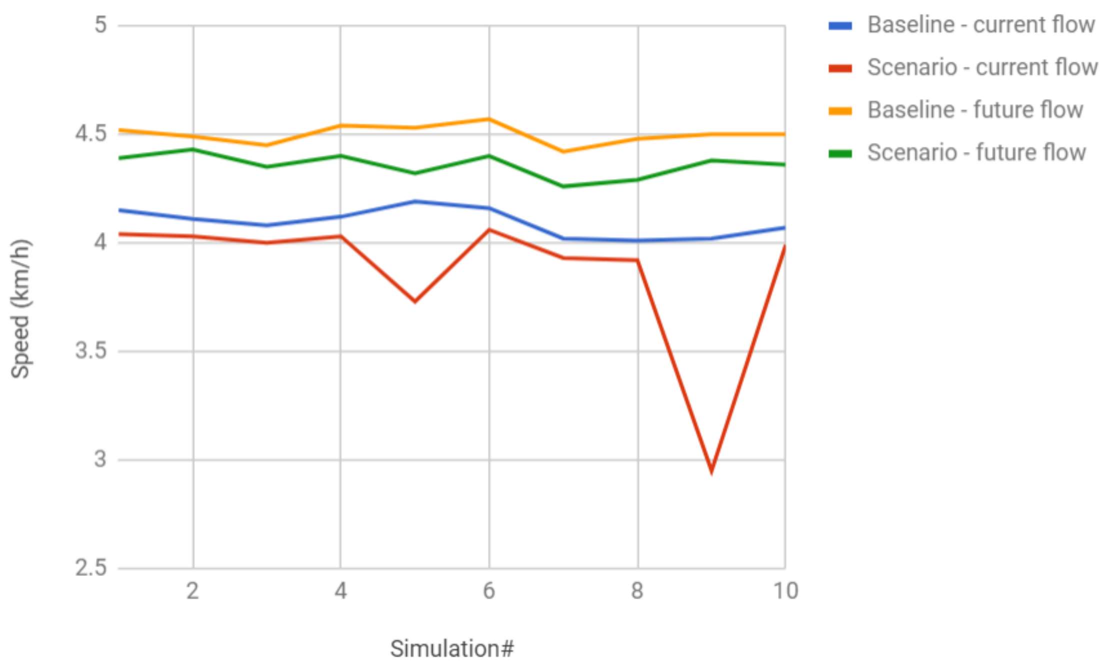

Figure 4.4: Pedestrians' speed from the network (bicycles and pedestrians combined)

In order to further evaluate the alternative design a series of other performance measurements was conducted, separating pedestrian and bicyclist performance, as indicated in the following sections.

4.2.2 Density

The densities for pedestrians in the different models are presented in table 4.1. The results come from the network performance and since the cyclists are modeled as pedestrians, the results take both the pedestrians and the cyclists into account. The density is expressed in pedestrians per square meter and the results can be seen in table 4.1.

Table 4.1: The density converted to pedestrian space for the cyclists and pedestrians

Models	Density p/m^2	Pedestrian space m^2/p
Baseline	0.05	20
Scenario	0.04	25
Baseline future	0.07	14.3
Scenario future	0.06	16.7

The densities showed the anticipated results that when adding more space for the pedestrians and bicycles, the density would decrease which it indeed does, see table 4.1. Thus the unexpected speeds do not result from space-related issues.

4.3 Speeds

In order to pinpoint what could cause the unexpected values in the network performance speeds for the pedestrians, travel time measure points were placed on each arrival and destinations for the pedestrians and the bicycles separately. With this method, speeds could be observed for the two modes individually.

First, speeds for the south-north and north-south directions were assessed both for the bicycles and the pedestrians (see figure 4.5 and 4.6 below).

4.3.1 Bicycles

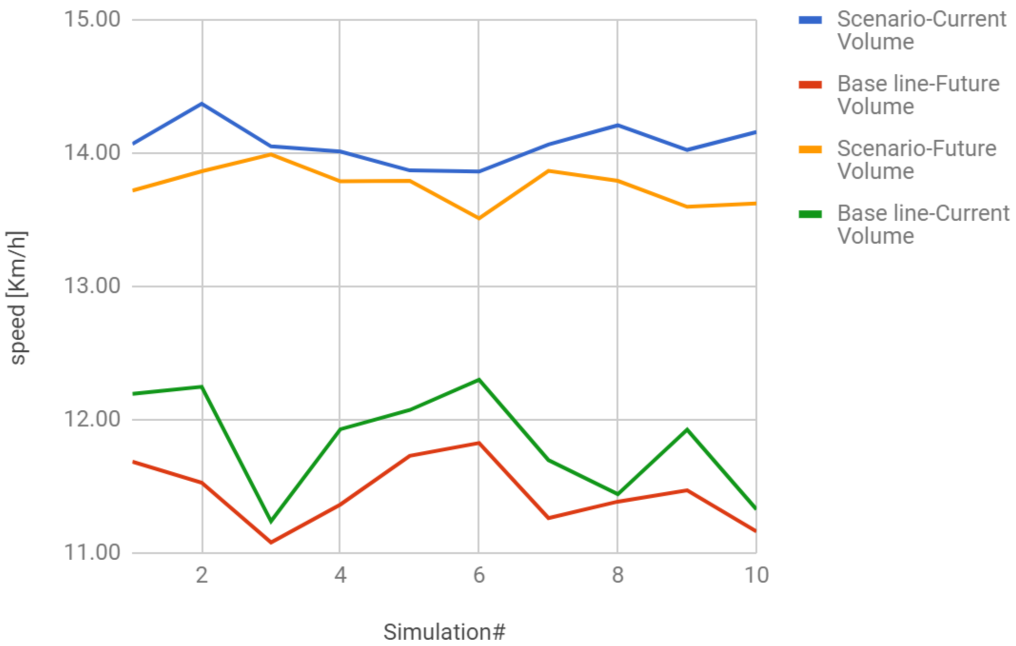

Figure 4.5: Speeds of bicycles in the two scenarios, direction south to north

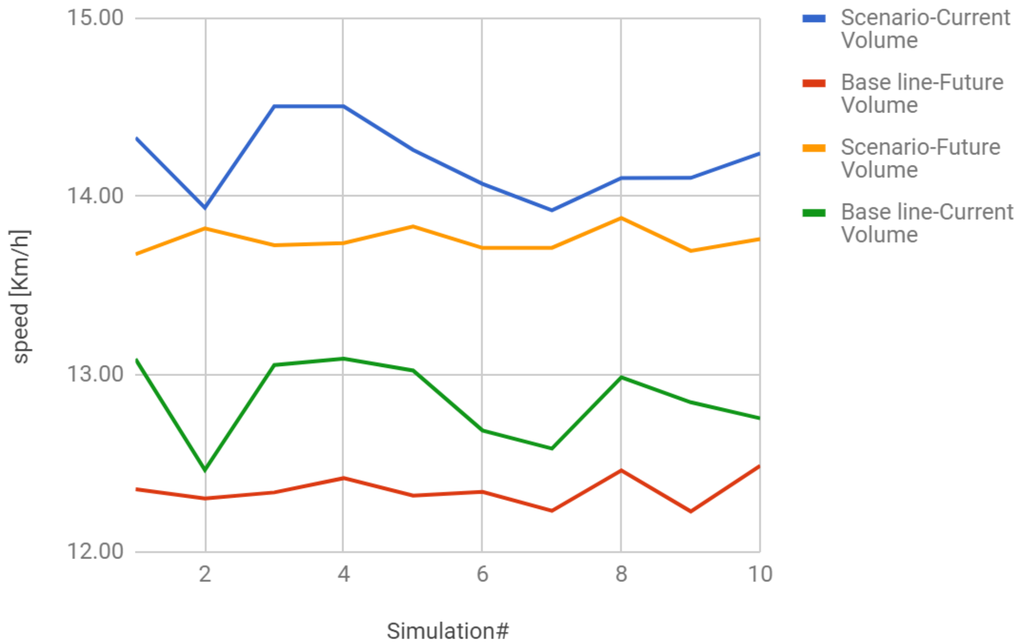

Figure 4.6: Speeds of bicycles in the two scenarios, direction north to south

In figure 4.5 and 4.6 it can be seen that the speeds are higher in the scenario both for current flows as well as future flows. In both baseline and scenario-based model, the speeds are lower with the future flows.

4.3.2 Pedestrians

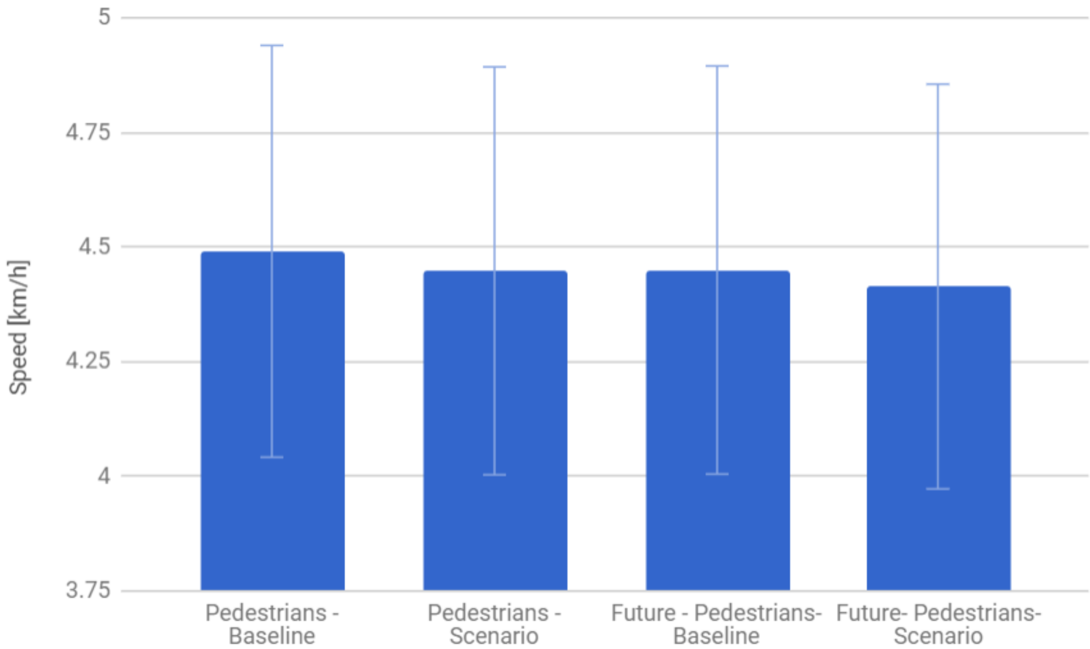

Figure 4.7: Graph over pedestrians' speed in the different scenarios with standard error bars

No clear change in the speeds for pedestrians could be derived from the 10 simulations runs in all of the four models as can be seen in figure 4.7.

4.3.2.1 Cross Section Analysis

To have better understanding of the results, the travel time for the pedestrians at the cross sections (illustrated in figure 3.4), was measured (see figure 4.8).

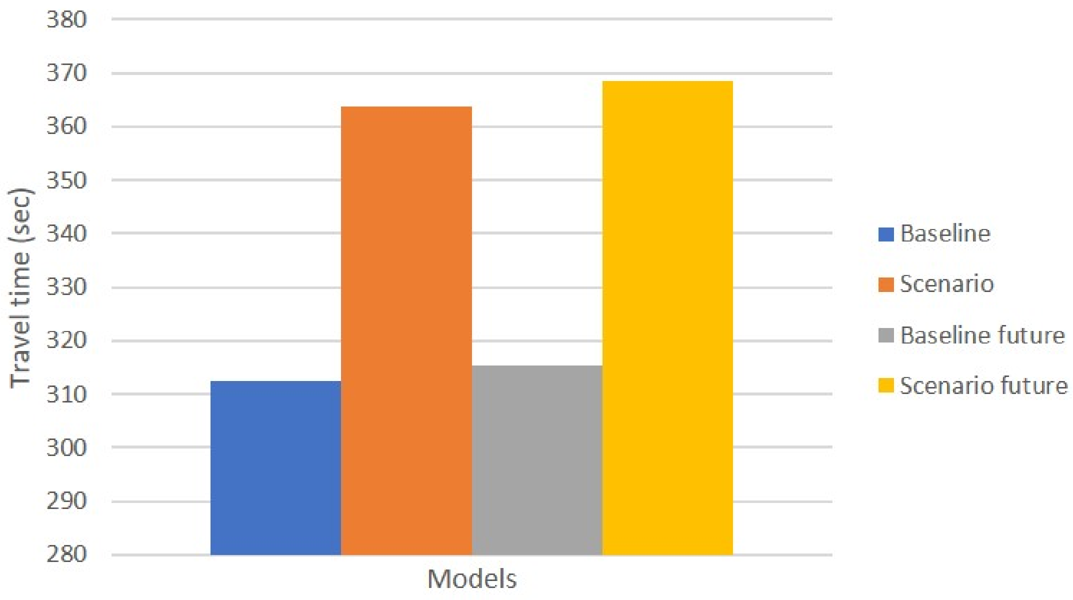

Figure 4.8: Average travel time at the 3 cross section in different models, see figure 3.4

It can be seen in figure 4.8 that the travel time from the separate pedestrian input for the crossings was significantly higher for the scenario design both for current flows and future flows.

4.3.3 Motorized Vehicles

To be able to see how the rest of the traffic has been affected by the change in the corridor design, a motorized vehicle network performance was extracted from the simulations, see figure 4.9 below for the motorized vehicles' speed.

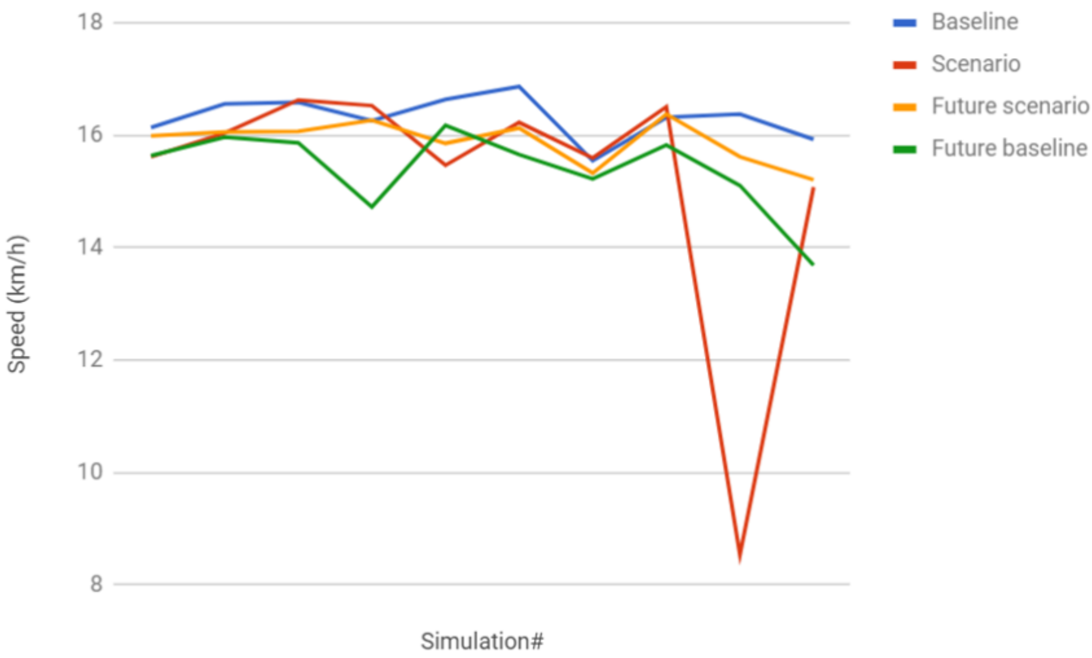

Figure 4.9: Graph of speed in the network performance

Figure 4.9 does not show any clear tendency to either a positive or a negative change in terms of private motorized vehicle speed.

5 Discussion

The following chapter will give a broader perspective of what effects and implications certain decisions made in the project might have had. A transparent and constructive discussion will aim to give a better understanding of strengths and weaknesses of this project as well as give a better foundation for further studies. The chapter follows the structure of the results which will be followed up by more general thoughts and ideas concerning the project.

Data collection was conducted at the beginning of January. In Sweden where the study was conducted, this is one of the coldest months thus one of the months with the lowest bicycle traffic. Due to the project time frame, it was not feasible to obtain the data at another time. This led to additional assumptions and uncertainties in the scaling of volumes to find the peak flows. However, with the relatively large data sets that were available to compare the acquired data, the traffic flow scaling is considered reasonable. If a similar study were to be conducted again it would be preferable to be conducted so that the data collection period coincides with a warmer month when daily traffic is at it's peak (in Sweden this would be the month of May).

The results of the calibration were adequate for the model functionality. There were no default values for the bicycle speed in Vissim and as explained in section 2.2.2, the recommended speed for bicycle traffic is 15-20 km/h. In the model, the speed was 10-16 km/h, same as the measured speed, which is considerably lower in value than recommended bicycle speed. The change in walking behavior parameters had a positive influence on the fluctuation and evened out the change, so the simulations had more similar results. As seen in the calibration for the pedestrians, the walking behavior parameters had an influence on the travel time. There was a small change in the travel time when changing the cycling speed but the main change was the change in the values of the walking behavior parameters. The speed for the pedestrians was not changed from the default value since the first results in the calibration showed adequate outcome. When finding the values to calibrate to, as described in section 3.2, there was good consistency with the travel time for pedestrians and bicycles speed but not for the private motorized vehicles. Therefore, when conducting the calibration for private motorized vehicles, the standard error was taken into account together with the average travel time. The desired speed was not changed, except for the speed reduction areas.

The results show a tendency that when all pedestrians and bicycles are combined in the model (pedestrian network performance), the speeds were reduced in the alternative design. However, the speeds for cyclists measured separately from pedestrians increased in the alternative design. For the pedestrians in the north-south direction as well as the south-north direction, the speeds were unchanged in the different designs. The pedestrians' travel time when crossing the corridor had increased in the alternative design, even though crossing design remained the same as well as the input traffic volumes. This is something that is not in line with what was expected and should be investigated and corrected if more time had been available. The pedestrians crossing the street were not the main focus of this study, and thus the deviating results were considered acceptable.

Comparing the pedestrians' densities results (in network performance) with the fundamental diagram for pedestrians in 2.2, the density is considerably lower than 0.5 ped/m^2, which means that pedestrians should move more smoothly. The results also take bicycles into account but since the densities are always lower or equal to 0.07 ped/m^2, an interpretation can be that the density will not have any effect on the speed. The pedestrian space is always more than 5.6 m^2/ped, which make the pedestrian facilities always with LOS A. As described in table 2.3, the LOS for bicycles facilities is measured with percent of hindrance, since Vissim is not able to calculate the hindrance, no accurate value for LOS can be stated. However, in the scenarios, there are no hindrances from the pedestrians (except in the crossings), which leads to lower percent in hindrances and better LOS.

When the future flow was modeled in the two scenarios, the input car volume was kept at the same level. This is despite the fact that it can be seen that a decreased supply of car parking will lead to a decreased flow which Göteborgs stad et al. (2009) describes as one of their methods for lowering the usage of cars. However, the magnitude of such a reduction is not possible to establish which led to the decision of keeping a conservative approach and use the values as they are in the present. One could argue that values in line with the trend lines should be used and thus use an increased motorized vehicle traffic but as well here the exact flows is not possible to establish. In the future, sensitivity analysis with different flows would be conducted.

As well as with the motorized vehicles, the bicycling speed in the alternative design scenario was designated using the conservative approach. The desired speed was kept the same in all four of the models. This was done in order to evaluate what impacts the geometry, by it self, would have on the recorded speeds. However, if the bicyclists would be granted a smoother separated bicycle track free from conflicts from other modes, with a greater possibility for over taking other slower bicyclists, the desired speeds would also increase in addition to the effect from only the geometry. Thus the results on the bicyclists' speeds might be underestimated.

Our results show that, the pedestrians crossing the streets results in big delays in the pedestrian system. This could be interpreted as the potential need for pedestrians to have more opportunities for crossing the street. In section 2.2.1 it is stated that the kind of street that is modelled should benefit from a pedestrian crossing along the whole link due to the shops, tram stops and offices along the whole stretch. This is something that was observed in field as well, that pedestrians crossed the street and tram tracks not only at the designated crossings. However, this kind of crossing would require the level to be the same in the whole corridor to allow the same mobility for all pedestrians (elderly, disabled, stroller etc.) which could possibly cause issues for car and public transportation mobility.

6 Conclusion and Recommendations

This study has shown that with an alternative design of a multi-modal urban street the speed for bicyclists would increase and the speeds for the pedestrians and motorized vehicles would not be changed.

This study has been conducted with simplifications and assumptions that might have had an impact on the results. Therefore, following future improvements are recommended.

In the simulation software, an integration between the two ways of modeling traffic is needed that is easier for the end user to implement. Today's options are limited to implementing coding or manual adjustments such as the ones we implemented.

A future study with pedestrian and bicycle interaction would benefit from a video analysis possibility where behavior parameters could be evaluated and determined in a structured way. Also, a cost benefit analysis would be suited as a future studies, e.g. cost for changing the design and the benefit from having a better, sustainable infrastructure.

If the project time frame allowed, the data collection would have been conducted in a warmer period of the year. With this change, fewer assumptions would be needed and higher accuracy in the results would be acquired. With the limited amount of time a sensitivity analysis was not performed and if more time was available, different travel demand scenarios would be evaluated for all road users.

The results from this study give an indication for that an implementations of the alternative design will be beneficial and in line with what the city of Gothenburg is aiming for in it's future development goals. However, further studies are needed to be able to recommend this design change with more certainty. In addition, other bicycle lane designs should be evaluated using similar approaches to the ones implemented in this study. The proposed design would contribute to more continuous and efficient cycling experience, and it is recommended to consider it and evaluate against other bicycling lane designs in the future.

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A Appendix

GPS measurement of two bicyclists, one with good biking experience in the area and one without any experience riding in the area.

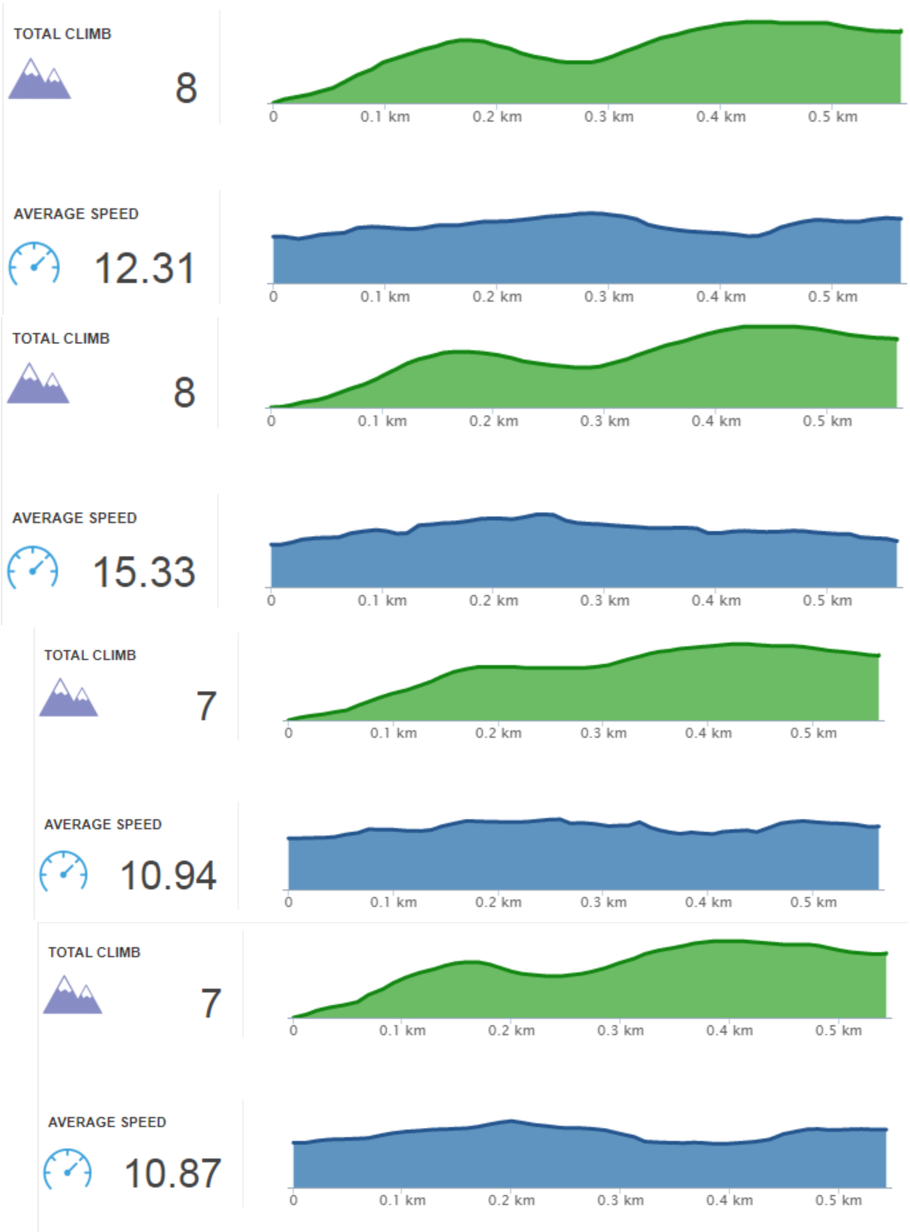


Figure A.1: Bikeruns uphill, top two runs is by the experienced rider and lower two graphs are run by inexperienced rider.

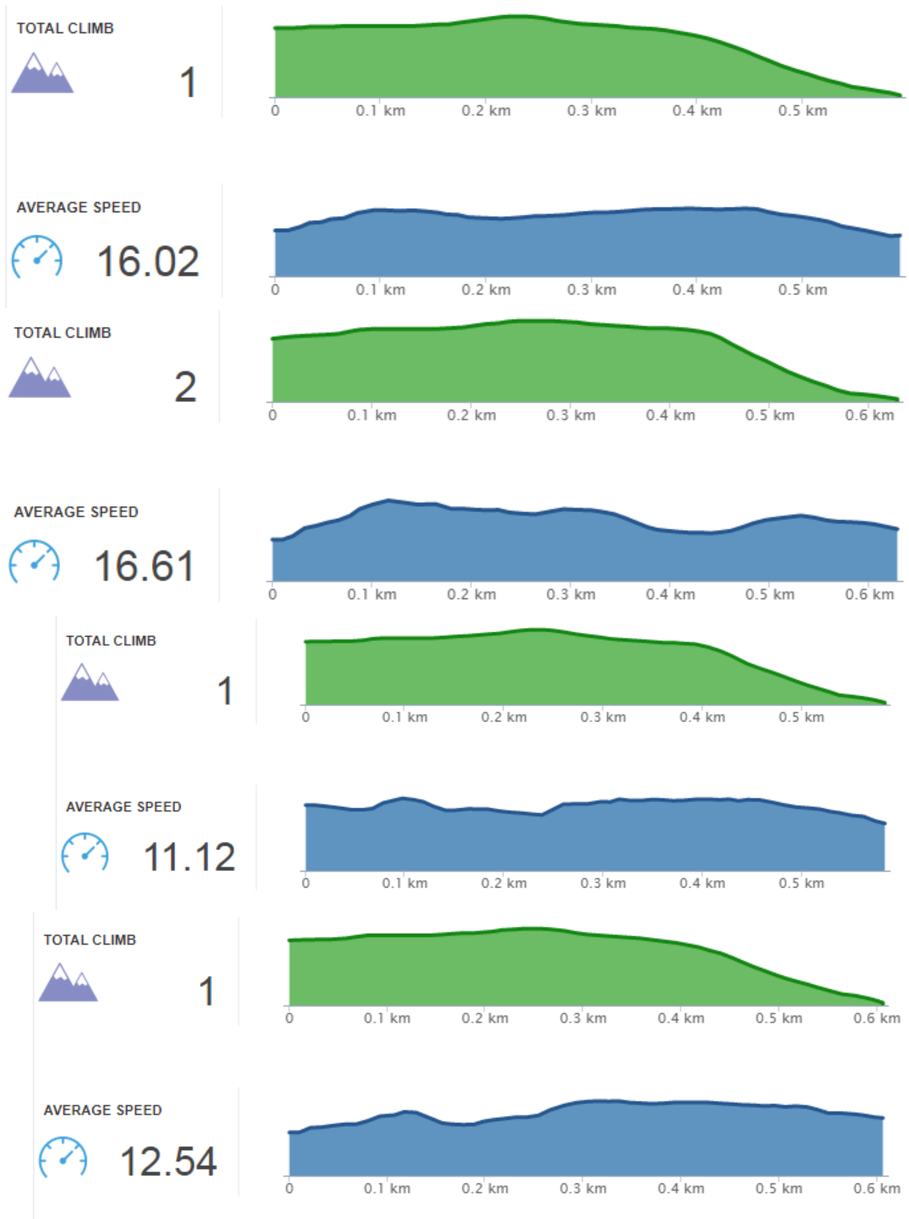
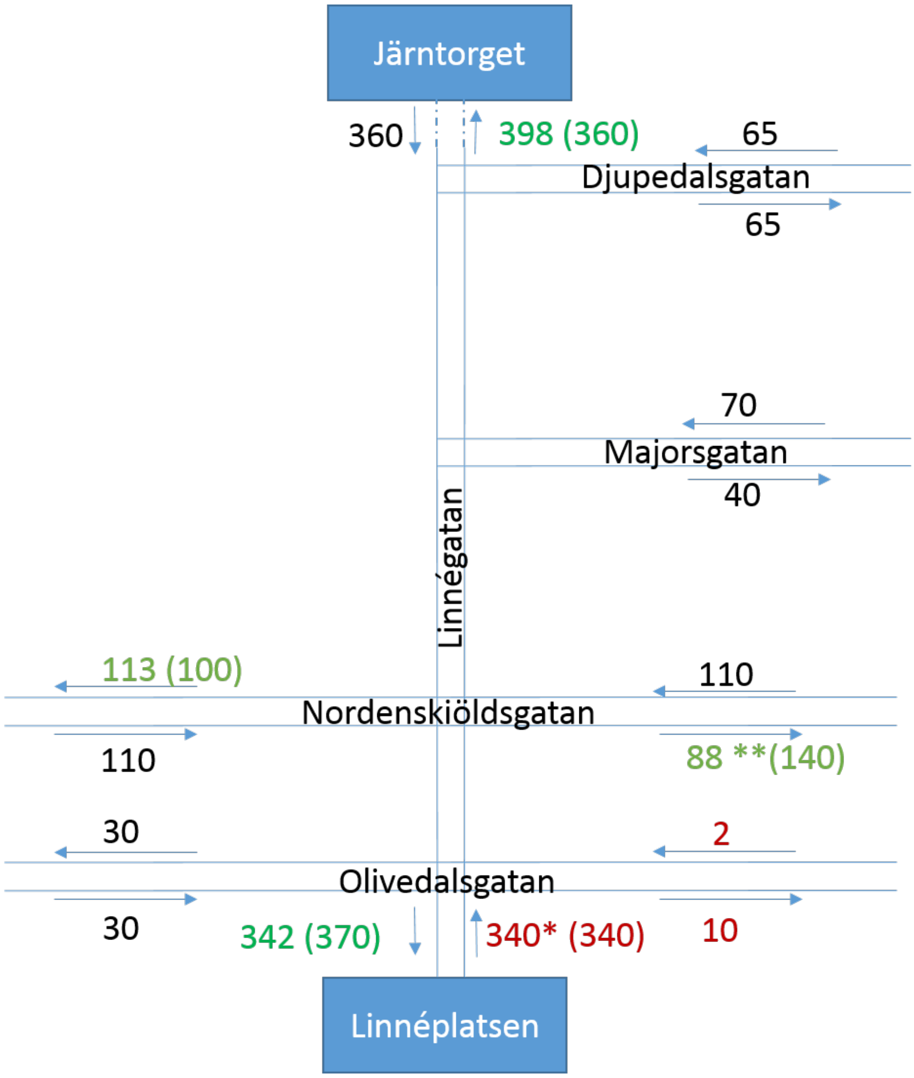


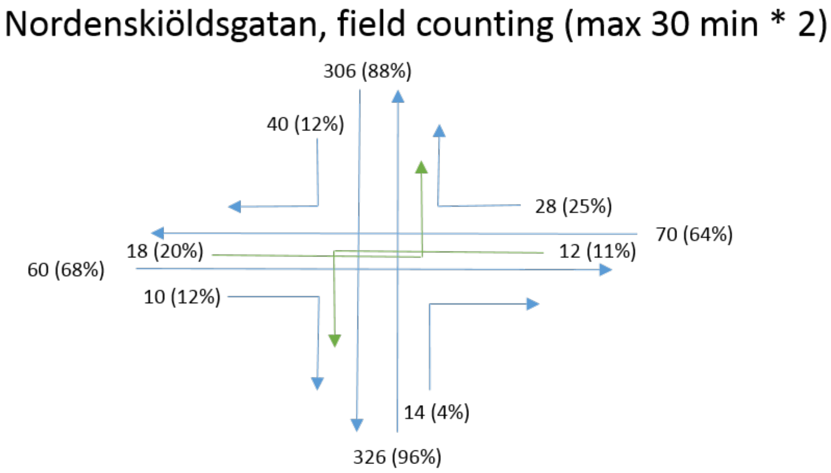
Figure A.2: Bikeruns downhill, top two runs is by the experienced rider and lower two graphs are run by inexperienced rider.

B Appendix Input data



*Max counted is 324 ((80+86)*2) however the number was rounded up to match the Nordenskiölsgatan intersection.
** The number was not rounded up Numbers in brackets are the numbers fro Göteborg stad.

Figure B.1: Traffic flow at Linnégatan as modelled in Vissim. Black numbers are from Göteborg stad website. The red numbers are counted numbers and the green numbers are adjusted. The numbers in the brackets are the numbers from Göteborg stad.



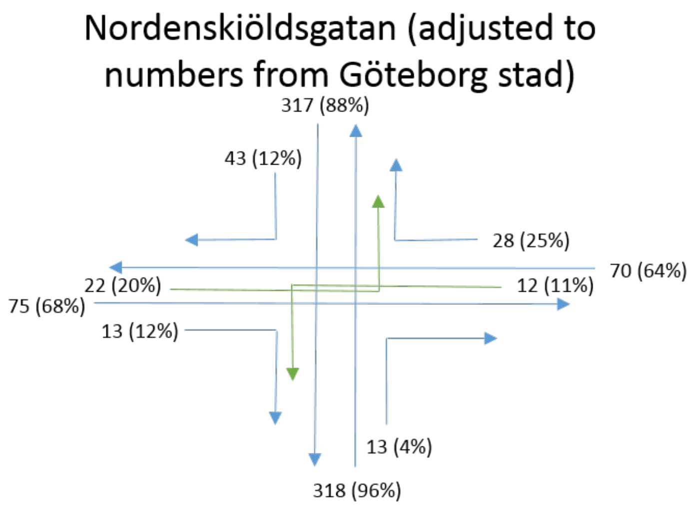


Figure B.2: Figure above, the counted traffic at the intersection at Nordenskiöldsgatan with calculated percent for the direction of the flow. The figure below is the percentage of the flow with the input data from Göteborg stad.

Car number	Count 1	Travel time	Count 2	Travel time	Count 3
1	7:40:09	0:00:19	7:40:28	0:00:20	7:40:48
2	7:41:15	0:00:21	7:41:36	0:00:30	7:42:06
3	7:44:36	0:00:24	7:45:00	0:00:29	7:45:29
4	7:47:07	0:01:10	7:48:17	0:00:34	7:48:51
5	7:49:11	0:00:13	7:49:24	0:00:49	7:50:13
6	7:50:32	0:00:40	7:51:12	0:00:21	7:51:33
7	7:52:17	0:00:55	7:53:12	0:00:19	7:53:31
8	7:53:49	0:00:40	7:54:29	0:00:18	7:54:47
9	7:55:24	0:00:15	7:55:39	0:00:26	7:56:05
10	7:56:27	0:00:46	7:57:13	0:00:19	7:57:32
	Average	0:00:34		0:00:27	
	Standar	0:00:19		0:00:10	

Figure B.3: On the right site, the location of the travel time measurements and on the left site the measured travel time.

C Appendix Calculations of AADT for Cyclists

specific day	Year i:	Startdate	End date
	2012-02-06	2012-01-01	2012-12-31
	2013-02-04	2013-01-01	2013-12-31
	2014-02-04	2014-01-01	2014-12-31
	2015-02-04	2015-01-01	2015-12-31
	2016-02-04	2016-01-01	2016-12-31
	2017-02-03	2017-01-01	2017-12-31

Vasagatan

sum year i	Days of the year	AADT	Average Daily traffic	Daily factor
662586	240	2760,775	1074	0,389021199
336078	78	4308,692308	0	0
869903	209	4162,215311	2133	0,512467482
945739	243	3891,930041	1528	0,392607263
941539	248	3796,528226	2395	0,630839509
851774	249	3420,779116	2535	0,741059248

Sprängkullsgatan

sum year	Days of the year	AADT	Average Daily traffic	Daily factor
0	0	#DIV/0!	0	#DIV/0!
0	0	#DIV/0!	0	#DIV/0!
129119	59	2188,457627	0	0
555145	245	2265,897959	804	0,354826217
538398	248	2170,959677	1302	0,599734769
408568	210	1945,561905	1404	0,721642419

Average daily factor:	0,54
99th percentile of Vasagatan specific date	305,92
99th pecentile of Vasagatan	644
Factor date to max	0,48
Counted bikes N-S	80
N-S Adjusted to peak	168,4100418
Counted bikes S-N	52
S-N Adjusted to peak	109,4665272

Figure C.1: Figure above, the counted traffic at the intersection at Nordenskiöldsgatan with calculated percent for the direction of the flow. The figure below is the percentage of the flow with the input data from Göteborg stad.