CHALMERS
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Optimisation of the simulated interaction between pedestrians and vehicles

A comparative study between using conflict areas and priority rule in Vissim

Master's thesis in the Master´s Programme Infrastructure and Environmental Engineering

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Master´s Thesis BOMX02-17-5
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ABSTRACT

The city of Gothenburg has developed a strategy to increase the share of travels that occur by public transportation, bicycle or by foot. The city will focus on connecting different travel modes into larger travel hubs. When planning for these new travel hubs, microsimulation is a useful tool in order to design the hubs. However, using the software Vissim to simulate traffic models with mixed traffic flows is today difficult. This because vehicles and pedestrians do not follow the same behaviour model, resulting in that the link-based vehicles cannot see the area-based pedestrians during simulation. This affects the simulated interaction between these two diverse road users, making it difficult to simulate non-signalised pedestrian crossings with a high pedestrian flow in a realistic way.

The aim of this study was therefore to investigate if there was a possibility to get a realistic behaviour in the interaction between the vehicles and pedestrians and study if the capacity for the vehicles was affected depending on how the conflict zone was handled, if the function conflict areas or priority rule was used. A study area was chosen to a specific pedestrian crossing at Korsvägen in Gothenburg. The location was representative for a pedestrian crossing at a travel hub with a high number of pedestrians and vehicles. For a comparison between the functions a base-model was created, one for conflict areas and one for priority rule. In order to compare the simulation with the reality, measured values was collected from the specific investigated crossing.

The result showed that the vehicles capacity was largely underestimated in the simulation when using both functions and to reach the desired real values a sensitivity analysis was conducted and after adjustments the result showed an underestimation of the capacity with 20%. The most significant effect using conflict areas was made when more than one *pedestrian link* was used to build the crossing and when *front gap* and *rear gap* was decreased, together with changing to *alternate priority* for the different pedestrian links. When using priority rule, the most significant change came from adjusting the *min. headway*, using more than one *pedestrian link* to build the crossing and to use more than one *stop line* per vehicle lane. Other study areas were also simulated using the optimised settings, resulting in a more generalised solution.

Keywords: microsimulation, interaction, pedestrians, vehicles, PTV, Vissim, conflict areas, priority rule, mixed traffic flows, travel hub

Optimering av den simulerade interaktionen mellan fotgängare och fordon
En jämförelsestudie mellan användningen av conflict areas och priority rule i Vissim
Examensarbete inom mastersprogrammet Infrastructure and Enviorinemental Engineering
LINA DAHLBERG
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SAMMANFATTNING

Göteborgs Stad har utvecklat en strategi för att öka andelen resor som sker med kollektivtrafik, cykel eller till fots. Staden kommer att fokusera på att ansluta olika trafikslag till större knutpunkter. När dessa nya knutpunkter ska planeras och utformas kommer mikrosimulering vara ett användbart verktyg. Dock är det idag svårt att använda programvaran Vissim för att simulera trafikmodeller bestående av olika trafikslag. Detta beror på att fordon och fotgängare inte följer samma beteendemodell, vilket medför att länkbaserade fordon inte kan se områdesbaserade fotgängare under simulering. Detta påverkar den simulerade interaktionen mellan dessa två trafikslag, vilket gör det svårt att simulera osignalerade övergångsställen med ett högt fotgängarflöde på ett realistiskt sätt.

Syftet med denna studie var därför att undersöka om det är möjligt att få ett realistiskt beteende i samspelet mellan fordon och fotgängare samt också undersöka om kapaciteten för fordonen påverkas beroende på hur konfliktzonerna hanteras, om funktionen conflict areas eller priority rule används. Ett studieområde valdes till ett specifikt övergångsställe vid Korsvägen i Göteborg. Platsen var representativ för ett osignalerat övergångsställe vid en knutpunkt med ett högt flöde av fotgängare och fordon. För att jämföra funktionerna skapades en basmodell, en där conflict areas användes och en där priority rule användes. För att kunna jämföra simuleringen mot verkligheten uppmättes relevant data från det valda övergångsstället.

Resultatet visade att fordonens kapacitet i stor utsträckning underskattas vid simulering när båda funktionerna användes och för att nå de önskade verkliga resultaten genomfördes en känslighetsanalys. Efter justeringar visade resultaten en underskattning av kapaciteten med 20%. Den största förbättringen när conflict areas användes var att använda mer än en *pedestrian link* för att bygga övergångsstället, att sänka *front gap* och *rear gap* samt att sätta *växlande prioritet* för de olika pedestrian links. När priority rule användes gavs den största förbättringen av att ändra *min. headway*, använda fler än en *pedestrian link* för att bygga övergångsstället samt att använda fler än en *stoplinje* per körfält. Andra studieområden simulerades också med de optimerade inställningarna, vilket resulterade i en mer generaliserad lösning.

Nyckelord: mikrosimulering, interaktion, fotgängare, fordon, PTV, Vissim, conflict areas, priority rule, olika trafikslag, knutpunkt

CONTENTS

Preface

This study is a result of a Master Thesis at the Department of Civil and Environmental Engineering, Chalmers University of Technology. The study was performed at the City of Gothenburg Transportation Administration during the spring of 2017. The authors of this report are Lina Dahlberg and Matilda Segernäs, with supervision from Lina Svensson and Jon Angelbratt at the Transportation Administration and Gunnar Lannér and Claes Johansson at Chalmers University of Technology.

We would like to thank the employees at the City of Gothenburg Transportation Administration for the help and support, and the providing of office space. Especially thanks to our supervisors Lina Svensson and Jon Angelbratt for helping us with assistance regarding the software Vissim and the programming language Python. We also thank Gunnar Lannér and Claes Johansson at Chalmers University of Technology for help and PTV for providing us with a license for Vissim and help along the way with questions. We would also want to thank Amritpal Singh at Viscando for help with providing data from video analysis.

Gothenburg, June 2017
Lina Dahlberg & Matilda Segernäs

Notations

In the report, there are some expressions and abbreviation frequently used, which are explained below.

Base-model: The base-model is the model built in chapter six in the case study. There is one base-model for using conflict areas and one for using priority rule. However, the pedestrian crossing is built with five pedestrian links and the pedestrians have priority in both functions.

Capacity: The capacity mentioned in the report is the capacity regarding the vehicles passing the specific pedestrian crossing.

COM: The Component Object Model, an add-on module to Vissim.

PTV: Planung Transport und Verkehr AG, the developer of the software Vissim.

Reality: The reality is the real measured values that are taken from a report written by (Viscando, 2017). All results in the report are compared to the real values.

Results: All results are either shown in the number of vehicles passing the pedestrian crossing or the share of vehicles passing the pedestrian crossing compared to reality.

Shared space: An open space where pedestrians, bicycles, public transport and vehicles coexist.

Travel hub: The English word for what the city of Gothenburg calls “Knutpunkt”, which is a place where various public transport lines meet and where there are many pedestrians and cyclists in motion.

Vehicles: When vehicles are mentioned in the report it refers to motorised vehicles and not bicycles.

1. Introduction

Cities are growing with an increased rate and have resulted in that more than 50% of the population today lives in cities. This has led to an increased demand on our towns and the importance for cities to become sustainable is more important than ever before. (Gibb, 2015) To become sustainable, our climate impact must decrease. The transportation sector is responsible for approximately one-third of the carbon dioxide emissions in Sweden and is therefore a vital factor to change. (Naturvårdsverket, 2016) Changes in the way we travel are one solution to decrease the carbon dioxide emissions. To achieve this, one way would be to build dense and cohesive cities. Such cities provide the basis for a more efficient transportation system and contribute to a decrease in the individuals total environmental impact.

This study is limited to the city of Gothenburg, who plans to increase by 150 000 occupants, 80 000 job opportunities and to be the core of a labour market region of 1.7 million inhabitants, in year 2035. This will bring many challenges, but also an opportunity to create a cohesive city that lives up to high environmental targets. (Trafikkontoret, Göteborgs Stad, 2014)

To meet these challenges a strategy called *Göteborg 2035 Trafikstrategi för en nära storstad* was developed by the Transportation Administration. The strategy focuses on three main areas, where one of them is travel. (Trafikkontoret, Göteborgs Stad, 2014) Within the area travel, there are a few targets, which are used as tools to concretize and follow up the strategy. Some of the targets mentioned in the strategy are:

- At least 35% of all travels in Gothenburg occur by foot or by bike in year 2035.
- A minimum of 55% of all motorised travels in Gothenburg occurs by public transport in year 2035.
- The travel time between two destination points are maximum 30 minutes for car or public transport.

This will hopefully result in that by year 2035 a doubling of the number of travels done by foot, by bike and by public transport will take place, as well as a reduction with a fourth in the number of travels by car. This is illustrated in Figure 1. (Trafikkontoret, Göteborgs Stad, 2014)

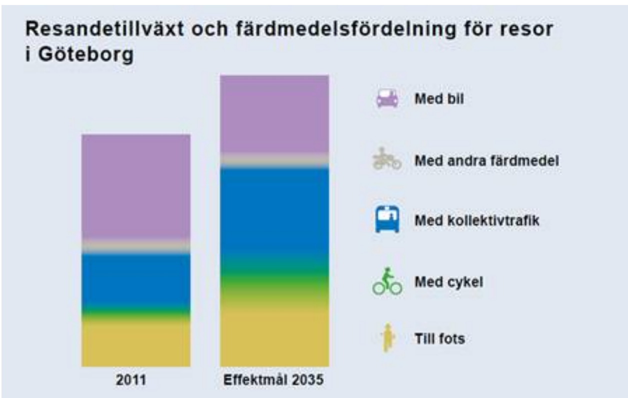


Figure 1. Illustrates the travel growth and the modal split in Gothenburg, 2011 and with targets for year 2035 (Trafikkontoret, Göteborgs Stad, 2014).

The strategy also focus on connecting the different travel modes into large travel hubs, this to make the everyday life easier for the citizens, shopping or errands can be done in the gap time between travel stops or modes. (Trafikkontoret, Göteborgs Stad, 2014) The city is therefore aiming to develop more of these travel hubs and rebuilt many of the existing ones. This will lead to an increase in the development of streets with more open spaces and a mixed traffic flow, where pedestrians, bicycles, public transport and vehicles must coexist and the concept of prioritising pedestrians, bicycles and public transport becomes more and more widespread.

Since it is a relatively new concept it is important to find methods that make it possible to evaluate future development plans where cars, bicycles and pedestrians will integrate with one another more than before. In order to plan for changes in the way we travel and to develop the infrastructure in a desired way, prediction techniques can be useful. In order to understand different traffic situations in the planning process, traffic simulation models can be used, where various options can be analysed in a cost effective and flexible way (Palmqvist, 2015).

PTV Vissim is a microsimulation software that is used to model urban traffic and pedestrian flows (PTV AG, 2016a). However, simulating pedestrians with the add-on module Viswalk is a relatively new approach and the program is today insufficient when it comes to the interaction between vehicles and pedestrians at non-signalised pedestrian crossings. This must do with the fact that vehicles and pedestrians do not follow the same behaviour model, vehicles are based on the car-following model meanwhile pedestrians are following the social force model, resulting in that pedestrians cannot see the vehicles during simulations. This leads to uncertainties in the results regarding the capacity, especially at previously mentioned travel hubs, where a large number of pedestrians are passing. This will likely affect the simulation and may therefore also affect the design of such hubs.

This report is therefore aimed to compare different ways of handling conflict zones regarding the interactions between pedestrians and vehicles, for a non-signalised pedestrian crossing at a travel hub. The selected crossing consists of two one-directional vehicle lanes. The standard functions of handling non-signalised junctions in Vissim today, priority rule and conflict areas, will be compared. Relevant parameters will also be studied and adjusted to optimise the interaction.

1.1 Background

The city of Gothenburg strives to strengthen the travel opportunities to, from and between the city centre, by building more and larger travel hubs where pedestrians, bikes and public transportation are prioritised. This result in an increased flow of pedestrians at spaces where other traffic user also exists, leading to mixed traffic flows becoming more common. (Trafikkontoret, Göteborgs Stad, 2014)

These new travel hubs in the city have created an increased demand for simulating mixed traffic flows, so that the capacity can be predicted and the design determined. The microsimulation tool used today by the city of Gothenburg Transportation Administration is the software PTV Vissim. In the software, vehicles and pedestrians do not follow the same behaviour model. Vehicles follows the Wiedemann car-following model and are link-based, meanwhile pedestrians are area-based and follow the social force model. This result in area-based pedestrians cannot see the link-based vehicles during the simulation, making the interaction between them ineffective and impossible for pedestrians to move around slow-moving vehicles (Gibb, 2015). This makes it difficult to simulate travel hubs in a realistic way, and an uncertainty regarding if the capacity is underestimated has been brought up.

This report will therefore analyse the problem in question and see if the real capacity can be reached with parameter optimisation and if the real behaviour for vehicles and pedestrians can be imitated.

1.2 Aim and objective

The aim of this study is to compare two functions in the microsimulation program Vissim regarding how the software handles the interaction between vehicles and pedestrians in conflict zones. The aim is also to identify a way to simulate the interaction in a realistic way.

The functions in question are conflict areas and priority rule. The focus of this study will be on the following research questions:

- Is it possible to get a realistic behaviour in the interaction between vehicles and pedestrians at travel hubs, by adjusting relevant parameters?

- Is the capacity for the vehicles affected, depending on the function used? Does the capacity correspond to the reality?

- Which parameters have the largest impact on the result?

1.3 Limitations

The study has a geographic limitation, which is a specific pedestrian crossing at Korsvägen in Gothenburg. The current crosswalk only crosses two unidirectional vehicle lanes and is non-signalised.

The simulations were run in Vissim 9, the newest version at the time this report was written. This results in that some parameters, settings, et cetera. may differ from other versions of Vissim. The version was chosen since it was the license received by PTV. When using the programming language Python, the version Python 2.7 was used since PTV recommended it.

The study is limited to the parameters that were found to be relevant according to research and the Vissim manual. For example, parameters that were excluded were visibility in conflict areas, and min. gap time since it was assumed not to affect the results according to the information in the manual.

The comparison was only focusing on the interaction between pedestrians and vehicles. Bicycles was included in the model to get a realistic result that could be compared to the reality, however the settings for the bicyclists were not adjusted and were therefore not included in the sensitivity analysis. This because the bicycles are link-based, like motorised vehicles and therefore the interaction was assumed to work better between the bicyclists and vehicles than it does between the pedestrians and vehicles.

The results of the study have only focused on the capacity for the vehicles and have not taken the capacity for the pedestrians under consideration.

2. Method

The method of this report is explained in this chapter and the progress of conducting this report can be seen in Figure 2. The report started with a literature study, to gather relevant information regarding the research questions and the software Vissim. Data was then collected both from own investigations and a literature study. With this foundation, a base-model was set up in Vissim and the two different functions were later tested. For the two functions a sensitivity analysis regarding affected parameters was conducted to find the optimised solution and finally, the results were evaluated. The results were later tested for different study areas to find a more generalised solution and heatmaps were created illustrating the possible volume combinations for when the model was working. During the entire work, report writing was done on the side.

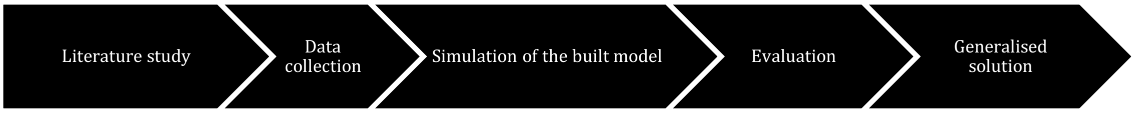


Figure 2. Shows the work process of this report.

2.1 Literature study

This study started with a literature study to find relevant scientific reports regarding the research questions, traffic simulation, requisites, the software Vissim and the functions used in the study; priority rule and conflict areas. Moreover, relevant parameters regarding this study were defined for each function. Research was also done regarding the add-on module COM interface.

2.2 Data collection

Most of the data was taken from already existing reports and statistics. One of the reports used was a pedestrian investigation report, *Rörelsemönster och trafikflöden vid korsvägen, Göteborg*, by Viscando, where data was collected during the Christmas rush between 2016-12-14 and 2016-12-18, at the selected pedestrian crossing at Korsvägen. The data was gathered by video observation with the technique OTUS3D, to find out how pedestrians, cyclists and vehicles use the traffic space. Other data obtained was the number of vehicles, pedestrians and bicyclists, their speed and directions. The cameras also record each vehicles/pedestrians movement patterns in the area. (Viscando, 2017b)

This study alone was however not sufficient and own investigations were made for counting the share of pedestrians walking in groups. Pedestrians walking in groups were counted separately and the share from the total number of pedestrians was calculated. This was done on the selected crossing at Korsvägen, between 3:30-4:00 PM on the 15th of February and 8:00-8:30 AM on the 24th of February. The selected hours were chosen, because they were assumed to represent the hours with the highest number of pedestrians passing the crossing.

2.3 Simulation

A model of the selected pedestrian crossing was built up in Vissim 9, with help of a background image from MapInfo Professional 12.5. The base-model was built with two one-directional vehicle lanes with a crossing consisting of five pedestrian links and one two-directional bicycle lane, see Figure 12 and Figure 13 in chapter 5.2. Data collection points were placed on both the vehicle lanes, in order to collect the total number of vehicles passing the crossing. The result was compared to the values from the study done by Viscando representing reality for the investigated hour, using both of the functions, conflict areas and priority rule.

The simulation was run during 90 minutes, taking out data for the later 60 minutes in 15 minutes intervals. The mean values were taken out from 20 random simulation runs. For every case, the data from the data collection points were used, and the system was saturated with 1500 vehicles per hour. This was done so that the different cases could be compared.

Sensitivity analysis were done for each relevant parameter and compared to the base-models results, the parameters are explained in chapter four. Parameters for conflict areas used were:

- Number of *pedestrian links*
- *Front gap*
- *Rear gap*
- *Avoid blocking major/minor*
- Different *priority* for pedestrians/vehicles in conflict zones

Parameters for priority rule used in the analysis were:

- *Min. headway*
- Number of *pedestrian links*
- Using only one *stop line* per lane
- Adjusting the *conflict markers* position

For both functions, other parameters have been analysed as well. For walking behaviour, parameters that were analysed were; *VD*, *lambda* and *react to n* and for the driving behaviour the *desired speed distribution* for the vehicles were also included.

Since the problem investigated related to a high *volume* of pedestrians, the *pedestrian volume* was analysed in the sensitivity analysis. Further the correlation between the number of vehicles and pedestrians was also investigated, to see when the functions were working correctly for different volumes.

To perform the sensitivity analysis in a thoroughly way, COM interface was used. A script in the programming language Python was written, saying that a specific Vissim file should open and automatically change the parameter in question. This made it possible to, for example test the parameter *VD* for all values between 0 - 50, with 10 random simulation runs for each value in a very simple and quick way.

2.4 Evaluation

An evaluation between using priority rule and conflict areas was performed regarding the base-model and the optimised model including the parameters mentioned. The results accuracy and the parameters effect on the model were analysed.

2.5 Correlation between the vehicle and pedestrian inputs

The *pedestrian* and *vehicle volumes* combinations were studied further, to investigate if there was a correlation between the different *volumes* and to see for which volumes the model worked correctly.

To perform an analysis, a python script was written, creating a matrix of 31x26 combinations simulating each *volume* combination in the same way as for the sensitivity analysis, but with one random simulation run. The matrix consisted of the *pedestrian volume* on the y-axis with a range between 0 – 6000 pedestrians and the *vehicles volume* on the x-axis with a range of 0 – 2500 vehicles. The result was still measured in the number of vehicles passing the crossing.

However, since the interest was if the same number of vehicles fed into the model also passed the pedestrian crossing, the matrix was transformed into the percentage of vehicles passing the crossing of the amount fed into the model. This gave a good indication of when the model was working correctly. A matrix was created for both the base-model and the optimised model, to see if there was any difference. The matrices were illustrated in heatmaps, to be graphically easy to verify if selected volume combinations could be modelled in a correct way.

To generalise the optimised solution, other similar study areas were chosen to simulate using the same settings as for the base-model and optimised model. This is explained more in chapter nine. The idea was to see if the result from the other study areas, matched the result of the heatmap and to see if the optimised solution was general.

3. Simulation in Vissim

PTV Vissim is a microscopic, time step oriented and behaviour-based simulation program that can be used to model motorised private transport, rail and road related public transport, goods transport, pedestrian and cyclists. The software is developed by the German company PTV Group. Creating detailed computational results or 3D animation for different scenarios are examples of what the software can be used for. (PTV AG, 2016a) Fields of applications are for example; comparing junction layout, transport developing planning, analysing the capacity and simulating public transportation. (PTV AG, 2016c)

Since the concept of travel hubs and shared spaces, have become accepted, mixed traffic flows are becoming more common to model and it is something developed countries today simulate more regularly. This together with the fact that cities today plan for and prioritise bicycles and pedestrians in a larger extent has led to an increased demand for traffic models that better handle the interaction between diverse traffic participants. (Weinan & Martin, 2012)

According to Gibb (2015) simulating such traffic models in Vissim is today difficult. This because pedestrians and vehicles do not follow the same behaviour model, resulting in that area-based pedestrian cannot see the link-based vehicles. This becomes a large dilemma, when pedestrians are expected to navigate around slow moving vehicles or when vehicles and pedestrians are expected to intertwine.

3.1 Pedestrian behaviour model

Simulating pedestrians is not a new concept, however a relatively new add-on module to Vissim called Viswalk was introduced a few years ago. Before, pedestrians were simulated in the same way as vehicles, on links. With Viswalk, pedestrians are instead area-based and have been given a new behaviour model called social force model. The concept of the social force model is to take the irrational behaviour of the pedestrians into account and the movements of the pedestrians can be seen as a result of humans being subject to external forces: (Helbing & Molnár, 1995) (Friis & Svensson, 2013)

$F = F_{driving} + F_{social} + F_{wall} + F_{noise}$

The force, F, consists of four factors and regulates the pedestrians acceleration or deceleration, see Figure 3.

$F_{driving}$ – the driving force in the desired direction
F_{social} – the force between pedestrians
F_{wall} – the force from walls
F_{noise} – the force that is implemented to prevent deadlocks at bottlenecks

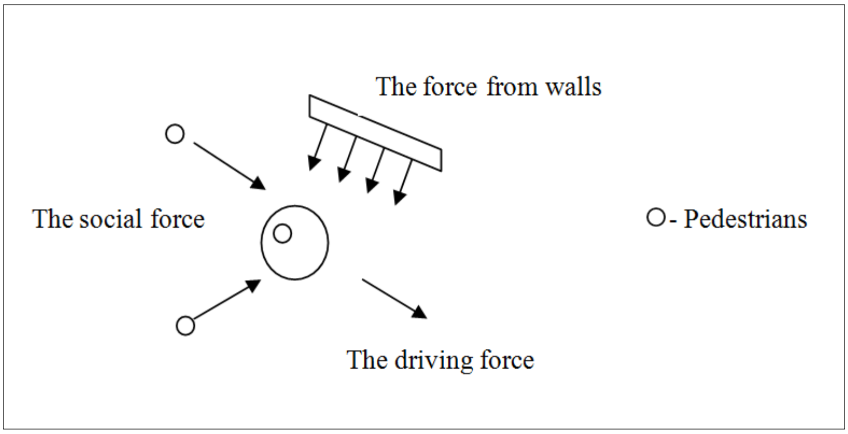


Figure 3. Shows the social force model.

3.2 Vehicle behaviour model

Vehicles are as mentioned before link-based and follow the car-following model, which today is the main traffic modelling method. The model describes the interaction between two adjacent vehicles. (Weinan & Martin, 2012) For Vissim the Wiedemann car-following model are used and can be described with Figure 4, where the x-axis show the relative speed of the leading vehicle and y-axis the distance between the following vehicle and leading vehicle. If a vehicle is not interfered it travels in its desired speed, however if the vehicle is approaching another vehicle with a higher speed, it will at a certain point, A, adjust the distance by starting to decelerate. The approaching vehicle strive to reach the same speed as the leading vehicle, but with no notice the vehicle will stop decelerate and at a certain point reach B and adjust the speed, this time by starting to accelerate. (Knoop, 2014) This action will continue until the leading vehicle accelerates or the following vehicle overtakes the leading vehicle and increases its speed. (Elefteriadou, 2014). The model is one-dimensional and therefore only considers longitudinal behaviours.

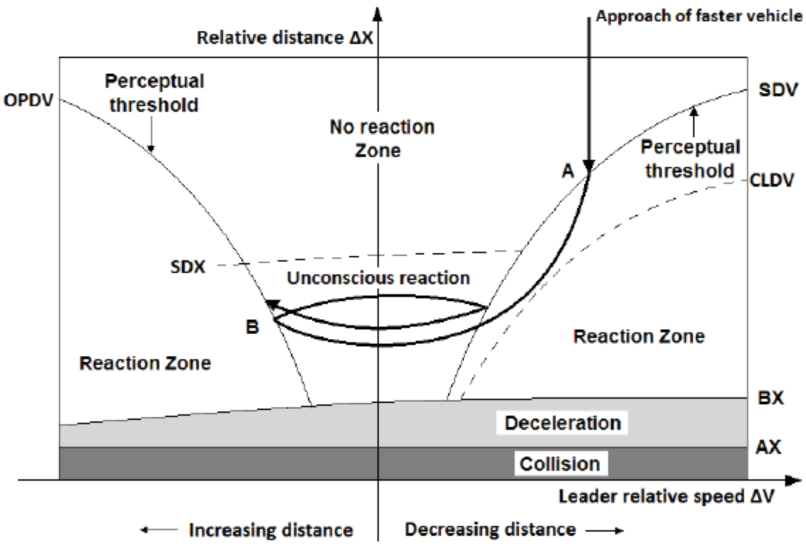


Figure 4. The thresholds of Wiedemann car-following model behaviour (Wiedemann, 1974).

3.3 Interaction between pedestrians and vehicles

Since simulating traffic situations with a high number of pedestrians have become more common in recent years, there has not yet been a lot of research done regarding the interaction between pedestrians and vehicles. However, some reports have been found where the attempt has been to find a solution to the problem regarding the interaction between link-based road users and area-based pedestrians.

The most relevant reports regarding handling the interaction in Vissim better, is summarized below, despite almost all of them are focusing on the complex situations that the shared space environment brings. However, since there is the same complex behaviour in the interaction between vehicles and pedestrians at a non-signalised pedestrian crossing, the papers are still useful and the concepts can be applied in this case as well.

Stuart Gibb presented in his paper *Simulating The Streets of Tomorrow* a new approach to model shared space. His approach was to trick the software so that pedestrians can see the slow-moving vehicles. This was done using COM interface and with a script replace a vehicle with a group of closely packed area-based pedestrians, with the result that vehicle and pedestrian now follow the same behaviour model. (Gibb, 2015) Resulting in pedestrians become able to navigate around vehicles. To perform such simulation in Vissim, a grid in which the pedestrians and vehicles are housed, must first be built.

The concept of the report was well explained and the script, replacing the vehicles with pedestrians is shown in the report. However, how to build the grid is not explained in detail, which made it hard to replicate the simulation.

Kupferschmid (2016) presented the study *How to model pedestrians and cyclists interactions with out-of-the-box features of Vissim*. His approach was similar to Gibb, but simplified. The approach was about changing the behaviour for one of the road users, however, it does not include the feature COM interface. Instead the possibilities of adapting the already existing behaviour parameters of Vissim standard simulation models were investigated. The study has focused on bicycles and pedestrians sharing a narrow street.

In one of the tests the option to simulate pedestrians as vehicles was tested. This means that the interaction with bicycles works, since they are now both link-based. However, it also means that the pedestrians behave as vehicles, they follow and overtake each other along defined lanes, which is not realistic. The report also included another test, where the option of simulating bicycles as pedestrians was tested, in order to avoid the mechanical and automated behaviour of the pedestrians some of the behaviour parameters were adjusted. In this case, both the pedestrians and bicycles follow the social force model and therefore the flows were more realistic. A problem with this option is however the reaction time for both the pedestrians and bicycles to others. It occurs too late, only a few meters before a collision, which is not true compared to reality. (Kupferschmid, 2016) However, none of these attempts solves the research question about how to make the interaction better.

Another report found was, *Social Force based vehicle model for traffic simulations*. The authors presented an approach to simulate vehicles on a two-dimensional space. The idea was to extend the social force model to vehicles, thus all vehicles and pedestrian types can be simulated. The focus was on simulating vehicles on an operational level and the approach describes and focuses on three basic behaviours: (Weinan & Martin, 2012)

- Turning
- Obstacle passing/overtaking
- Heterogeneous queue forming

The paper included the proposed model, an evaluation, and was concluded that the authors hope was the development of a new behaviour model, which in that case should be a combination of the developed social force model and the traditional car-following model. (Weinan & Martin, 2012)

The paper *Modelling Shared Space Users via Rule-based Social Force Model*, presented the concept of shared space. The author stated that the complex interaction between vehicles and pedestrians in a shared space environment can today not be mathematically described in Vissim. It is therefore a need to better be able to explain the vehicles and pedestrians movements in these environments. In the paper the authors presented a *"new three-layered mathematical model for heterogeneous agents (vehicles and pedestrians) in a shared space environment with single surface pavements, no lane discipline and identical priority for all road users"*. (Anvari, Bell, Sivakumar, & Ochieng, 2015)

Chao, Deng & Jin (2015) presented in the report *Vehicle-pedestrian interaction for mixed traffic simulation* a method for simulating vehicle-pedestrian mixed traffic flows, with the aim to model a more realistic interaction. A gap-acceptance judging criteria was introduced to determine the behaviour of the pedestrians, to wait or walk. Both vehicles and pedestrians needs to know during simulation how to pass each other safely, and they are therefore dependent on getting feedback regarding environmental influences. To drive their motion, it was necessary that the feedback was connected to their original behaviour control model. The method can be used on spaces were both pedestrians and vehicles travels, such as shared space, but also at non-signalised pedestrian crossings. (Chao, Deng, & Jin, 2015)

It can be concluded that there is a large variety on how to solve the problem in question. However, many of the solutions are mathematically complex and time consuming, resulting in that the solutions are too extensive for this study. Another factor to consider is that pedestrians have priority at pedestrian crossings, which is not the case for a shared space environment.

3.4 Conflict zones

Today Vissim offers three different ways of handling conflicting traffic flows, without a signalised intersection: conflict areas, priority rule and stop signs. In this study, only conflict areas and priority rule were relevant. According to PTV, the standard way of handling non-signalised junctions and pedestrian crossings are conflict areas, and priority rule should only be used where conflict areas do not produce the desired results. (PTV AG, 2016a) In this chapter the different two way of handling conflict zones are explained.

3.4.1 Conflict areas

Conflict areas is used to avoid collisions where a decision in turning movement is missing. Vissim displays the conflict areas automatically and can be defined wherever two links/connectors overlap. The conflict occurs when two links are crossing, two connectors connect to the same link or when a connector connects to a link with new upstream traffic. (PTV AG, 2016a) For each conflict area, the desired right-of-way will be selected:

- *Both yellow*: all movements yield (default setting)
- *Green*: right-of-way
- *Red*: yield

The function conflict areas is more easily defined than priority rule, since it is a built-in function, which automatically appears when a conflict arise. The only adjustment required is to activate the priority. The function also includes many parameters, which makes it possible to adjust the function after different situations. A new setting included in Vissim 9, *avoid blocking major*, was developed to making simulation of shared spaces more easily handled. If a large number of pedestrians cross a non-signalised pedestrian crossing with priority to vehicles, the vehicle will start to yield for the pedestrians at a certain point (Kretz, 2017).

At a pedestrian crossing the priority can be given either to the pedestrians or to the vehicles. In Sweden, pedestrians always have priority at crossings and therefore the common method is to set priority to pedestrians (Transportstyrelsen, n.d.). Conflict areas, is easy to use when modelling a non-signalised pedestrian crossing, where vehicle yield for pedestrians. The pedestrian link builds up a so-called detector area, covering the conflict zone and within this area, pedestrians are under consideration. The vehicles inform and act when no pedestrians approach the conflict zone. (PTV AG, 2016a) When vehicles and pedestrians are desired to intertwined, conflict areas is limited.

3.4.2 Priority rule

Priority rule is used when a conflict in the traffic is about to happen, or to keep intersections clear. A priority rule consists of two markers, a red and a green line. (PTV AG, 2016a)

- *Red line:* is called a stop line, an approaching vehicle/pedestrian/bicycle must wait behind the stop line if there is another vehicle/pedestrian/bicycle in the conflict area.
- *Green line:* is called a conflict marker, one or more conflicting markers can be applied to a stop line. The area behind a conflict marker is called conflict area, see Figure 5.

The difference from conflict areas is that this function is not built-in, instead one must by hand place the markers in the model. This requires some experience and knowledge of the function. (PTV AG, 2016a)

When a vehicle arrives to a stop line, it represents a waiting position for the vehicle (see vehicle 2 in Figure 5). At the stop line, vehicle 2 will check if vehicle 1 is within the conflict area.

Vehicle 2 also checks if vehicle 1 will reach the conflict marker within the minimum gap time when travelling with its present speed. Vehicles only stop at the stop line if a vehicle is either in the conflict area or within the gap time zone. (PTV AG, 2016a)(Fellendorf & Vortisch, 2010)

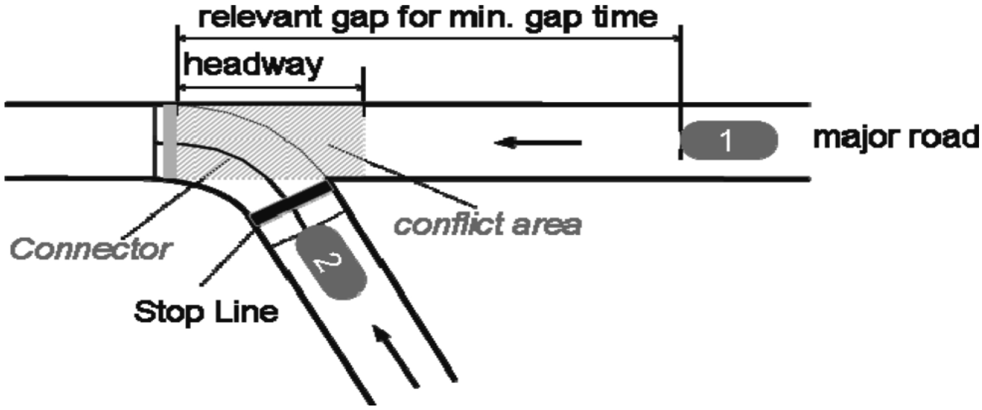


Figure 5. Illustrated how priority rule works (Fellendorf & Vortisch, 2010).

In order to adjust the conflict area, either *min. gap time* or *min. headway* can be changed. *min. gap time* is the minimum time that a vehicle in its present speed reaches the conflict marker. *Min. headway* is the distance from the conflict marker to the vehicle heading to the conflict area. (PTV AG, 2016a)

For situations with slow-moving traffic as pedestrians, only the *min. headway* is relevant. The speed is too low for having time to pass the conflict area. Therefore, the *min. headway* is used when the pedestrian already reached the certain location and the pace is irrelevant. (PTV AG, 2016a)

3.5 COM interface

COM interface is an add-on module that gives access to functions and data contained in other programs. Data contained in Vissim are also accessed via COM, using Vissim as an automation server. This however only works with Vissim version 4 or later. The COM feature is not dependent on any specific programming language, instead a wide range of scripting and programming languages can be used, and examples of such are: MATLAB, VBA, VBS and Python. Scripts can be called directly from the main menu in Vissim or the script can be written so that Vissim is accessed via COM Interface. (PTV AG, 2016b)

It is important to follow the strict hierarchy of the COM model when accessing Vissim via COM. In order to access a sub-object, one must follow the hierarchy in Figure 6. (PTV AG, 2016b)

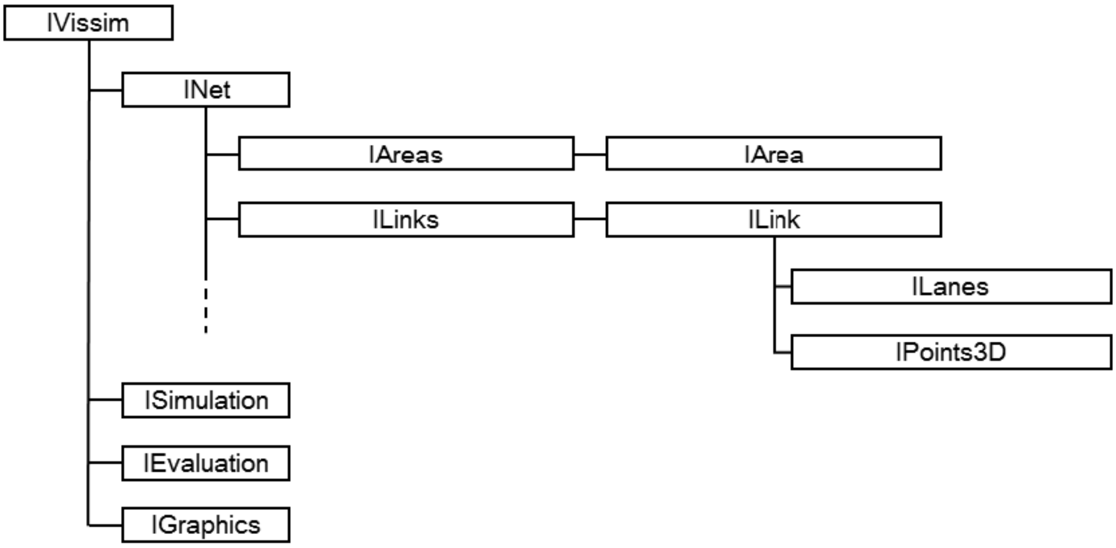


Figure 6. Illustrates the hierarchy of Vissim COM Interface module, where I stand for Interface (PTV AG, 2016b).

For example, to run Vissim via COM the python command used is Vissim.Simulaton.RunContinuous() and to change the *vehicle volume* via COM, the python command used is Vissim.Net.VehicleInputs.ItemByKey(veh_number).SetAttValue('Volume(1)) notice that they both follow the hierarchy according to Figure 6.

To perform a sensitivity analysis on the relevant parameters for respective function conflict areas and priority rule in a thoroughly way, COM interface was used. The studied parameters are presented in chapter four.

In this report the programming language used was Python. Scripts were written, ordering Vissim to open a specific file and change the parameter in question. This made it possible to test the parameter thoroughly, with a wide range of values and a number of random simulation runs for each chosen value, this to make the analysis as correct as possible. This will be further explained in chapter eight and the script used can be seen in Appendix IV.

4. Investigated parameters

The comparison of the two functions includes a sensitivity analysis of selected parameters for each function. In this chapter the affected parameters are explained more in detail and the values used in the sensitivity analysis are explained in chapter seven. The parameters are divided into different sections, conflict areas, priority rule, walking behaviour, driving behaviour and pedestrian and vehicle volume.

4.1 Conflict areas

The parameters for conflict areas are influenced by the driving behaviour and will change the default driving behaviour settings. The parameters considered in the study are explained below:

- *Numbers of links used to build the pedestrian crossing*: One factor that can be adjusted using conflict areas is how many and the width of the links used to represent the pedestrian crossing and how they are placed. They can be adjusted in different ways, for example one or many links can be placed overlapping each other. This will affect how many conflict areas that emerge.

- *Front gap:* The gap time between the yielding vehicles front end entering the conflict area and the prioritised vehicles rear end leaving, see Figure 7. The default value for front gap is 0.5 seconds. (PTV AG, 2016a)(RITA)

- *Rear gap:* The gap time between the yielding vehicles rear end after leaving the conflict area and the prioritised vehicles front end entering, see Figure 7. The default value for rear gap is 0.5 seconds. (PTV AG, 2016a)(RITA)

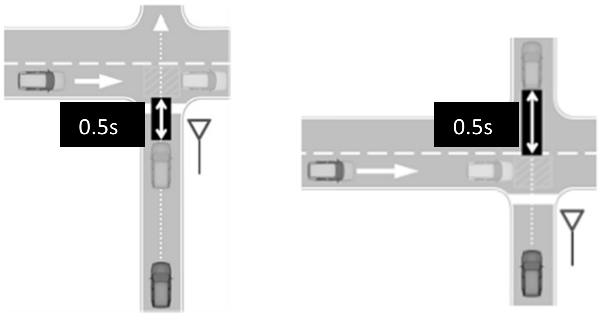


Figure 7. Illustrates front gap to the left and rear gap to the right (PTV AG, 2016a).

- *Avoid blocking minor:* The prioritised vehicle considers the actions downstream the conflict area. The distance should be minimum the size of the vehicle plus 0.5 meter, the blocking vehicle must be faster than 5 m/s and faster than 25% of the desired speed distribution if the prioritised vehicle will be entering the conflict area. The default value is 100%. (PTV AG, 2016a)

- *Avoid blocking major:* The default setting is when avoid blocking major is activated and means that the yielding vehicle does not enter the conflict zone whether not the vehicle can pass the whole conflict in one go. If this setting is not activated the vehicle can drive into and stop in the middle of the conflict zone, this even though the vehicle cannot enter the following conflict zone and thereby block the major flow. (PTV AG, 2016a)

  When this setting is not activated, it can also affect the rear gap settings. This setting is new for Vissim 9 and is developed to make simulations of pedestrian crossings and shared spaces easier. (Schubert, 2017)

- *Alternate priority for pedestrian links:* If the pedestrian crossing is divided into more than one pedestrian link there also emerges more conflict zones, these can be set either with priority for vehicles or pedestrians to achieve various behaviour.

4.2 Priority rule

When using the priority rule only two parameters are adjustable (PTV AG, 2016a):

- *Min. gap time*
- *Min. headway*

As explained in chapter 3.4.2, the *min. gap time* is not relevant when simulating pedestrians. However, the *min. headway* is very important and was assumed to have some effect on the results, therefore it was included in the sensitivity analysis.

Other parameters that were investigated are:

- *Numbers of links used to build the pedestrian crossing*: As mentioned in chapter 4.1 the effects regarding numbers of pedestrian links will also be analysed using priority rule.

- *Number of stop line:* If the pedestrian crossing is divided into more than one link, the number of *stop lines* implemented can be at minimum one per vehicle lane and maximum up to an endless amount (as many as possible that still are manageable) for each pedestrian link. The number of conflict markers depends on how many *stop lines* that are used (there are no rules regarding how many conflict markers that should be used) to each *stop line*. This action affects the distance the approaching vehicle drive before yielding for the prioritised traffic, affecting how the vehicles and pedestrians intertwined.

- *Conflict markers*: The conflict markers are connected to the stop lines. Since it requires experience of using Vissim to handle this function correct and should therefore be analysed in the sensitivity analysis.

4.3 Walking behaviour

The parameter setting for walking behaviour could be important and was therefore chosen study further. The parameters that were included in the sensitivity analysis were the following:

- *VD*: Takes the relative velocities of pedestrians into account and contributes to the social force, F_{social}. With an increased value, opposing pedestrians will evade earlier when passing or meeting. (PTV AG, 2016a)

- *Lambda:* Consider that people and events behind a pedestrian do not influence its movement as much as people and events ahead of the pedestrian do. *Lambda* affects the social force, F_{social} (PTV AG, 2016a). A significantly increased value make real pedestrians push through the gaps created between stationary vehicles (Gibb, 2015).

- *React to n*: Determines the maximum number of pedestrians that are taken into consideration when calculating the social force, F_{social} (PTV AG, 2016a). A higher value makes pedestrians avoid groups more (Gibb, 2015).

The parameters were chosen since they seemed relevant according to the Vissim manual and because Gibb recommended changing these values in his paper. The default values and the values recommended by Gibb are shown in Table 1.

Table 1. Values set for walking behaviour, the default values are taken from (PTV AG, 2016a) and the values recommended by (Gibb, 2015).

Parameters:	VD	Lambda	React to N
Default values	3	0.176	8
Values recommended	30	1	12-24

4.4 Driving behaviour

For the vehicles, the only relevant parameter included in this report was the desired speed.

- *Desired speed:* the desired speed distribution is the individual speed a vehicle in the simulation desires to achieve. Meaning that the *desired speed* not necessarily is the current speed of a vehicle. If a vehicle speed is less than its desired speed, the vehicle will automatically check if it can overtake the leading vehicle in a safe way. (PTV AG, 2016a) Increasing the desired speed will hopefully make the vehicles drive faster at the pedestrian crossing as soon as there is no pedestrian around.

4.5 Pedestrian and vehicle volume

Other parameters that were assumed to affect the result were the volume input, more specifically:

- *Vehicle input*
- *Pedestrian input*

The input represents the volumes that are fed into the model. Depending on the volume of pedestrians and vehicle the result will likely be affected. If the pedestrian volume decreases, there will be fewer gaps between the pedestrians passing the crossing.

The share of pedestrians walking in groups will also affect the pedestrian volume, and will be investigated in chapter five.

5. Model setup

To represent the problem in question one of Gothenburgs largest and most central travel hub, called Korsvägen, was chosen to use in the case study and the investigated pedestrian crossing can be seen in Figure 8-10. Today a large volume of pedestrians, cyclists, public transport (trams and buses) and vehicles passes the selected travel hub. However, the selected pedestrian crossing is only passed by pedestrians, bicyclists and vehicles and is located between the amusement park Liseberg, the Science Centre Universeum and a travel centre placed in the middle of the hub. Vehicles passing on the unidirectional two-lane street, are heading towards the motorway or the district Gårda, see Figure 8.

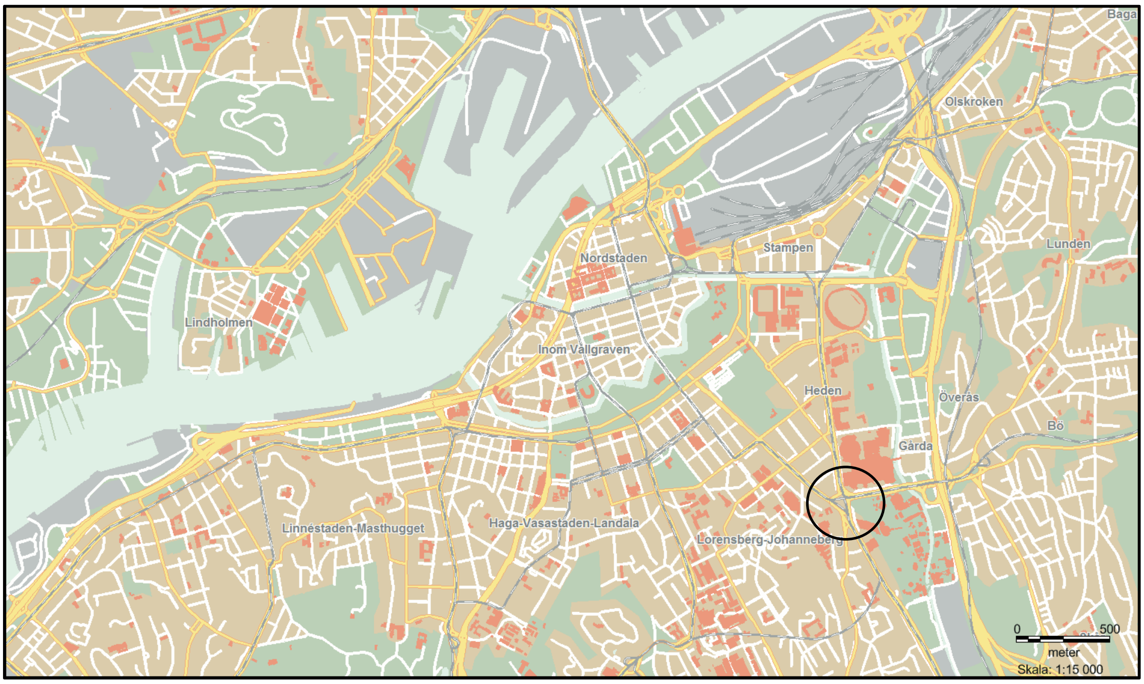


Figure 8. Shows the location of the travel hub Korsvägen in Gothenburg, Sweden in scale 1:15000.

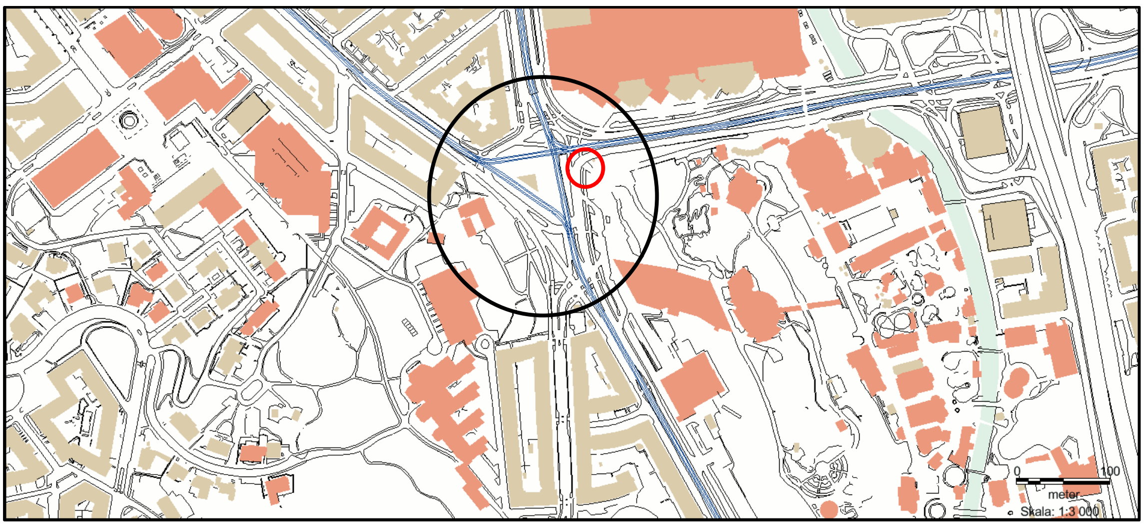


Figure 9. The location of the pedestrian crossing at the travel hub Korsvägen in scale 1:3000.

Figure 10. Shows the studied pedestrian crossing at Korsvägen and the directions; Liseberg and travel centre at scale 1:325.

5.1 Data input used for the model

Almost all required data was found in a pedestrian study done by Viscando, *Rörelsemönster och trafikflöden vid Korsvägen, Göteborg*, with the purpose to provide road users actual movement patterns. In the report numbers of passengers per day, speed and observations of the movement patterns was found. The measurements for vehicles were done about four meter before the crossing, and for pedestrians and bicycles just before the crossing, see Figure 11.

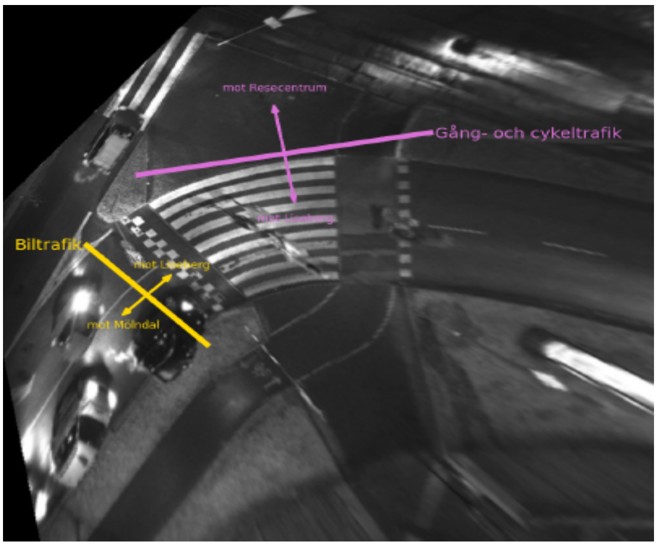


Figure 11. Illustrates where the measurements were conducted, the yellow line shows where measurements of the vehicles were done and the purple line shows where measurements of pedestrians and bicycles were done (Viscando, 2017a).

Pedestrian and vehicle input

The study was done during Christmastime, and with the location of the popular Christmas market at Liseberg, it was therefore assumed that the numbers of pedestrians were higher than an average day. The chosen hour used in the simulation was the 17th of December between 12:00 AM - 1:00 PM. The selected time was chosen because it represents an average value for the amount of pedestrians.

For a more accurate simulation 15 minutes interval was used for the pedestrian input and the distribution for the chosen hour is shown in Table 2. However, for the model some adjustments were done regarding the pedestrian volume, and can be seen in Table 4, in chapter 5.1.2. For bicycles, the total value was used as input and for the vehicles, the input of 1500 vehicle was used, since the aim was to always run the simulation with a saturated system.

Table 2. Numbers of passages in 15 minutes interval for Saturday 17th of December between 12:00 AM - 1:00 PM (Viscando, 2017a).

Type of road user	**Bicycle**		**Vehicle**	**Pedestrian**	
Direction/ Time interval	towards Liseberg	towards travel centre	towards Liseberg	towards Liseberg	towards travel centre
0-15 [min]	4	6	309	362**	119**
15-30 [min]	5	4	358	375**	85**
30-45 [min]	2	8	357	300**	132**
45-60 [min]	5	9	350	308**	126**
Total	16	27	1374*	1345**	462**

*1500 vehicles were used for each case in the model

**The number was adjusted taking that pedestrians are walking in groups into consideration, see Table 4.

Speed distribution

The speed of the pedestrians and bicycles were measured, see Table 3. For vehicles, the speed limit for the actual road is 50 km/h.

Table 3. Velocity for the different road users (Viscando, 2017a).

Type of road user	**Bicycle [km/h]**	**Pedestrian [km/h]**
Average	6.8	5.1
85 – percentile	10.1	8.9
Minimum	3	1
Maximum	20	11

Share of heavy traffic

The share of heavy traffic was set to 7%. (Trafikkontoret, Göteborgs Stad, 2012)

5.1.1 Field investigations

All the input required to build the model was not found in the literature study and therefore more investigations were needed. The share of pedestrians walking in groups and actual dimensions of the pedestrian crossing was investigated.

Share of pedestrians walking in groups

One factor that needed further investigation was how large the share of pedestrians that were walking in groups actually was. The numbers of pedestrians will affect the numbers of times that vehicles need to stop at the pedestrian crossing, this will in turn affect how many vehicles that passes through the pedestrian crossing. The result will lead to an adjustment in the volume of the pedestrian input. In this report a group is defined as a minimum of two pedestrians walking together.

As mentioned in the method, pedestrians were counted when passing the selected crossing at Korsvägen and the results are shown in Table 12, in Appendix I. The investigation was done at two separate times. One was done between 3:30-4:00 PM in the afternoon and the other was done in the morning between 08.00-08.30 AM. The survey conducted in the afternoon showed that 60% walked in groups meanwhile the survey done in the morning resulted in a share of 30% of the pedestrians walking in groups. Observation during investigation also showed that most groups consisted of two pedestrians.

The investigation shows that it was a large variation on how high the share was. The first investigation was conducted during a school holiday and many families passed the area. It was also noted that there were many pairs consisting of one adult and one child passing, since the Science Centre Universeum was opened. The second investigation was during morning and noted that most people passing were on their way to work or school.

Since the results from the model were compared to the pedestrian study done by Viscando, it was assumed to be most comparable to use the higher share, since the data from the study probably also has a high share of pedestrians walking in groups. Since it was measured during a weekend with the Christmas market ongoing, this could mean that there were a lot of families passing the pedestrian crossing at that time.

The pedestrian composition could be changed depending on the share of pedestrians walking in groups, so that a group is represented by a 3D Figure “women and child” in Vissim.

Measures over the pedestrian crossing

To build the model, the width of the pedestrian crossing needed to be measured. Since measuring the width at the site was assumed difficult, because of the traffic, measurements were done in the software MapInfo Professional 12.5 provided by the city of Gothenburg Transportation Administration. The widest side, heading towards the travel centre was measured to be 10.8 m and the shorter side, heading towards Liseberg was measured to 5.6 m.

5.1.2 Adjusted data

Since the share of pedestrians walking in groups, needs to be considered when the numbers of pedestrians were specified in the model, some adjustment on the number of pedestrians needs to be done. Since the share of pedestrians walking in groups was 60% and most of them were walking in pairs, a new value for the pedestrian input can be calculated, see Table 4. The adjusted values represent the data used for pedestrian input in the model. The pedestrian composition used in the model was changed to include: 60% "woman and child", 20% "woman" and 20% "man".

Table 4. New adjusted values for the numbers of pedestrians, for the different time intervals.

Direction/ Time interval	**towards Liseberg**		**towards travel centre**	
	Amount of pedestrians	Adjusted value	Amount of pedestrians	Adjusted value
0-15 [min]	362	254*	119	84*
15-30 [min]	375	263*	85	60*
30-45 [min]	300	210*	132	93*
45-60 [min]	308	216*	126	89*
Total	1345	943	462	326

*The calculation for all time intervals and directions looks the same, x-((x*0.6)/2) = adjusted value, x= amount of pedestrians.

5.2 Building the model

For the case study, see chapter six, a base-model is used so that the two functions can be compared. This section presents a short description of how the base-model was built. The base-model was created to be as similar to the reality as possible and for conflict areas and priority rule to be applied without any further changes. To begin with a map over the pedestrian crossing from MapInfo Professional was used as a background image. A link was drawn where the road was located according to the background image, consisting of two lanes (with the width of 3.5 metre per lane), and two pedestrian-areas were placed on both sides of the pedestrian crossing. A two-lane link representing the bicycle lanes was placed along the street and crosses the pedestrian crossing. An extra-long vehicle link was created, representing the street, since the model will be run with a number of vehicles that makes the model constant full and gives the vehicles some driving time before entering the crossing to accustomed them to the model. The base-model can be seen in Figure 12.

Figure 12. Shows a screenshot of how the base-model was built in Vissim.

The pedestrian crossing was created with five links that were drawn between the two pedestrian areas, and set as “use as pedestrian area” in the settings. Placing five links overlapping each other created the shape and size of the pedestrian crossing. A pedestrian input was placed on both sides of the pedestrian crossing, generating pedestrians in both directions. However, since the road was unidirectional, only one vehicle input was placed in the model. Two vehicles input were also used to generate bicycles in both directions. The pedestrian crossing can be seen in Figure 13 and all the inputs were taken from Table 2 and Table 4.

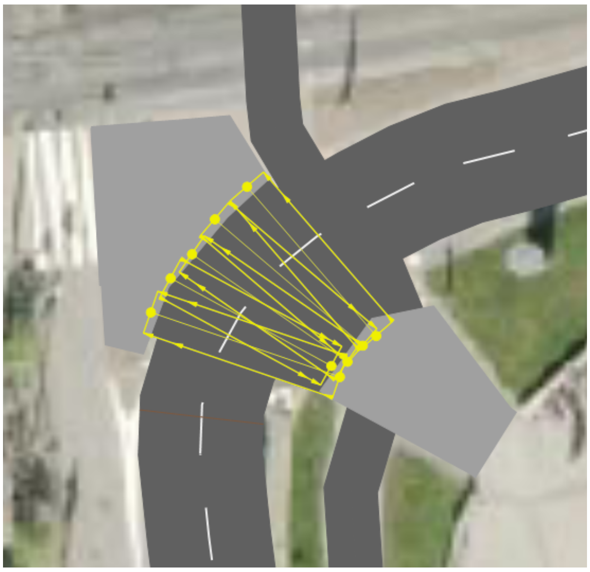


Figure 13. Shows a screenshot of how the pedestrian crossing was built in the base-model in Vissim.

The desired speed distribution was adjusted both for the pedestrians and bicycles. This was done by creating new desired speed compositions for pedestrians and bicycles based on the values in Table 3, see chapter 5.1. The vehicles have been set up to have the default settings for the desired speed: 30 km/h.

6. Case studies

To investigate the differences between the two functions, a case study was performed for each function separately. In this section the base-model, see chapter 6.2, was studied. In order to evaluate the difference in the handling of conflict zones, a data collection point was used, so that result lists could be produced containing desired information, in this case the amount of vehicles and speed were collected. The amount of vehicles that passes the pedestrian crossing was measured and used to compare the different case studies with each other and the reality.

The simulation run for 90 minutes and the selected results were taken out with 15 minutes intervals, starting after 30 minutes, meaning that the results gained were for one hour, with 15 minutes intervals. The simulation was run for 20 random simulation times and the average for each time interval was used. All relevant results from the different simulations are placed in, Appendix II.

A sensitivity analysis was performed for the two different cases in chapter eight, including the parameters presented in chapter four.

6.1 Conflict areas

In the first case study the base-model was used with conflict areas activated for all conflict zones at the crossing, prioritising pedestrians and bicycles see Figure 14.

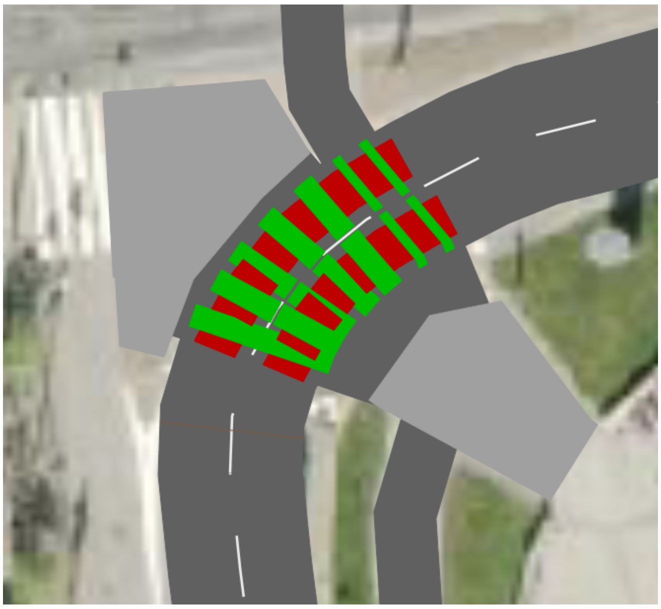
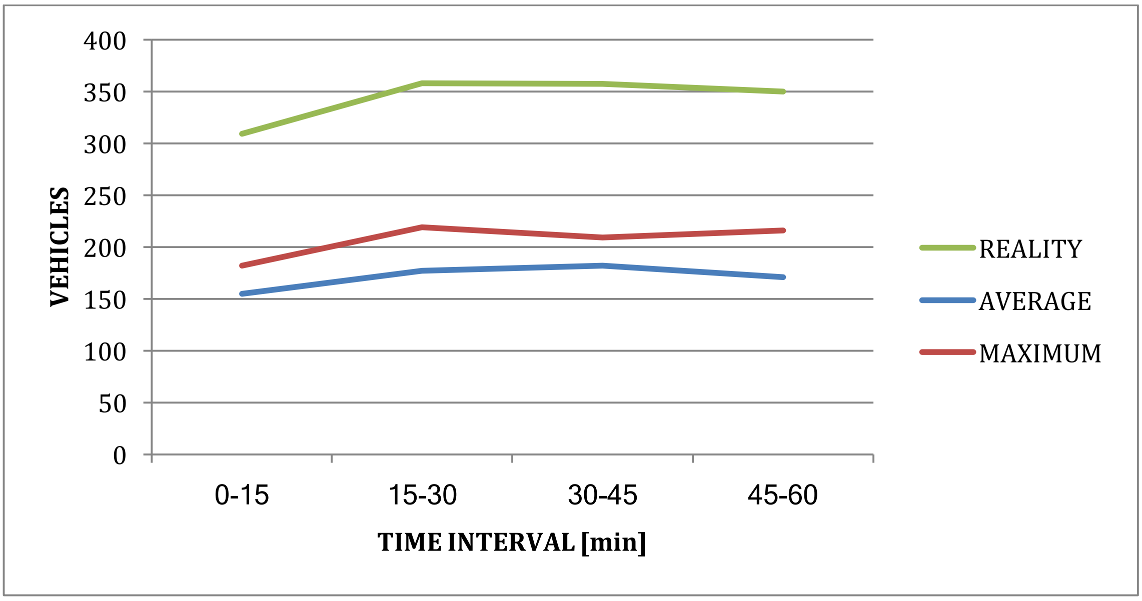


Figure 14. Illustrates the base-model with conflict areas activated.

6.1.1 Results

The number of vehicles passing the crossing was approximately 49.9% of the real values, taken the values from the report by Viscando. The standard deviation from the values does not show any large variation, and therefore all 20 random simulation runs were used, to produce an average value. The number of vehicles passing the crossing with five pedestrian links is shown in 15 minutes interval, see Graph 1.



Graph 1. Numbers of vehicles passing the investigated crossing with conflict areas activated five pedestrian links and priority for pedestrians for all links. The maximum and average values from the simulation runs were compared to the real values.

6.2 Priority rule

In the second case study the function priority rule was used to regulate the non-signalised pedestrian crossing. The stop lines and conflict markers were placed according to Figure 15. A stop line was placed for every pedestrian link in each lane, resulting in five stop lines per lane at the pedestrian crossing and one stop line per vehicle lane for the bicycle passing. The headway used on all of the conflict markers was four meter, this because it represents the width of one lane, including some margin.

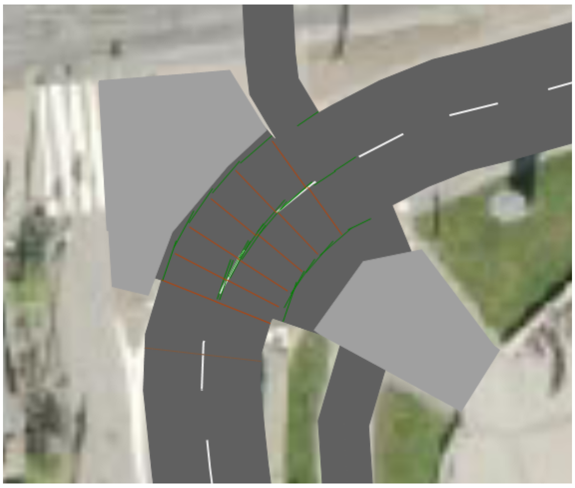
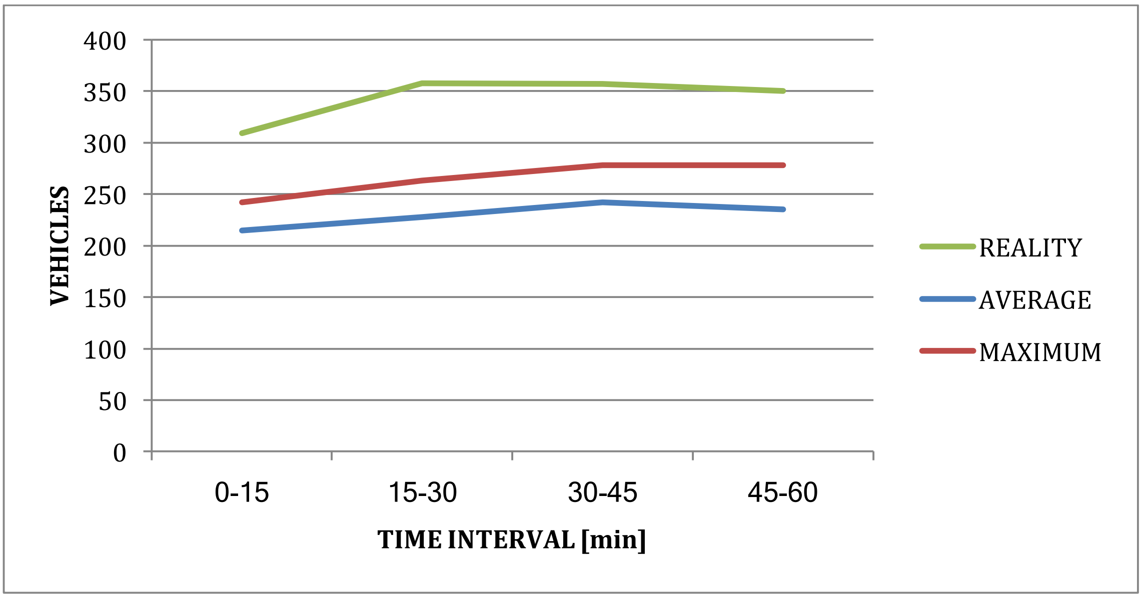


Figure 15. Illustrates the base-model with priority rule.

6.2.1 Results

The number of vehicles passing the crossing was approximately 67.0% of the real value, when priority rule was used. The standard deviation was low with no big digression, meaning that all 20 random simulation runs were used. Numbers of vehicles passing the crossing, with 15 minutes interval is shown in Graph 2.



Graph 2. Number of vehicles passing the investigated crossing using priority rule, with five pedestrian links and min. headway four meters. The maximum and average values from the simulation were compared to the real values.

7. Sensitivity analysis

To study the two functions further, the parameters presented in chapter four, were included in a sensitivity analysis. All results from the different simulations are placed in Appendix III.

For the simulations done with COM Interface, where a large range of values were tested, 10 random simulation runs were performed and for other parameters where less values were studied 20 random simulation runs were run. For each parameter studied and for every value, the average value from several random simulation runs were used and compared with the real values from Viscando.

For some cases, it was sometimes noticed that vehicles were changing lane at the pedestrian crossing and to avoid this happening to often, the *min. headway* in the vehicle behaviour settings was set to 100 meter.

7.1 Conflict areas

For the function conflict areas, the following parameters were investigated.

Numbers of links used to create the pedestrian crossing

Different numbers of *pedestrian links* were tested, see Figure 16, where models with simplified pedestrian crossings, consisting of only one or three links, can be seen. This can be compared to the base-model in chapter 6.1, where five links were used. The model consisting of one *pedestrian link* was also used to investigate if a narrower pedestrian crossing affects the results. The link was given the width of 8.2 m, since it was the average of the real width, taken both sides into account.

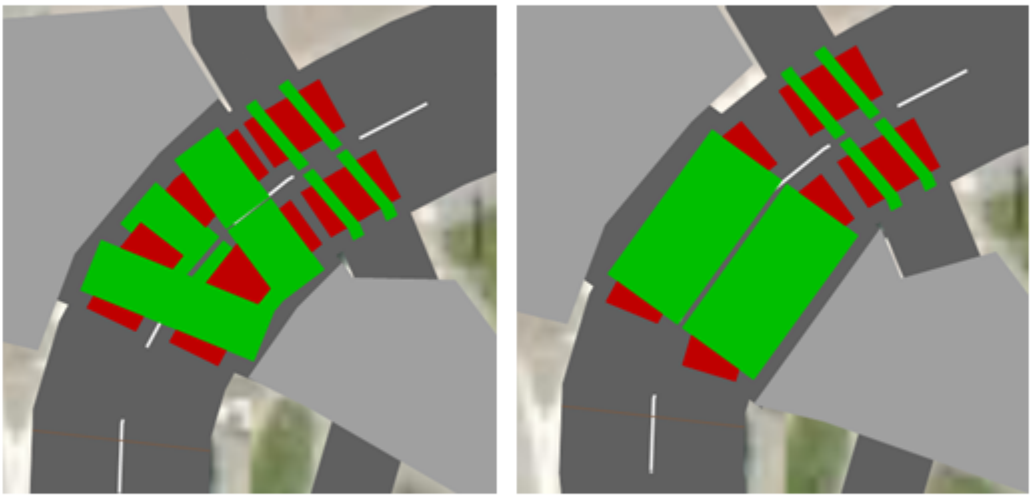


Figure 16. Simplified pedestrian crossing, the Figure to the left is consisting of three pedestrian links and the Figure to the right consists of one pedestrian link.

Simulations was also done with six, seven and nine links, to find the optimised result, this with different width to fit the dimension of the pedestrian crossing, see Table 5.

Table 5. Width of one pedestrian link for the different numbers of pedestrian links used to build the pedestrian crossing.

Numbers of pedestrian links	1	3	5	6	7	9
Width of each pedestrian link [m]	8.2	3.5	2.5	2	2	2

Alternate priority for pedestrian links

As mentioned in chapter 4.1 the priority for the different conflict zones can be changed to achieve various behaviours. For the base-model uniform priority for pedestrians were chosen at all five pedestrian links. In this analysis tests on alternating priority, between vehicles and pedestrians were done, starting with priority for pedestrians, see Figure 17.

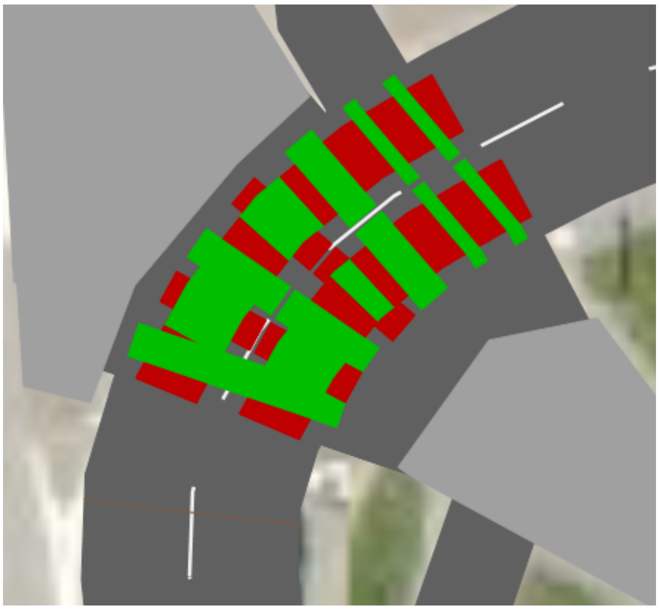


Figure 17. Illustrates the alternate priority for pedestrian links.

Front gap and rear gap

For the parameters, *front gap* and *rear gap* the values in the range 0 – 1 seconds (with 0.1 steps) was studied. This was done with the help of COM interface and the script used can be seen in Appendix IV.

Also, a combination of adjusting both *rear gap* and *front gap* was done, this with the best value for each of the parameters.

Avoid blocking

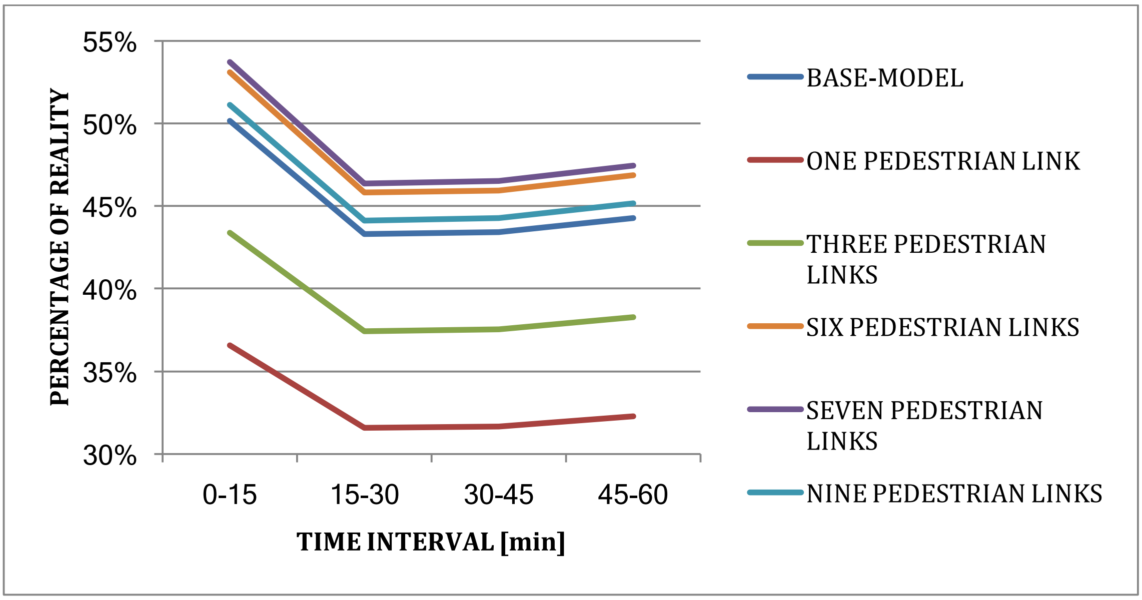
Avoid blocking minor was studied, using COM interface. The script used can be seen in Appendix IV. The values between 0 – 100% (with steps of 5%) were investigated. The parameter *avoid blocking major* was also tested in both activate and deactivated setting.

7.1.1 Results

In this chapter, the results using conflict areas are presented for each parameter. The results are compared to the base-model with 49.9% of reality, counting the vehicles passing the crossing for one hour.

Numbers of links used to create the pedestrian crossing

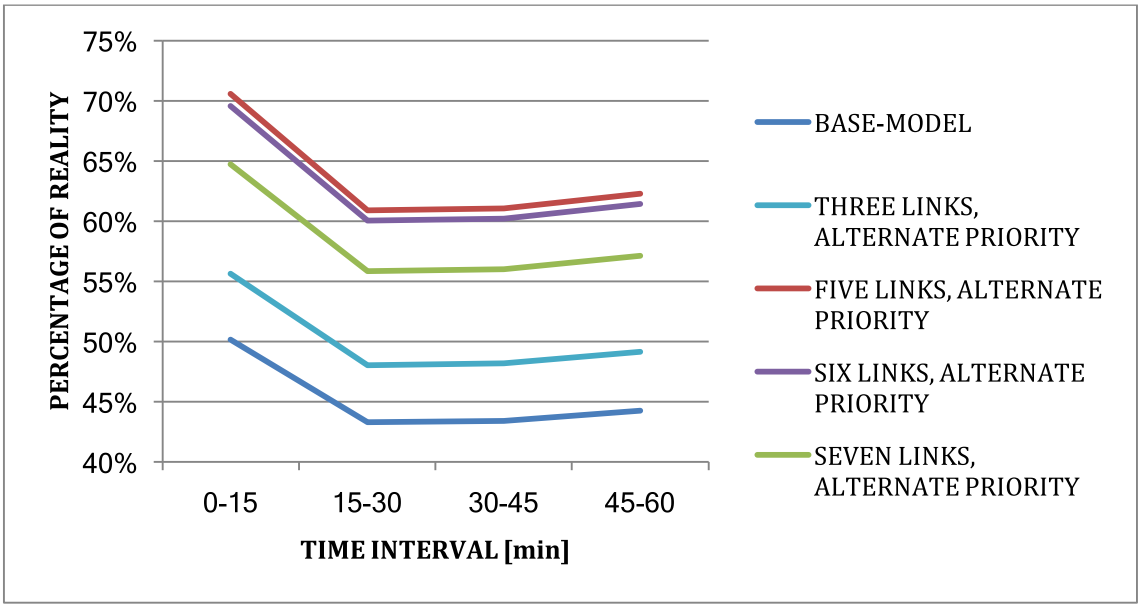
Comparing the number of pedestrian links shows a maximum result at seven links with a result of 53.3% of the real values, see Graph 3.



Graph 3. The percentage of reality counting numbers of vehicles passing the crossing, a comparison between the base-model with five pedestrian links and different number of pedestrian links, all taken from average values.

Alternate priority for pedestrian links

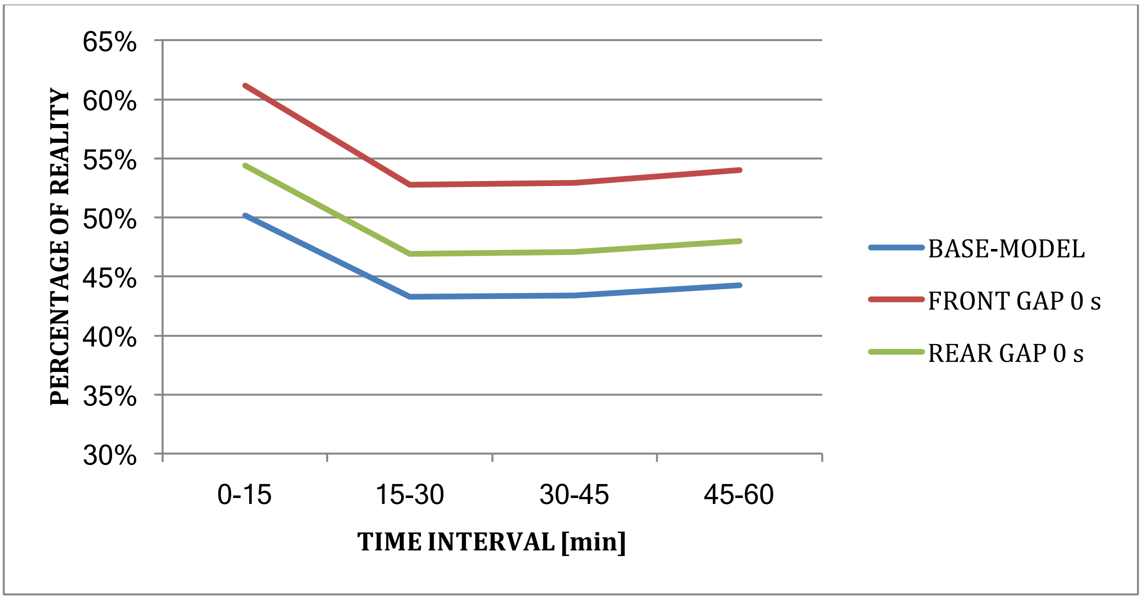
The results for *alternating priority* follows the same result pattern as the base-model, see Graph 26 in Appendix V. It has increased result with 18% from the base-model at 68.1% of reality. Since the result for *alternate priority* was to the better, it was tested to combine the numbers of links with the *alternate priority* to see how it affected the result, see Graph 4. The result shows that the best option was the base-model combined with *alternate priority*.



Graph 4. The percentage of reality counting numbers of vehicles passing the crossing, a comparison of adjusting both the priority and the numbers of pedestrian links, all taken from average values.

Front gap and rear gap

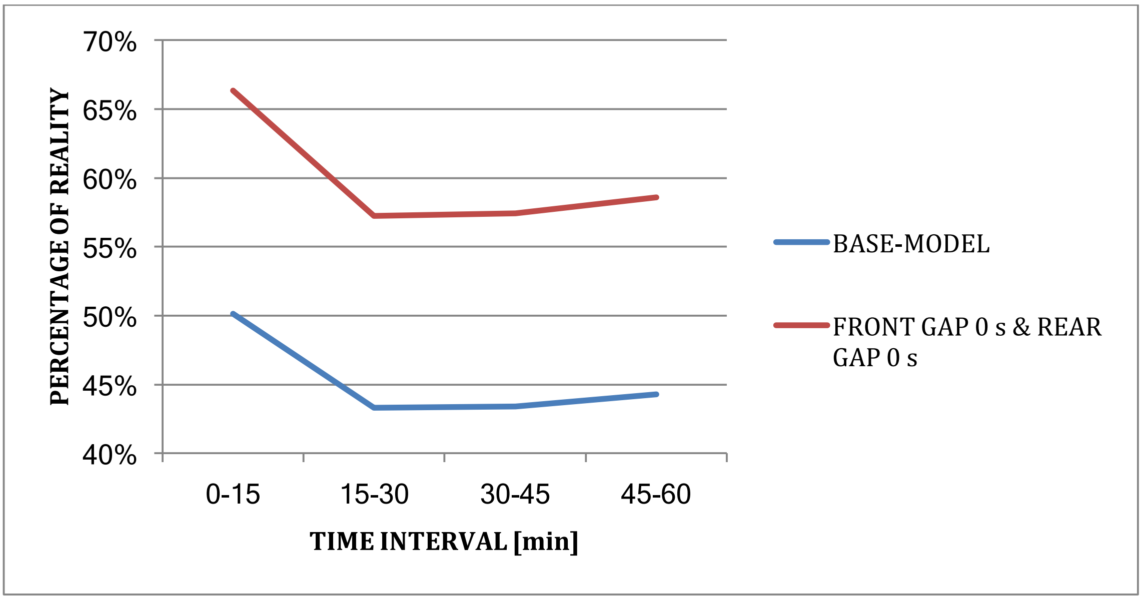
The best results when adjusting front gap and rear gap was gained using zero seconds, see Graph 5. Adjusting *front gap* using the base-model gave a result of 59.6% and adjusting *rear gap* using the base-model gave a result of 53.7%.



Graph 5. Average numbers of vehicles passing the crossing, comparing the default values for the base-model with changes in front gap and rear gap.

The results from changing *front gap* and *rear gap* can be seen in Graph 27 and 28 in Appendix V. The parameters were also adjusted combined with *alternate priority* giving the result of 74.9% when *front gap* was changed to zero seconds respectively 72.1% when *rear gap* was adjusted to zero seconds.

A combination of adjusting both *front gap* and *rear gap* to zero seconds, using the base-model, resulted in an increased number of vehicles passing the crossing with 64.4% of reality, see Graph 6 below. The result when both *front gap* and *rear gap* were adjusted to zero seconds combined with *alternate priority* gave a result of 79.2%.



Graph 6. The average value with the default settings for base-model was compared to average values from combining adjustments for both front gap and rear gap.

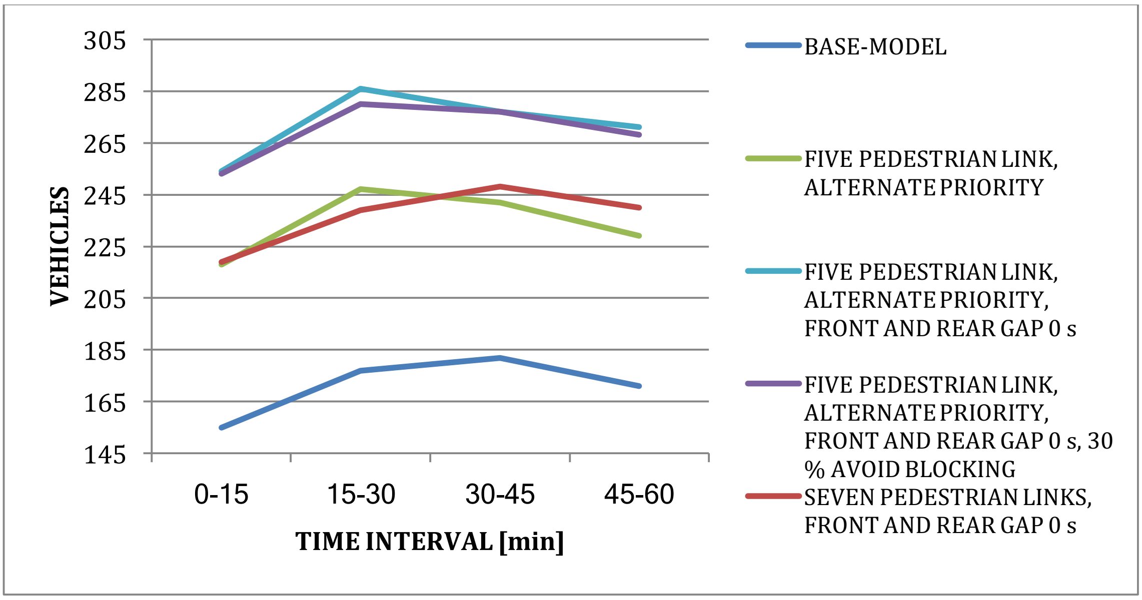
Avoid blocking

Changes in the parameter *avoid blocking minor* can be seen in Graph 29, in Appendix V. The results for each adjustment follow the same result pattern with almost no noticeable change, both for using the base-model and the *alternate priority*. For adjustments on the base-model the result was about 49.9% of reality and the result was about 68.8% of reality when using the base-model with *alternate priority*. The highest result using *alternate priority* was given when using the parameter values of 30-35%.

Using *avoid blocking major* gave a small increase of the result compared to the base-model. However, since using *alternate priority* gave a larger increase of the result, the *avoid blocking major* was not further investigated.

Combinations of the mentioned parameters for conflict areas

To find the best possible result for the parameters using the function conflict areas, all parameters giving a better result than the base-model, were combined, see Graph 7. It can be seen in the graph that all the different combinations were better than the base-model, except the combination with *avoid blocking minor* set to 30%. The best result was gained when using five *pedestrian links*, *alternate priority* and adjusting *front gap* and *rear gap* to zero seconds. These adjustments gave a maximised result, represented by the light blue line in Graph 7, with the result of 79.2% compared to the reality. This represents an increase with 29.3% from using the base-model.



Graph 7. The average value for the base-model was compared to average values from combinations for all the best results gained in the sensitivity analysis.

7.2 Priority rule

For priority rule the following parameters were investigated.

Min. headway

The effects of the parameter *min. headway* were studied and the default values together with the changed values can be seen in Table 6, below. The default value in Vissim is five meter, thus the value used in the base-model was four meter. The values chosen to investigate were 3.5 meter, since it represents the exact width of the lane, and seven meter since it represents the width of both two lanes. Also, a combination of four and seven meter was investigated.

Table 6. The studied values for the parameter min. headway used. The min. headway is explained from a vehicles perspective in the right lane, where right is on the right side of the vehicle and vice versa. The opposite is applied for the left lane.

	Min. headway [m]	
	Right	Left
Default value	4 (5)	4 (5)
Values to study in the sensitivity analysis	3.5	3.5
	4	7
	7	7

Figure 18, shows the settings, *min. headway* seven on the left side and *min. headway* four on the right side, for a vehicle standing in the lane to the right. This setting is used so that a vehicle should be able to drive when a pedestrian has passed the same lane the vehicle is driving in. Figure 19, shows the adjustment of the *min. headway* to 3.5 meter on both sides.

Figure 18. Illustrates the headway for the vehicle lane to the right, with the settings 4 and 7 meter. The opposite was applied for the other vehicle lane.

Figure 19. The headway was adjusted to 3.5 meter on both sides.

Numbers of links used to create the pedestrian crossing

As for conflict areas, a pedestrian crossing consisting of more and less than five *pedestrian links* were also studied. The numbers of *pedestrian links* used and the width of the links can be seen in Table 5, in chapter 7.1.

One stop line

The minimum implementation effort was to use one *stop line* for each lane, see Figure 20, and was therefore tested. For the base-model six *stop lines* were implemented for each vehicle lane, one for each *pedestrian link* and one for the bicycle lane. The difference was the number of conflict markers implemented for each *stop line*, for the base-model two conflict markers were implemented and when using one *stop line*, 14 conflict markers were used.

Figure 20. Illustrates one stop line per vehicle lane and 14 conflict markers.

Adjusted conflict markers

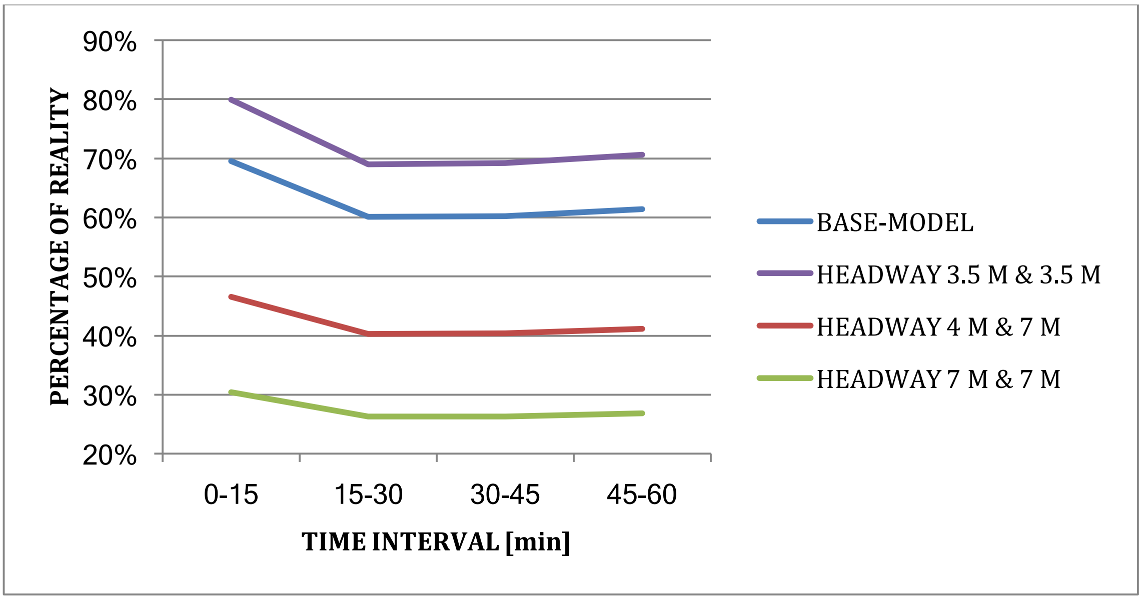
To see how much the results were affected by how the conflict markers were placed, they had in this scenario all been moved at both ends of the pedestrian crossing, so that it differs from the base-model.

7.2.1 Results

Results from adjusting parameters relevant for priority rule are presented in this chapter. The results are compared to the base-model with 67.0% of reality for one hour, counting the vehicles passing the crossing.

Min. headway

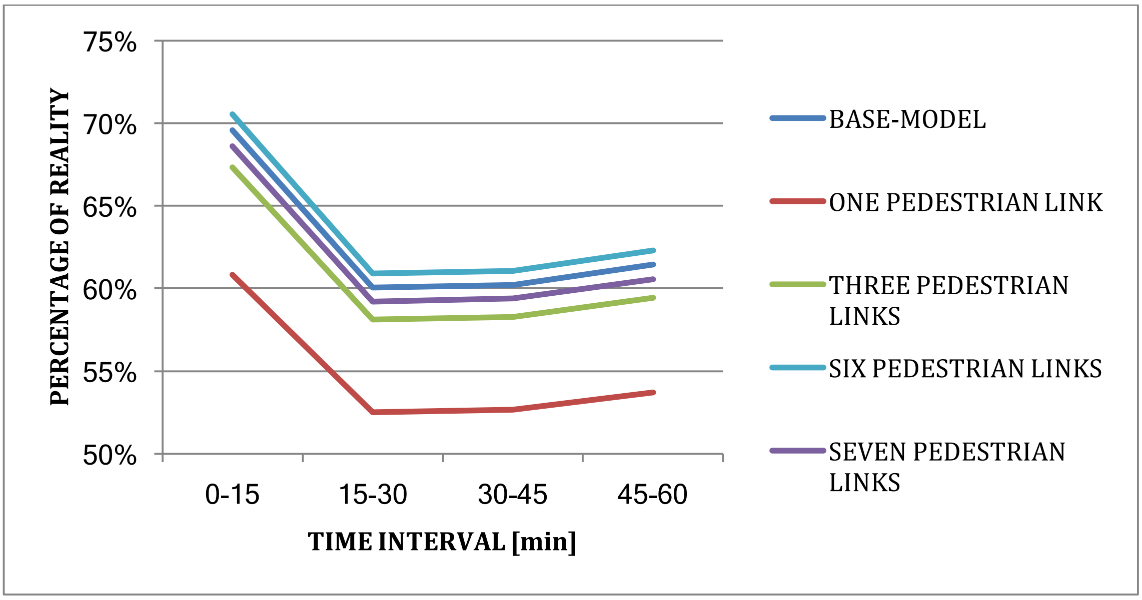
The results from changing the *min. headway* in the base-model can be seen in Graph 8. The scenario when both sides were changed to 3.5 meters was the one most like the reality, with an average result of 76.6% compared to the real values.



Graph 8. Comparison between the base-model and adjusting the min. headway, with the average percentage compared with reality.

Numbers of links used to create the pedestrian crossing

The optimum number of *pedestrian links* for priority rule were six links, see Graph 9. The number of vehicles passing the crossing was for the average result 67.6% of the real values, when six *pedestrian links* were used.



Graph 9. Comparison between the average numbers of vehicles for the base-model with five links and changing the numbers of pedestrian links.

One stop line

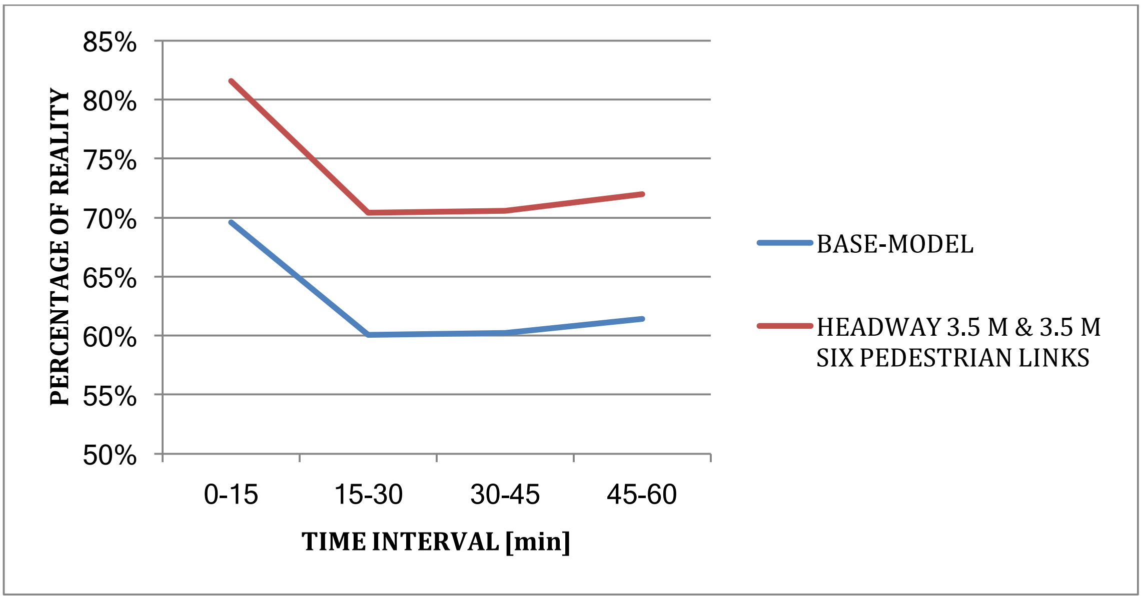
By implementing one *stop line* instead of one for each *pedestrian link* gave a decreased result with 18%, see Graph 30, in Appendix V. The result was 49.5% of the reality comparing the number of vehicles passing the crossing for an hour.

Adjusted conflict markers

Adjusting the conflict markers did not change the result much, which can be seen in Graph 31, in Appendix V. It was therefore assumed not to affect the results with any greater difference, when building a model.

Combinations of the mentioned parameters for priority rule

The model implemented with six *pedestrian links* as the pedestrian crossing and the *min. headway* at 3.5 meter for both directions was studied further, since those parameters gave the best results. The result is shown in Graph 10, and the number of vehicles passing the crossing was increased for an hour, to approximately 77.3% of the real values. This was an increase of 10.3% compared to the base-model.



Graph 10. Comparison between percentage of reality for the average number of vehicles with the base-model and adjusting both the numbers of pedestrian links and min. headway.

An observation during the simulations was that it occasionally happened that pedestrians were run over by vehicles, see Figure 21. This was something that happened for both functions and all adjusted parameters, thus it was more common when changing *min. headway*. This was probably because of an error in the software.

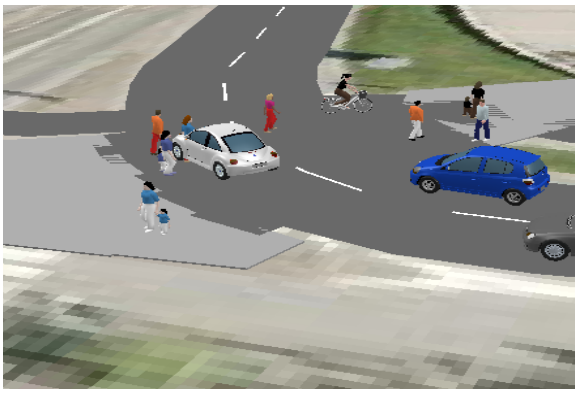


Figure 21. Shows a screenshot from Vissim, where pedestrians were being run over by vehicles.

7.3 Walking behaviour

The parameters that were being used and found to be relevant for this analysis were *VD*, *lambda* and *react to n*. The aim with adjusting these parameters was to make the pedestrian behave more realistic.

To perform a thorough and accurate analysis, COM interface was used. This to test many different values and simulate with 10 random simulation runs for each value. The programming language Python was used to access Vissim and change the chosen parameter. For the parameters *VD* and *react to n* the chosen values to study were all integers in the range 0 - 50.

For the parameter *lambda,* the values in the range 0 – 1 was studied. The script used for all three parameters can be seen in Appendix IV.

The parameters were tested one at the time to find the best value. This was done for the base-model using conflict areas and priority rule. However, for conflict areas, the base-model has been slightly adjusted. Since the *alternate priority* gave such a good result the following simulations for pedestrians walking behaviour have been done with *alternate priority* and the settings from the base-model.

To investigate further and find an optimum value, a combination of all three parameters was simulated, this time using 20 random simulation runs.

7.3.1 Results

The result gained from the script was a vector for each parameter and function, it can be seen in Appendix III. Below the value giving the best result for each parameter is presented.

VD

As described above, simulations adjusting the parameter *VD* have been done for values between 0 - 50. When conflict areas was used, the value giving the best result was 40, at a result of 952 vehicles passing the crossing, representing 69.3% of reality. However, even though there was a maximum value, the average value was 68.6% the variation is thus very small. This can be seen in the Graph 32, in Appendix V.

The result for the parameter *VD*, when using priority rule can be seen in the same graph as for conflict areas, in Appendix V. The graph shows an even smaller variation, and all values were between 66.7% and 67.2% of the real value.

Lambda

For *lambda,* simulations were done for values between zero and one. Graph 33, see Appendix V, shows that the better values for this study area, when conflict areas was used, were 0.3 and 1 giving the result of 69.5% respectively 69.4% of the real value. Most of the tested values gave a better result than the default value at 0.176, thus, an increased value gave a better result.

When using priority rule, the same trend as for conflict areas could be seen. An increased value for *lambda* gave a better result. See Graph 33, in Appendix V. The values giving the better result were 0.9 and 1.0, with a result of 67.5% and 67.3%.

React to n

When adjusting, the parameter *react to n* the result had small variations for the lower values, both for conflict areas and priority rule. The result was then constant at 68.7% respectively 66.7% of the reality, see Graph 34 in Appendix V. The value giving the highest result was the value one.

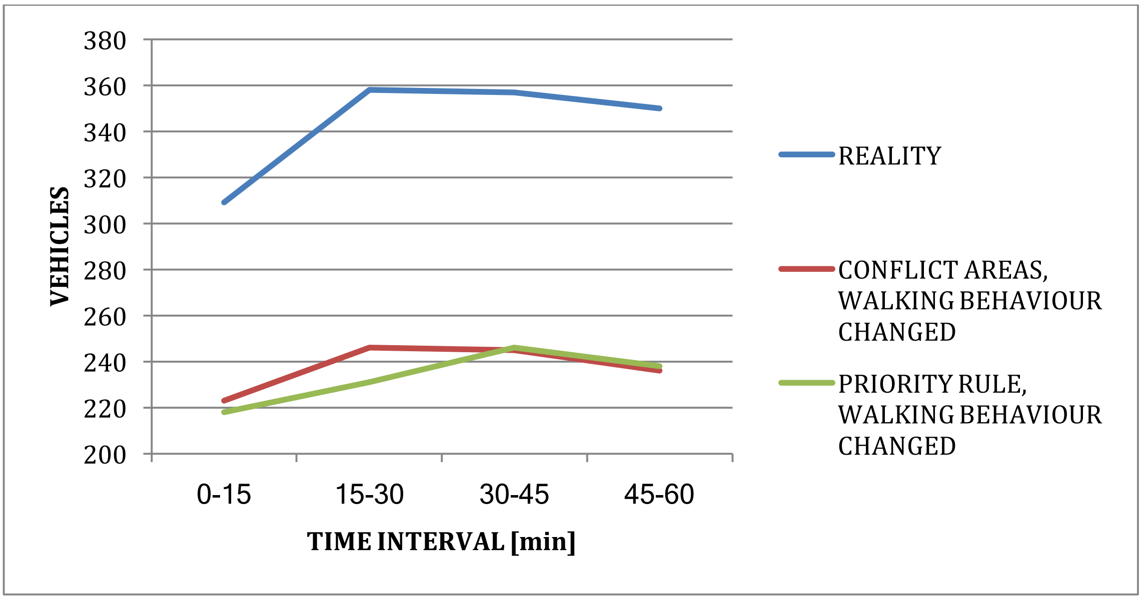
Combination of parameters

A combination of all three parameters have also been tested where the values in Table 7 was used for the different parameters. Also, *lambda* 0.9 was tested but gave a worse result.

Table 7. The best values for each walking behaviour parameter.

Parameter	VD	Lambda	React to N
Value	40	1	1

For conflict areas, the result was 950 vehicles passing the crossing representing 69.1% of the real values for one hour. However, priority rule gave a result of 933 vehicles passing the crossing for one hour, representing 67.9% of the real values, see Graph 11 for share with the 15 minutes intervals.



Graph 11. All three walking behaviour parameters changed as Table 7, for conflict areas and priority rule compared, with 69% respectively 67% of reality.

7.4 Driving behaviour

The vehicles desired speed was changed from 30 km/h to 40 km/h, 50 km/h and 70 km/h, using both conflict areas and priority rule. The average speed for the vehicles were also collected in order to be validated. The real average speed of 8 km/h was also tested.

7.4.1 Results

The results can be seen in Table 8. The best result using conflict areas was obtained from using 50 km/h as *desired speed*, with a result of 50.8% compared to reality for one hour. For priority rule the best result was also obtained from using 50 km/h as *desired speed*, with a result of 67.8% compared to reality. Moreover, the average simulated velocity is also presented in the table to be validated against the real average values from Viscando. For the chosen hour, the average velocity was 8 km/h and the 85-percentile was 13.8 km/h (Viscando, 2017a). When the vehicles desired speed was decreased to 8 km/h the results were much lower than when the base-model was simulated.

Table 8. Shows the average number of vehicles passing the crossing in percentage of reality for the base-model and the average velocity of the vehicles in the simulation.

	Conflict areas [Percentage of reality]	**Conflict areas Average velocity [km/h]**	**Priority rule [Percentage of reality]**	**Priority rule Average velocity [km/h]**
Base-model	49.9	15.2	67.0	12.9
40 km/h	50.6	16.0	67.7	13.4
50 km/h	50.8	16.3	67.8	13.6
70 km/h	50.6	16.3	67.7	13.7

7.5 Pedestrian and vehicle volume

In this chapter the pedestrian and vehicle input were studied further.

Adjusting the pedestrian volume

Another factor that was tested was the *pedestrian volume*, meaning the numbers of pedestrians fed into the model. The test includes both an increase and a decrease of the volume of pedestrians. Two new hours were chosen from the study by Viscando, one of the hours represented a time when the pedestrian volume was lower than the volume used in the case study and the other hour represented an hour when the pedestrian volume was higher.

- Saturday 17th of December, between 4:45 - 5:45 PM, on this chosen hour the pedestrian volume was increased to 4236 pedestrians in both directions. The data used for the different inputs can be seen in Table 13, in Appendix VI.

- Thursday 15th of December, between 7:15 - 8:15 AM. The pedestrian volume was decreased to 403 pedestrians in both directions and can be seen in Table 14, in Appendix VI.

The results can be compared to the results for the base-model used in the case study with a total *pedestrian volume* of 1269 pedestrians in both directions.

Correlation between numbers of vehicles and pedestrians

An investigation was also conducted regarding changing both the volume of pedestrians and vehicles, to see if and how the result was affected and to see if there was some correlation between the volumes. The investigation was performed using COM Interface in order to make it more extensive.

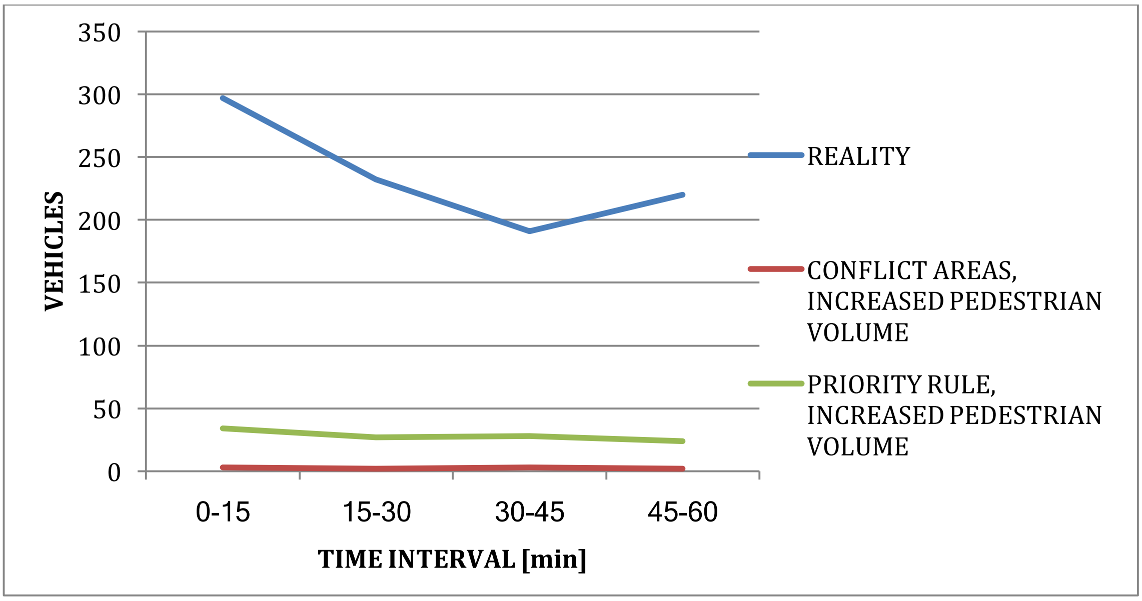
A script was written, see Appendix IV, where a matrix was created based on simulating the base-model both for conflict areas and for priority rule, with the *pedestrian volume* on the y-axis and the *vehicle volume* on the x-axis, with 31x26 volume combinations. For the pedestrians, the volume was changed from 0 - 6000 and for vehicles the volume was changed from 0 - 2500.

7.5.1 Results

The result from adjusting the *pedestrian volume* and correlation between pedestrian and *vehicle volume* are presented in this chapter.

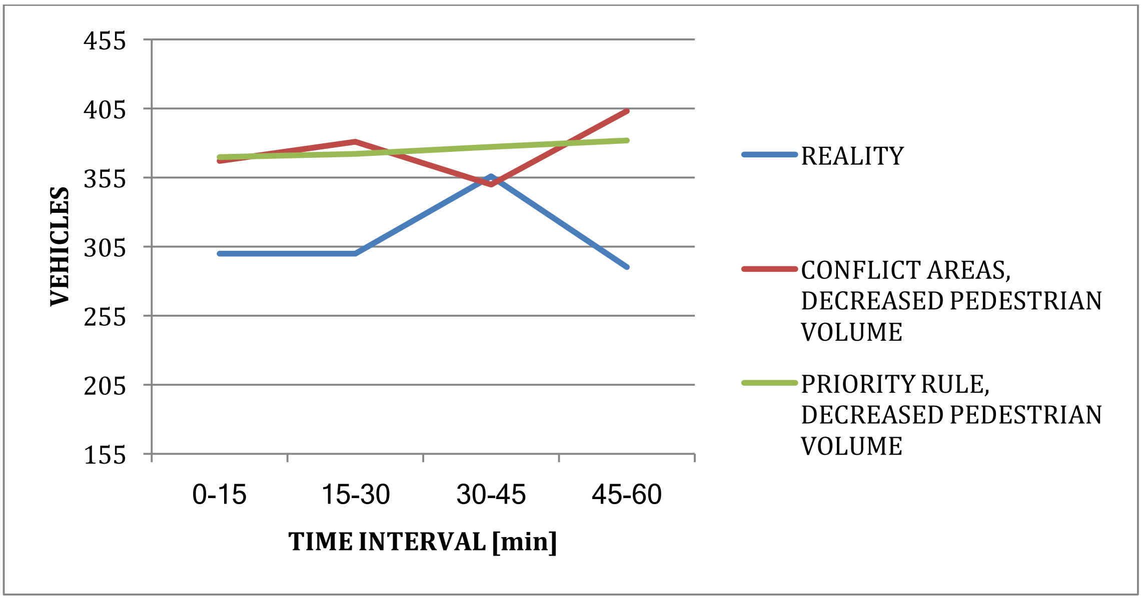
Adjusting the pedestrian volume

For the increased pedestrian volume, the amount of vehicle passing the pedestrian crossing was reduced. For conflict areas 1.1% of the vehicles passed compared to reality, whereas for priority rule there was 12.0%, see Graph 12.



Graph 12. Increased pedestrian volume of total 4236 pedestrians for both conflict areas and priority rule compared to reality.

The decreased pedestrian volume gave result, with 120.5% of the real values for this hour, both for conflict areas and priority rule see Graph 13.



Graph 13. Decreased pedestrian volume of total 403 pedestrians for both conflict areas and priority rule compared to reality.

Correlation between numbers of vehicles and pedestrians
The matrices created are presented as heatmaps and can be seen in Appendix VII.

7.6 Combinations

An attempt was done to combine the changed results in a best combination for the parameters included in the sensitivity analysis, this to present an optimised solution. Parameters for walking behaviour and driving behaviour has been combined with parameters connected to each function, conflict areas and priority rule.

7.6.1 Results

The best result using conflict areas was found when:

- Using five *pedestrian links* with *alternating priority*
- Changing *front gap* and *rear gap* to zero
- Changing all three *walking behaviour* parameters (VD = 40, lambda = 1, react to n = 1)
- Changing the vehicles *desired speed* to 50 km/h

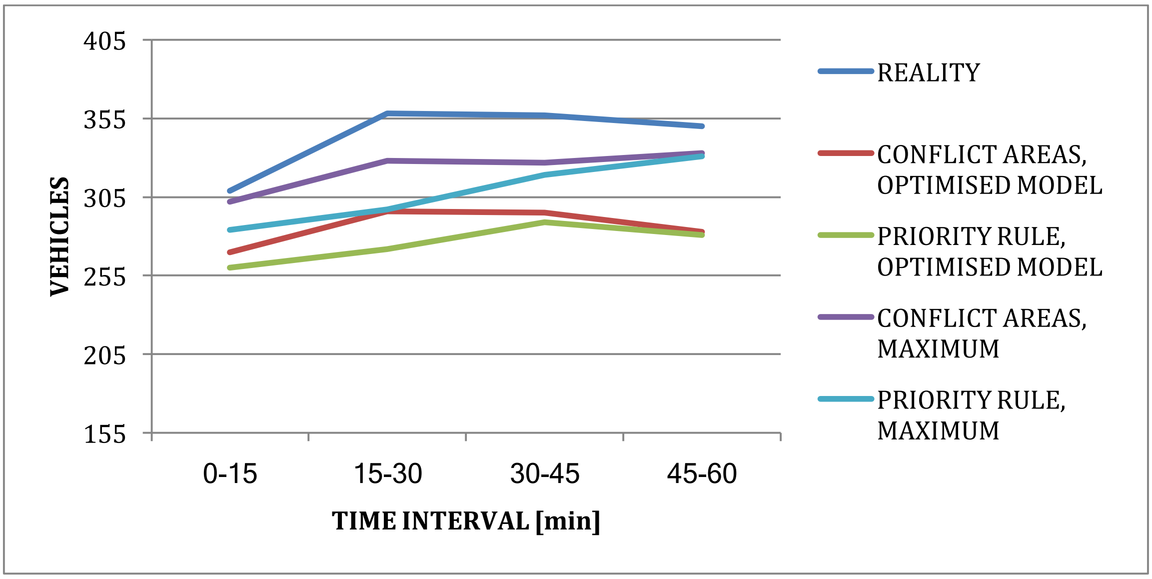
The result for the average value, taken from 20 random simulation runs, was 82.5% compared to reality. The maximum value from these 20 random simulation runs was also included to see if it was closer to the real values. The result for the maximum value was 93.9% compared to reality, see Graph 14.

The best result using priority rule was found when:

- Using six *pedestrian links*
- Using *min. headway* 3.5 meter

- Changing all three *walking behaviour* parameters (VD = 40, lambda = 1, react to n = 1)
- Changing the vehicles *desired speed* to 50km/h.

The result for the average value of 20 random simulation runs was 80.2% compared to reality and the maximum value gave a result of 89.6% compared to reality, see Graph 14 in Appendix VIII.



Graph 14. The average result for the best combinations for both functions was compared with the maximum results for both functions and reality.

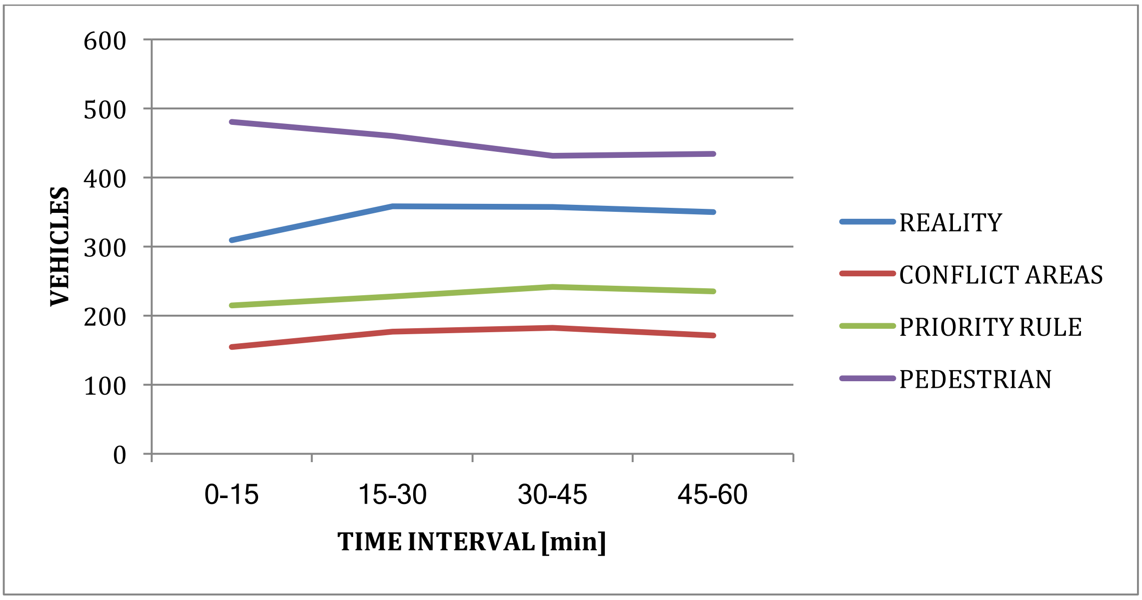
8. Evaluation

In this chapter an evaluation was done, were all parameters from the case study and the sensitivity analysis were considered.

8.1 Comparison of the case studies

In order to evaluate the difference between the functions, conflict areas and priority rule, and to find the most realistic of them, a comparison was done, including the result originating from the case study in chapter six. The model used for both functions in this comparison was the base-model, see Graph 15. Looking at the graph, the values for conflict areas and priority rule follow the same result pattern, with a similar trend as the reality. The result also shows that priority rule gave a better result than conflict areas.

The number of pedestrians was also included in the graph, to illustrate all traffic flows. When the amount of pedestrians decreases, the number of vehicles increases. This confirms the theory that vehicles have difficulties passing the pedestrian crossing at times with a high number of pedestrians.



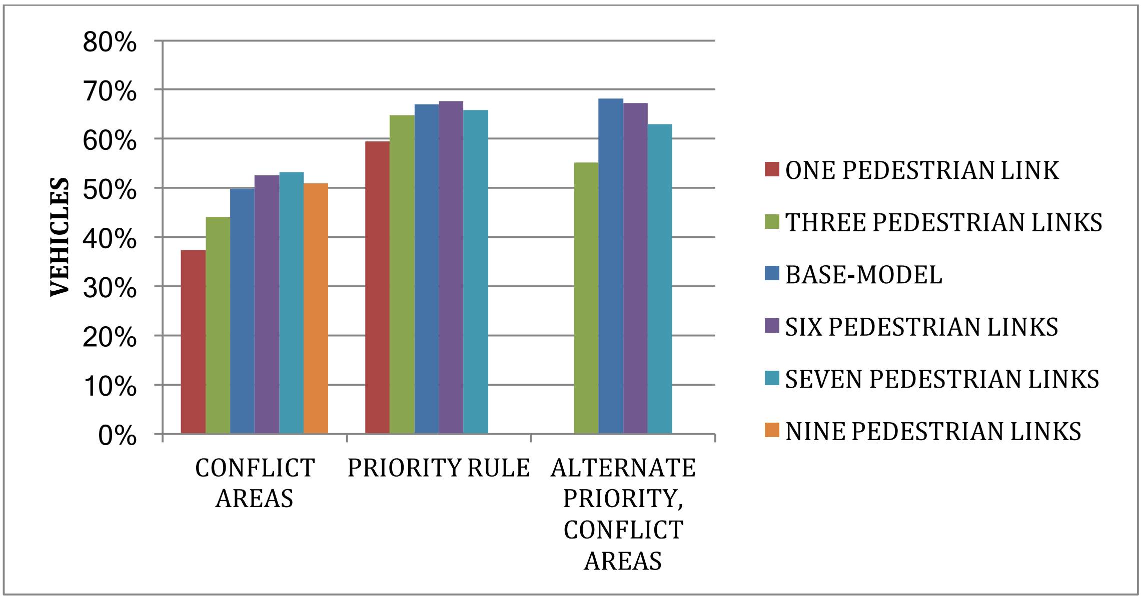
Graph 15. Average number of vehicles for the default values in each function compared to reality and pedestrian volume.

8.2 Sensitivity analysis

In this chapter an evaluation of the results from the sensitivity analysis was performed.

8.2.1 Number of pedestrian links

For both the functions, increasing the number of *pedestrian links* gave a better result. This has to do with the fact that increasing the number of links used to build the crossing increased the amount of conflict zones. This gives the opportunity for the vehicles to pass a small part of the pedestrian crossing at a time, instead of being forced to wait until the entire crossing is empty of pedestrians. However, the increase was not linear, instead it reaches a maximum, which differ between the functions, see Graph 16.



Graph 16. The results when the number of pedestrian links was changed.

When using conflict areas and increasing the numbers of links, the number of vehicles passing the crossing increase up to the use of seven links, then the result decreases. Thus, the best result was gained using seven *pedestrian links*. Looking at the results from when the priority was alternated, it clearly shows the same trend, however the best result was gained from using five *pedestrian links* as base-model.

For priority rule the number of vehicles passing the crossing increases up to six *pedestrian links* and then the number of vehicles decreases. The best result was therefore given at the usage of six *pedestrian links*.

The graph shows a larger increase in the result, when adding *pedestrian links* and using conflict areas. Using one *pedestrian link* gave a result of 37.4% of reality and when increasing the amount of *pedestrian links* the best result gained was 53.3% of reality. For priority rule the variation was not as large, going from 59.5% using one *pedestrian link* to the best result at 67.6% of reality.

8.2.2 Walking behaviour

The result from the investigation regarding the adjustments of the pedestrian behaviour parameters had very small variations, leading to difficulties when deciding the optimised value for the three parameters. With only a few vehicles difference, the percentage was basically almost the same for all values in the tested range. However, since the optimised value for simplicity should be the same for both functions the chosen values have been selected to fit both for conflict areas and priority rule, and can be seen in Table 9. The table shows the result for using the optimised values for each parameter, the result from combining the three parameters and the result using the default settings.

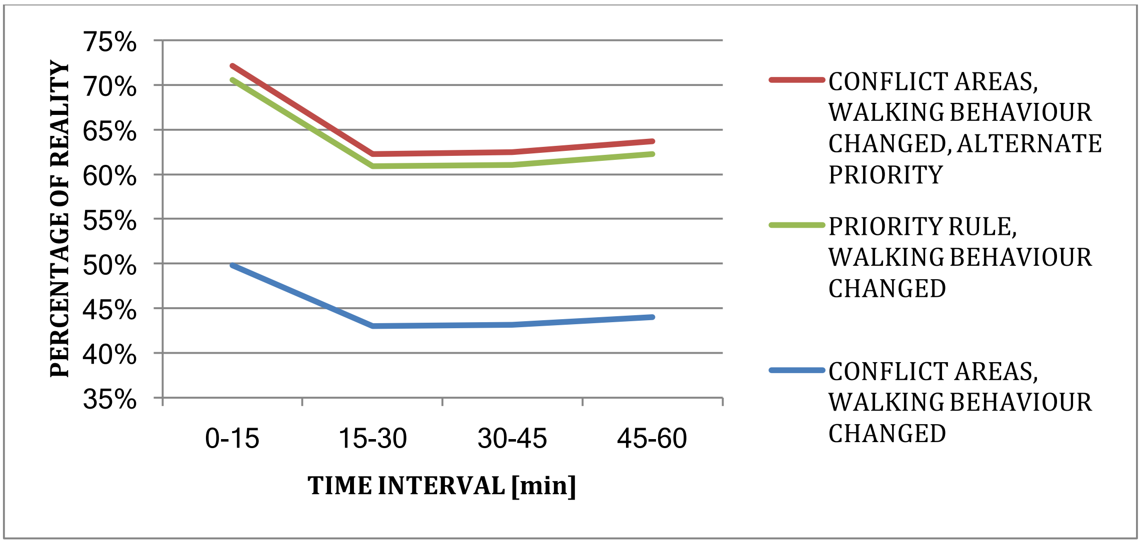
For conflict areas, since the result using *alternate priority* gave very positive results, changing the walking behaviour parameters was done both for the base-model and with *alternate priority*.

Table 9. Shows the results in percentage of reality from adjusting walking parameters for using conflict areas (base-model and alternating priority) and priority rule.

Parameter:	**Value**	**Conflict areas [percentage of reality]**	**Conflict areas, Alternate priority [percentage of reality]**	**Priority rule [percentage of reality]**
VD	40	49.9	69.3	67.2
Lambda	1	50.9	69.4	67.3
React to n	1	49.6	68.7	66.7
Combination of adjusted values: VD Lambda React to n	 40 1 1	50.7	69.1	67.9
Default settings: VD Lambda React to n	 3 0.176 8	49.9	68.1	67.0

The results indicate that the adjustment of the walking behaviour parameters has a small impact. The percentages only differ in decimal level, making it hard to draw any conclusions.

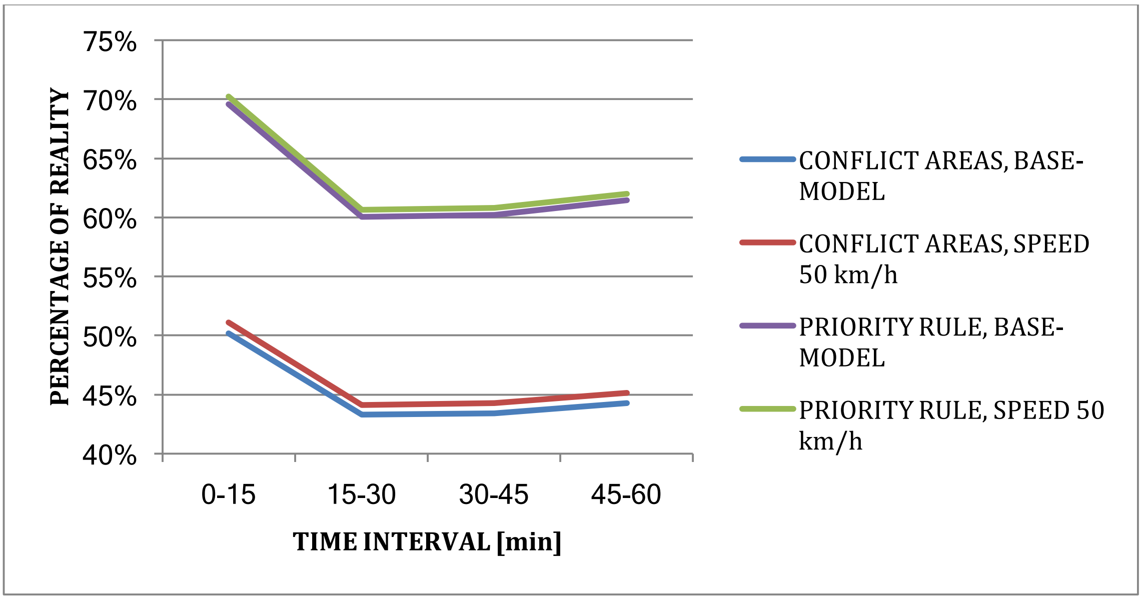
When all three parameters were changed, it did not lead to the best result when conflict areas was used. However, looking at Graph 17, it can be seen that the trend for both conflict areas and priority rule were the same.



Graph 17. Percentage of reality when the combination of walking behaviour was changed, comparison between conflict areas and priority rule.

8.2.3 Driving behaviour

When changing the *desired speed* for vehicles, it was shown that 50 km/h was resulting in the highest number of vehicles passing the pedestrian crossing. In Graph 18, the difference between the base-model and changing the desired speed can be seen for both conflict areas and priority rule, in percentage of reality.



Graph 18. Average results from changing desired speed for both functions compared with base-model at 30 km/h.

The result clearly shows that there was a small improvement for both functions. The average speed of the vehicles passing the pedestrian crossing was also collected when simulating the different speeds. In order to validate the model, the speed of the simulated vehicles was compared with the measured real speed. The results were presented in Table 8, in chapter 7.4.1. It can be said that using conflict areas gave a higher average speed than using priority rule. However, both functions have a higher average speed than the measured real average speed. Looking at using the desired speed at 50 km/h, since it was the recommended value giving the best result, the average speed for conflict areas was 16.3 km/h and for priority rule 13.6 km/h. These values can be compared to the measured real average speed at 8 km/h, however the measured 85-percentile was 13.8 km/h. Since the average values for the functions were close to the real 85-percentile speed, it was assumed that the model worked correctly.

It can also be said that the result from the table shows that increasing the *desired speed* in the model results in that the vehicles in the model drives faster. The highest average speed was obtained in the optimised model, where the *desired speed* used was 50 km/h, meaning there could be other factors affecting the speed. Otherwise the highest tested desired speed, 70 km/h should give the highest average speed in the model.

8.2.4 Realistic behaviour in the interaction when adjusting parameter

The aim with this study was also to investigate if the behaviour in the interaction between vehicles and pedestrians could be more realistic. However, since the results regarding the vehicles capacity was largely underestimated, focus was instead directed to adjusting the parameters to reach a more positive result. Thus, some observations regarding the behaviour in the interactions at the pedestrian crossing were also made.

For conflict areas, the parameters with the most significant change on the behaviour was *front gap* and *rear gap*, decreasing the value made the vehicles drive more close to each other, making a more realistic behaviour at the crossing with high flows of both vehicles and pedestrians. It was however hard to notice the difference only by observing the simulation but since the result increased dramatically it was assumed to work.

The parameter *avoid blocking minor* and *avoid blocking major* were also adjusted but no changes in the behaviour at the interaction between the vehicles and the pedestrians could be noticed either in the results or from observations.

The numbers of links used to build the pedestrian crossing was something that also made the behaviour more realistic. When more narrow links were used, it made it possible to shape the crossing to imitate the real shape, creating a larger area where the pedestrians could walk. With more *pedestrian links*, more conflict zones were created, which also made the model more realistic. It was thus noticed that there was a limit to how many *pedestrian links* that could be used. When too many were used, many conflict zones arise making the simulation not working correctly, consequently vehicles run over the pedestrians at the crossing.

When using conflict areas, using more *pedestrian links* means that the priority can vary for the different links. The simulation becomes more realistic in the interaction when the priority was alternated. Meaning that at some conflict zones, vehicles have priority and thus force the pedestrians to hesitate before they pass the crossing. This created a weaving pattern between pedestrians and vehicles, allowing more vehicles to pass the crossing, making this the parameter with the greatest effect on the behaviour regarding the interaction.

When using priority rule, using more pedestrian links means that more *stop lines* and conflict markers needs to be placed at the crossing. This can be done as detailed as possible with multiple *stop lines* and conflict markers per vehicle lane and *pedestrian link*, making the model work more similar to reality. However, consequently, since it requires much accuracy it was very time consuming. Another parameter used for priority rule was *min. headway*, changing the parameter can also have the effect of making the simulation more realistic, in this study the *min. headway* was adjusted to be 3.5 meter, making it the same length as the vehicle lanes width. Resulting in, that a vehicle only stopped if a pedestrian was right in front of the vehicle.

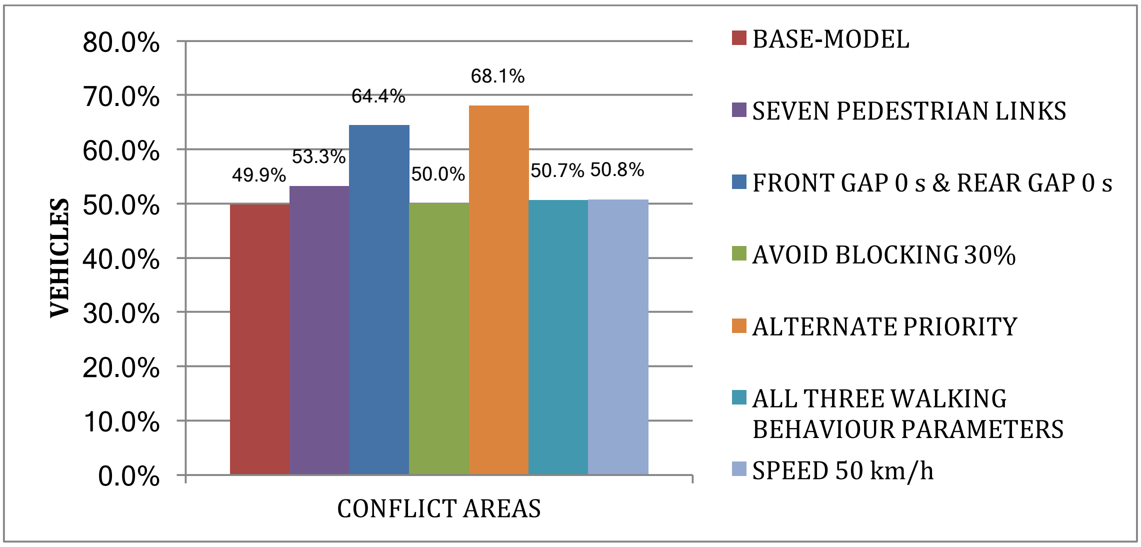
Changing the *desired speed* made a positive influence on the results, but it also made the vehicles drive faster, which do not correspond to the reality.

8.3 Optimised results

In this chapter the optimised result is presented.

8.3.1 Conflict areas

The best results obtained from the sensitivity analysis for each parameter regarding conflict areas, are presented in the Graph 19.



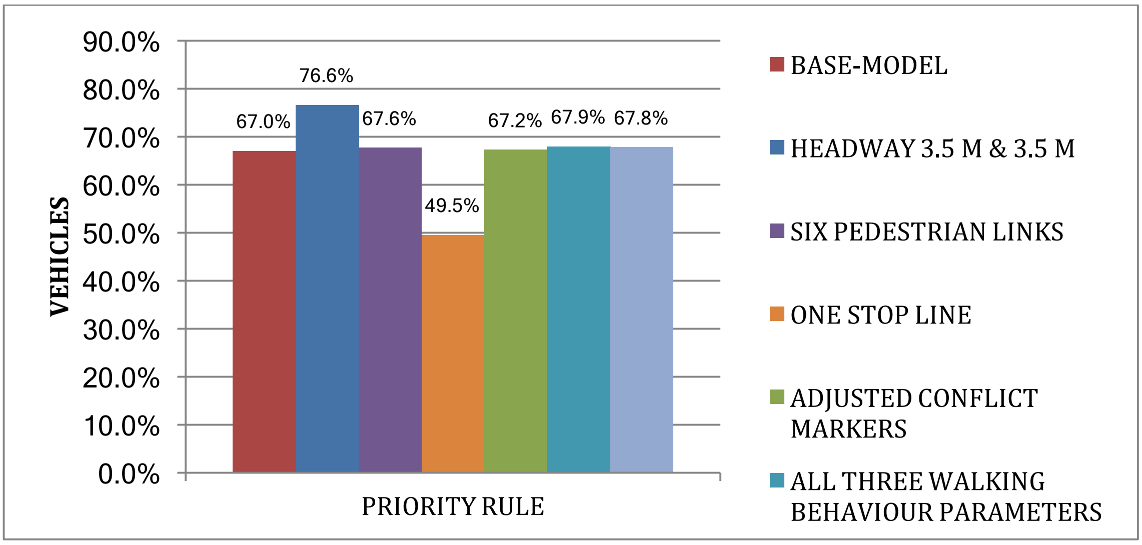
Graph 19. Average number of vehicles passing the crossing for the different parameters included in the sensitivity analysis, during one hour, using conflict areas.

All changes in the parameters included in the sensitivity study gave a more positive result than the base-model used in the case study, if they were adjusted. The result clearly shows that lowering *front gap* and *rear gap* to zero seconds and change to *alternate priority* will both affect the result to a more realistic value. However, none of the adjustments alone reaches up to the reality.

Even though changing the parameter *avoid blocking minor* to 30% alone resulted in a small positive increase of the result, the combination with adjusting other parameters gave a negative impact on the result. This was shown in Graph 7 in chapter 7.1.1 and therefore the parameter *avoid blocking minor* will not be included in the optimised model.

8.3.2 Priority rule

The best results from the sensitivity analysis for each parameter regarding priority rule, are presented in the Graph 20.



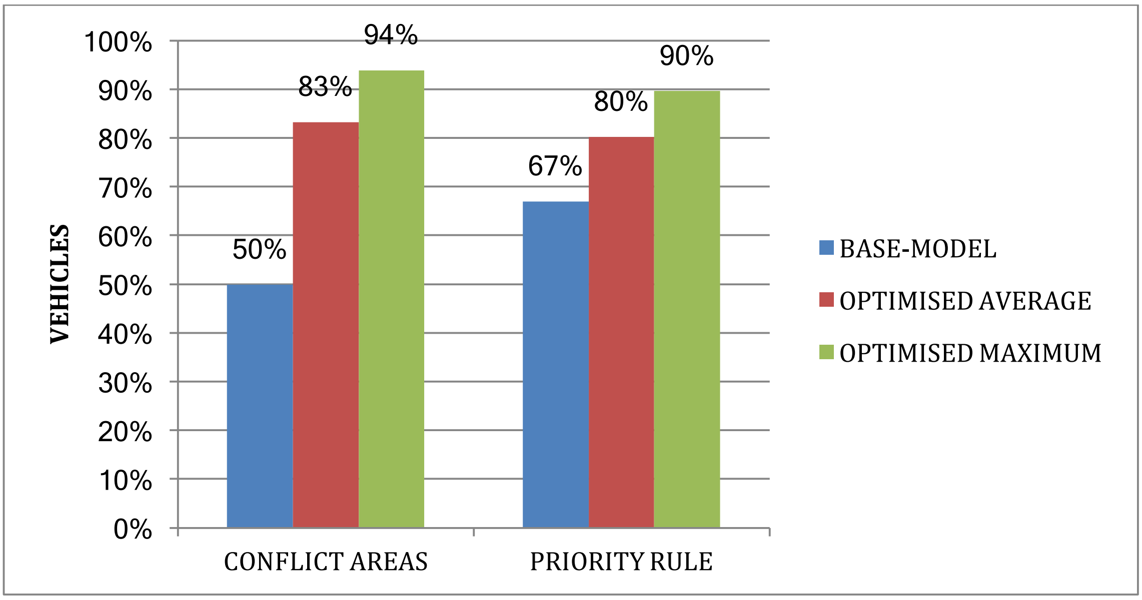
Graph 20. Average number of vehicles passing the crossing for the different parameters included in the sensitivity analysis, during one hour, using priority rule.

For priority rule, almost all parameters that were adjusted gave a positive result, except for using only one *stop line*. Changing the *min. headway* to 3.5 meter, thus, to the width of the road, gave the result most similar to the reality. As for conflict areas, none of the adjustments alone reached the reality.

Instead the parameters were combined in order to find a final optimised value. The parameter adjusted for both conflict areas and priority rule to reach this optimised value was presented in chapter 7.6.1, creating the optimised model.

8.3.3 Final optimised result

A final comparison between using conflict areas and priority rule was done, and can be seen in Graph 21. In the graph, the base-model was compared with the optimised model that is representing the best possible results. For the optimised model, both the average value and the maximum value from the 20 random simulation runs are presented.



Graph 21. Percentage of results compared with reality, from base-model and optimised-model for conflict areas; front and rear gap 0 sec, five pedestrian links with alternate priority and all walking parameters changed and desired speed 50 km/h and priority rule; six pedestrian link, all walking parameter changed, desired speed 50 km/h and min. headway 3.5 m. The graph shows the maximum and average result from the optimised model for each function with 20 random simulation runs.

Using conflict areas and the base-model from the case study gave a result of 49.9% compared to reality, meanwhile after the sensitivity analysis, when the optimised settings were found the result were as high as 93.9% of the reality. However, the results come from taking out the maximum values from all 20 simulation runs, and the average value of 83.3% was a more realistic value to use.

When using priority rule, the base-model gave a result of 67.0% compared to reality, meanwhile the best possible results were found to be 89.6% of the reality for the maximum value and 80.2% for the average value.

It can be said that using conflict areas gives a worse result than using priority rule, looking only at the base-model when no adjustments was done. However, with some small changes the results can increase drastically and almost reach the real values. With some adjustments, conflict areas can give just as good results as using priority rule and when comparing the average value for the optimised settings, using conflict areas gives a slightly better result than using priority rule.

Since the function conflict areas has more parameters included, it was easy to adjust relevant parameters to optimise the result. Therefore, the variation between the base-model and the optimised model was very large. Using priority rule was more complicate and had less parameter to adjust, which made it harder to optimise the result. The variation between the base-model and the optimised model was also smaller for priority rule than for conflict areas.

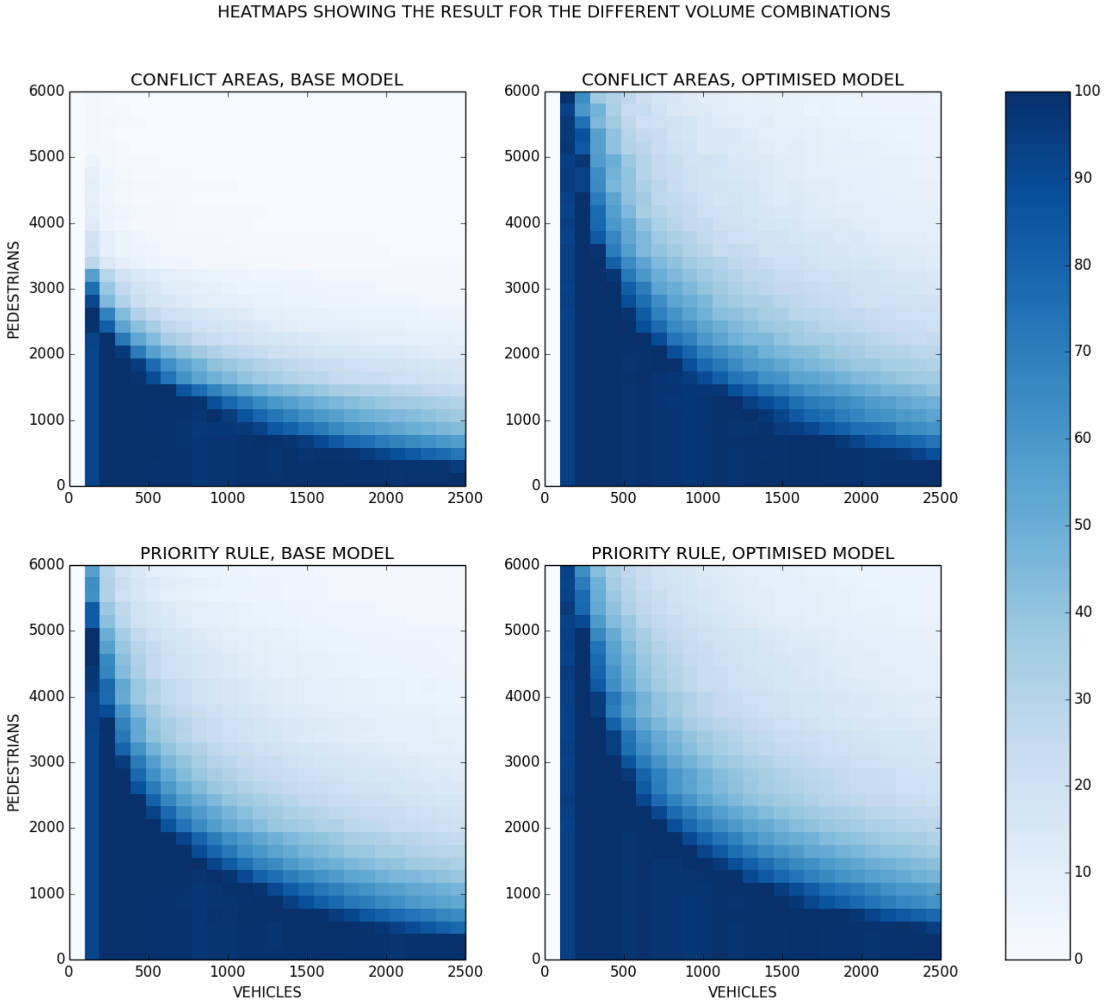
8.3.4 Correlation between pedestrian and vehicle volume and generalisation of the optimised result

From the heatmaps created for the base-model in chapter 7.5.1, the correlation between the pedestrian and vehicle volume could be investigated further. The same matrices were also created simulating the optimised model, in order to see if there were any differences between them.

To see when the best result was obtained, the matrices created were transformed, showing the share of vehicles passing the crossing of the total number of vehicles used as input in the model that is represented in the x-axis. Where the dark blue colour represents 100%, meaning that the number of vehicles fed into the model was also passing the pedestrian crossing.

The heatmaps for the base-model was compared with the heatmap for the optimised model in order to see how large the difference was, when adjustments on the relevant parameters were done, see Graph 22. The result of the optimised model shows that larger volumes of pedestrians can pass the crossing at especially the lower vehicle volumes.

Both graphs shows the same trend, when the pedestrian and/or vehicle volume were low it reached almost 100% for all vehicle inputs. The two functions had a resembling trend, nevertheless priority rule tends to work for a bit larger range looking at the lower vehicle volumes.

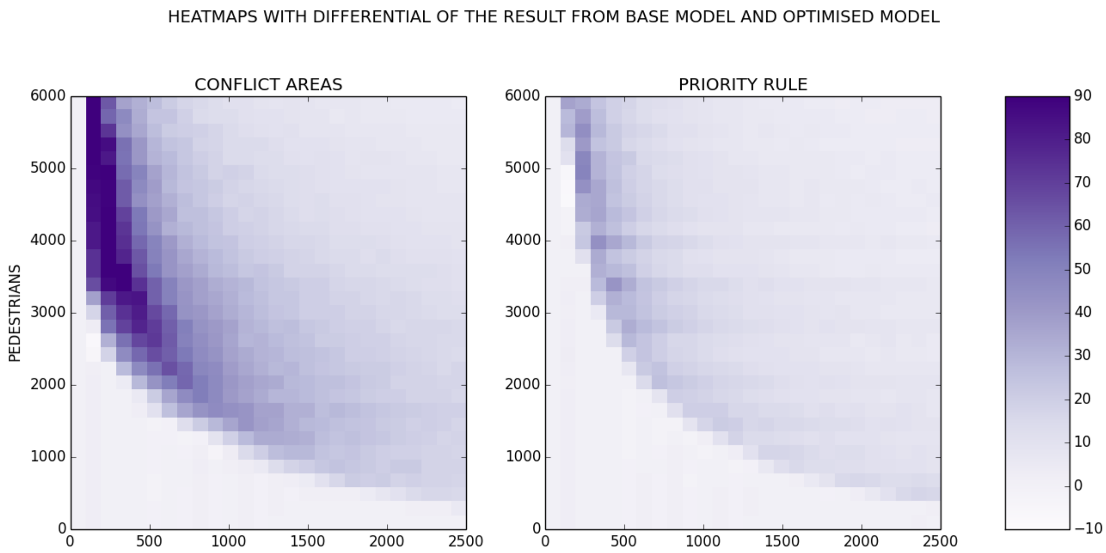


Graph 22. Heatmaps, showing the percentage of vehicles passing the crossing for different vehicle and pedestrian inputs for both conflict areas and priority rule, using the base-model and the optimised model.

Since every square in the heatmap illustrate a range of 200 pedestrians times 100 vehicles, the heatmap is not definite and therefore it can only be read graphically and not with equations. The border between the dark blue colour and the white colour are not so clear and to find the exact turning point for the investigated hour, when the model is working correctly a new vector have been created using COM interface to simulate the optimised model. The vehicle volume was kept constant at 1500 vehicles and the pedestrian volume was decreased at every simulation run, from the original volume used in the model before (1269 pedestrians) with 10 pedestrians each time.

To reach a result of 100%, meaning that all vehicles fed into the model also passes the crossing for the selected hour, the pedestrian volume was decreased with 14% using conflict areas and 23% using priority rule.

In order to illustrate the difference between the base-model and the optimised model for the functions, new heatmaps were created, see Graph 23. The dark purple represents where the largest difference was regarding using the optimised model instead of the base-model.



Graph 23. Illustrates the difference between the base-model and the optimised model for conflict areas and priority rule. The colours represent the percentage of the share of vehicles passing the crossing compared to the reality.

The graphs clearly show that there was a larger difference using the optimised model rather than the base-model when using conflict areas. The difference was also largest where the vehicle volume where low (between 0 – 1000) and the pedestrian volume high (between 1500 – 6000). For priority rule the difference between the base-mode and optimised model was rather low, which the heatmap describe well.

9. Applying the optimised solution

To see if the optimise solution can be applied generally, other study areas were also investigated.

9.1 Selected study areas

Other areas were selected with the requirements that the chosen location had to include a non-signalised pedestrian crossing, preferably without public transport and with a large number of pedestrians passing the crossing. The chosen study areas were:

- Study area 1: Södra Strandgatan - Jönköping
- Study area 2: Sprängkullsgatan - Göteborg
- Study area 3: Västra Sjöfarten - Göteborg
- Study area 4: Bergslagsgatan - Göteborg
- Study area 5: Östra Hamngatan - Göteborg

The locations had a varied range of pedestrian and vehicle volumes. The idea was to first simulate the study area with the settings applied in the base-model to see if the location was problematic and later also test the optimised solution in order to see if it makes any difference. Every model has a vehicle input of 1500 vehicles per hour (the same as for Korsvägen), so that the different study areas could be compared. The results from all study areas can be seen in Appendix IX, Table 20.

Study area 1 - Södra Strandgatan
The first location was a non-signalised pedestrian crossing at Södra Strandgatan in Jönköping. This location was chosen since Viscando already had done a video analysis over the selected crossing and therefore all data needed could easily be accessed. The street consists of two opposite lanes for vehicles and two opposite lanes for public transport, however the model will only look at the two lanes used by the vehicles and the pedestrian crossing. The study area can be seen in Figure 22, in Appendix IX. The model in Vissim was built to resemble the reality from the figure and the data used to build up the model can be seen in Table 14 in Appendix IX.

The simulation resulted in that all the vehicles could pass the crossing for both conflict areas and priority rule in the scenario with the settings from the base-model and the results were very similar when the optimised model were used. The result can be seen in Appendix IX and will be compared to the other locations in chapter 9.3.

Study area 2 - Sprängkullsgatan
The pedestrian crossing at Sprängkullsgatan was selected since it has a high number of pedestrians passing the crossing. The street consists of two opposite lanes and one bus lane in the middle. Since there were very few buses that passed the crossing every hour (about 20 buses per hour (Västtrafik, 2017)) the location was considered to work for the study.

The data needed was collected from statistics found at the City of Gothenburg Transportation Administration, see Table 16 in Appendix IX. The model in Vissim was built to resemble the Figure 23, in Appendix IX.

When the base-model was simulated, it resulted in a capacity of 85% of the reality using conflict areas and 130% using priority rule. When adjusting the parameters to the optimised ones, the result was increased and was above 100% for both conflict areas and priority rule. This can be seen in Appendix IX, in Graph 37 and Graph 38.

Study area 3 - Västra Sjöfarten
Another selected pedestrian crossing was one at Västra Sjöfarten in Gothenburg, the crossing is located close to a bus stop and therefore it was assumed to be a high number of pedestrians passing the crossing to and from work. The crossing is passing two narrower opposite vehicle lanes. Data have been collected through own investigations and the volumes was counted at the location, see Table 16 in Appendix IX. The model in Vissim was built to resemble the Figure 24, in Appendix IX.

The same as for Södra Standvägen the pedestrian volume was low and resulted in that all vehicles could pass the crossing during the simulation for all scenarios.

Study area 4 - Bergslagsgatan
The selected pedestrian crossing at Bergslagsgatan, close to the central station was chosen because it was assumed to have a high number of vehicles passing. The pedestrian crossing was located near a larger roundabout and therefore differs greatly from the crossing at Korsvägen. Data have been collected through own investigations and the volumes was counted at the location, see Table 17 in Appendix IX. The model in Vissim was built to resemble the Figure 25, in Appendix IX.

The simulation gave the same result as for Södra Strandvägen and Västra Sjöfarten that all vehicles could pass the crossing without difficulties when only using the base settings, this because of the low pedestrian input.

Study area 5 - Östra Hamngatan
The selected pedestrian crossing at Östra Hamngatan was chosen because of its central location and the assumption that there was a high number of pedestrians moving in the surrounding area, because of the shopping stores and offices in the area. The pedestrian crossing crosses a one lane road on each side of a two-lane bus and tram road in the middle. The vehicle lanes are a so called cycle-speed street, meaning that the vehicles must adapt their speed after the bicycles. In this study, only the vehicle lane towards Kungsportsplatsen was used. Data was collected through own investigations and the volumes can be seen in Table 18 in Appendix IX. The model in Vissim was built to resemble the Figure 26, in Appendix IX.

Using conflict areas and the base-model gave the results of 68% of the vehicles passing the pedestrian crossing. Priority rule gave the result of 125% for the base model. Both conflict areas and priority rule gave an increased result for the optimised model with 145% for conflict areas and 216% for priority rule.

9.2 Other hours from Korsvägen

To verify the concept created with the heatmaps, more volume combinations from different parts of the heatmaps was desired to investigate, especially some extreme points. It was difficult to find non-signalised pedestrian crossings with high volumes of both pedestrians and vehicles and therefore, some other hours, was used from the pedestrian crossing at Korsvägen. The used hours from the increased and the decreased pedestrian volume from chapter 7.5.1 were studied again and one more hour with a high vehicle volume was also chosen.

- Study area 6: Decreased pedestrian volume
- Study area 7: Increased pedestrian volume
- Study area 8: Increased vehicle volume

The results from study area 6: *the decreased pedestrian volume*, gave for both the base-model and the optimised solution the result that all vehicles fed into the model also could pass the pedestrian crossing. For study area 7: *the increased pedestrian volume*, using conflict areas, the capacity was increased from 1% of reality using the base-model to 9% of reality using the optimised solution. Priority rule increased the capacity from 12% to 26% for the optimised solution.

Study area 8: *the increased vehicle volume* had 719 pedestrians and 1521 vehicles and the result for conflict areas was 74% for using the base-model. By changing the settings to the optimised solution, the result gained was 97% of reality. Priority rule gave the result of 94% for base-model and come up to 98.2% for optimised model, see Table 19 in Appendix IX. The model was as for all other crossings simulated with 1500 vehicles as input and could therefore just come up to 98.6% of reality.

9.3 Comparison between the study areas

From chapter 9.1 eight study areas were simulated for both the base-model and the optimised solution. The results for four of these crossings reached the highest capacity when only the base-model (default settings) was used. The four study areas were; nr 1. *Södra Strandgatan*, nr 3. *Västra Sjöfarten*, nr 4. *Bergslagsgatan* and nr 6. *decreased pedestrian volume* at Korsvägen. In Graph 24, it can be seen that these four cases had a lower pedestrian volume and lay in the dark blue area, which means that 100% of the vehicles should manage to pass the crossing, which verify the theory from Korsvägen.

The other four study areas; nr 2. *Sprängkullsgatan*, nr 5. *Östra Hamngatan*, nr 7. *increased pedestrian volume* at Korsvägen and nr 8. *increased vehicle volume* at Korsvägen, had a higher pedestrian or vehicle volume. In Graph 24, looking at the base-model for conflict areas, all four cases are positioned near the border or outside the dark blue area. This was expected, since the results did not reach 100% of reality when simulating the base-model using conflict areas, see

Table 10. When looking at the optimised model in Graph 24, the study areas; nr 2. *Sprängkullsgatan*, nr 5. *Östra Hamngatan* and nr 8. *increased vehicle volume* has now been positioned in the dark blue area, since the results in Table 11 shows that all of them now reach 100%. The results for increased vehicle volume has a higher vehicle volume than what is fed into the model and can only reach 98.6%. However, the result for study area 7, *increased pedestrian volume* is still far from reaching 100%.

Table 10. Shows the four study areas that do not reach 100% when using the base-model, and results for optimised model.

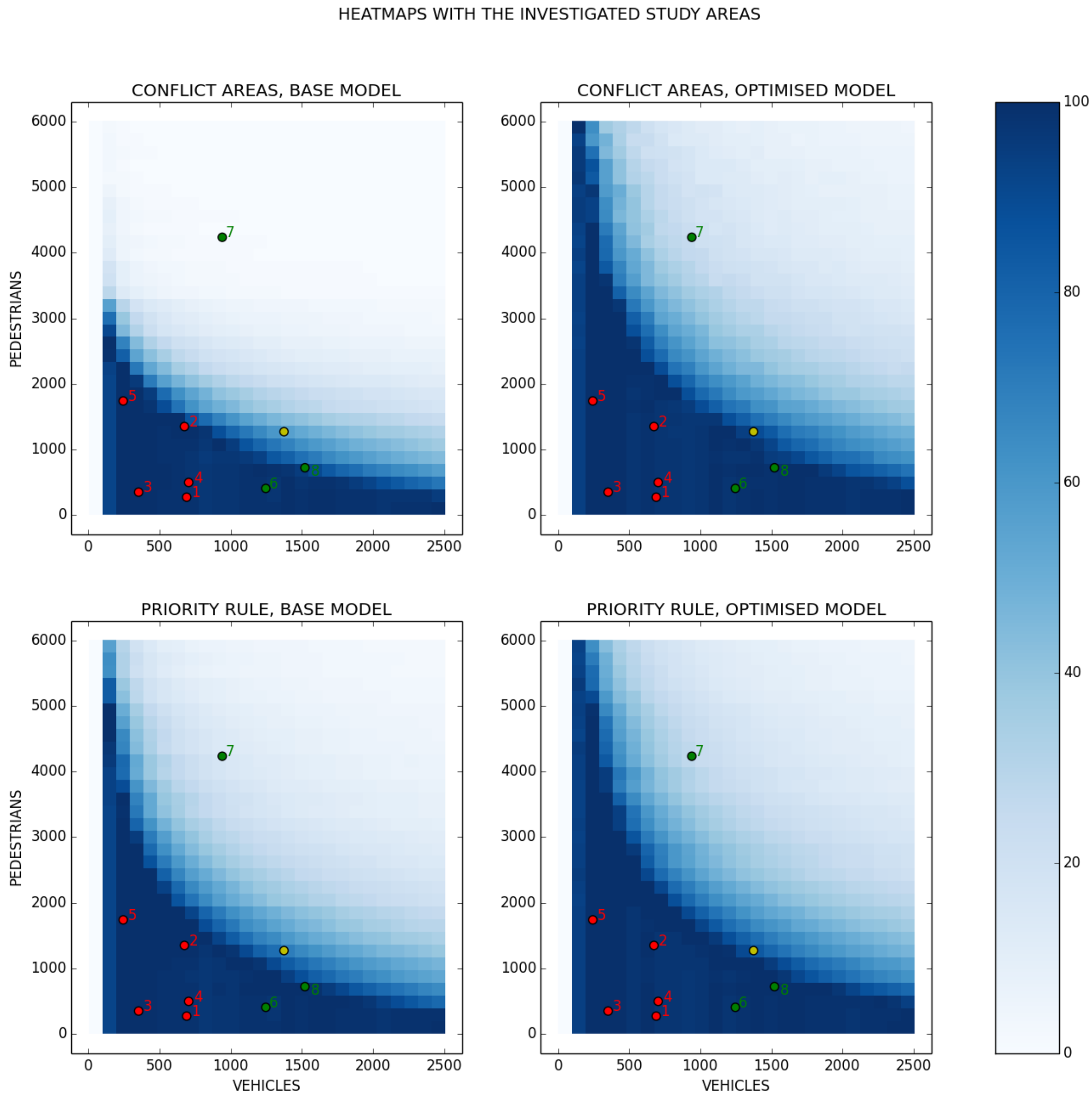
		Pedestrians	**Vehicles**	**Result conflict areas [%]**		**Result priority rule [%]**	
Nr	Roads			Base-model	Optimised model	Base-model	Optimised model
2	Sprängkullsgatan	1348	674	85	113	130	156
5	Östra Hamngatan	1738	100*	68	145	125	216
7	Increased pedestrian volume	4236	940	1	9	12	26
8	Increased vehicle volume	719	1521	74**	97.2**	94**	98.2**

*Östra Hamngatan is a cycle-speed street where bicycle cycle on the same lane as vehicles, therefore the volumes for vehicles (100) and bicycles (144) was combined and used as vehicle input.

** The result can only reach 98.6%, because the model is fed with 1500 vehicles and reality has 1521 vehicles.

Priority rule reached better results when the base-model was simulated than conflict areas did, this can be seen in Graph 24. This led to that only two study areas had a result below 100%, nr 7. *increased pedestrian volume* at Korsvägen and nr 8. *increased vehicle volume* at Korsvägen, see Table 11. After changing to the optimised solution, both crossings increased their result and study area 8 did almost reach the desired result (however since the model was fed with 1500 vehicles it could not reach 100%). The result for study area 7, *increased pedestrian volume* was still far from reaching 100%, see Graph 24.

Finally, the results from the studied crossings followed the results from Korsvägen where volumes combinations in the dark blue area gave 100% capacity and the volumes at the borders of outside the area gave a decreased capacity.



Graph 24. Illustrates the heatmap for the respective function using the base-model and the optimised model, where the five red dots are the volumes of the tested crossings from the previous chapter, the green dots the volumes of the other chosen hours from Korsvägen and the yellow dot represents the studied hour from the case study.

10. Discussion

Overall, when using the functions conflict areas or priority rule, the capacity for vehicles was underestimated with about 20%, when simulating a non-signalised pedestrian crossing at the travel hub Korsvägen in Gothenburg. However, if no adjustments were done using conflict areas, the capacity for vehicles can be underestimated with as much as 50%. This can have large effects on the planning of travel hubs or other spaces in the city where a large amount of pedestrians moves.

The result shows that priority rule gave a better result than conflict areas, when no adjustments were done. Thus, it must be considered that the base-model itself was not generalised and some assumptions and adjustments had already been made when it was built. It can therefore be difficult to compare the two functions. Using conflict areas was easy since it only needed to be activated. Assumptions that were made were for example the number of *pedestrian links* and the priority for pedestrians. Thus, for priority rule, choices and adjustments were done directly since *stop lines* and *conflict markers* had to be placed by hand. Adjustments as the number of *pedestrian links* and the parameter *min. headway* were changed together with the choice not to include the *min. gap time*. However, the base-models were built to be as similar as possible in order to make them comparable to each other and the reality. The priority was given to the pedestrians and five *pedestrian links* were used with the width two meters to build the pedestrian crossing for both models.

Even though using conflict areas gave a worse result when no further adjustments had been done, it gave on the other hand a better result after adjusting relevant parameters. Thus, there was a large range between the results, from using the base-model to the optimised model. The main reason for this was probably because the function itself includes many different parameters that easily can be changed and optimised for a better result. Meanwhile priority rule itself only includes one relevant adjustable parameter, *min. headway*, which already had been adjusted to a certain extent in the base-model, leading to a smaller range of results.

However, the investigated pedestrian crossing is unique and the results are specific to this case study, even though attempts were made to generalise it. Thus, to a larger pedestrian crossing that passes two unidirectional vehicle lanes. The pedestrian crossing was also taken from its content and could give other results with more input from the surroundings, for example the stop light for the vehicles further downstream and to include the buses and trams in the model.

10.1 Which parameters have had the largest impact and which ones have not affected the result at all?

Using conflict areas, the parameters with the largest positive effect on the result were to alternate the priority. This had the effect that the pedestrians stopped at the conflicts where the vehicles had priority, creating more opportunities for the vehicles to pass the pedestrian crossing. This made it closer to a weaving pattern between the vehicles and pedestrians, resulting in that it visually resembles reality better.

Another adjustment that had a large positive effect was to change *front gap* and *rear gap* in the conflict areas settings to zero seconds. This affected how close the vehicles drove to each other, both before and after a conflict zone. Decreasing the value to zero seconds, resulted in reduced time gap between the vehicles, which was also observed during the simulation. This was an easy change that did not visually make any errors in the simulation, and would therefore be recommended to change for other crossings, if the vehicles should drive more closely.

Using priority rule, the parameters with the largest positive effect on the result was to change the *min. headway* to 3.5 meter, thus, to the exact width of one vehicle lane. This adjustment makes the conflict zone smaller and creates more gaps where the vehicles are allowed to pass the pedestrian crossing. The use of six *pedestrian links* made a small improvement of the result.

Increasing the *desired speed* to 50 km/h, adjusting the selected pedestrian parameters (*VD*, *lambda* and *react to n*) and changing *avoid blocking minor* and *avoid blocking major* had a small positive effect on the result when using both conflict areas and priority rule. However, they were all negligible compared to the adjustments mentioned above. The function of *avoid blocking major* was added to the latest version of Vissim, Vissim 9, and was implemented to easier be able to mimic the pedestrian and vehicle behaviour at a shared space environment. The parameter gave some improvement on the result, however, using alternate priority was a better option.

To mimic the simplest way of implementing priority rule, using only *one stop line* per vehicle lane for the whole crossing was also tested, thus the result was much worse than the base-model. This was also one factor that was chosen when building the base-model, to use one *stop line* per vehicle lane and *pedestrian link*. This makes it possible for the vehicles to pass one or more pedestrian links at a time. They do not need to wait until the entire crosswalk is completely empty.

The result from using one *stop line* per vehicle lane might change if other adjustment is tested and combined with the usage of one *stop line*. This is something that has not been tested since it was assumed that it would not make any larger differences on the result. Something that has been quickly tested was implementing even more *stop lines* and conflict markers per vehicle lane and per *pedestrian link*, this however required more accuracy and patient, and could potentially give a better result, especially in the cases with fewer *pedestrian links* used for the crossing. Due to this reports timeframe, it was decided not to conduct a comprehensive analysis in this report.

In the manual PTV said that it requires some knowledge of the function priority rule, in order to make it work properly. Therefore, the conflict markers were adjusted to see if there was any difference in the result. However, it was concluded that if the markers were placed correctly, small changes do not affect the result. The main problem was when it did not work correctly, which led to that people accidentally was run over by the vehicles. This is one of the biggest weaknesses of using priority rule and it requires some experience and knowledge to place the markers correctly. Using priority rule can therefore be more time consuming to use rather than conflict areas, however using priority rule have other benefits, such as it is much more flexible since the required number of markers can be used and they can be placed anywhere desired.

Regarding the adjustments of the *desired speed*, a validation of the model was made comparing the average speed between the simulated vehicles and the measured real values. It concluded that when using conflict areas, the simulated vehicles speed was higher than when using priority rule. However, both were higher than the real values. Instead they were both more similar to the measured real value for the 85-percentile. The speed in the model was mostly dependent on the acceleration, since almost all vehicles in the model were queuing to the pedestrian crossing, and when a gap between the passing pedestrian arises, the vehicles accelerates away and passes the crossing. Adjusting the acceleration has been considered to be to complex and has therefore not been included in this report. Thus, it will most likely affect the results.

In reality the crossing has a small built-up in the street, to symbolise an obstacle and to make the vehicles drive slower. This can be one reason why the measured vehicles speed was lower than the simulated vehicles. The built-up resulted in a lower velocity and to imitate this in the model, a reduced speed area could be placed just before the crossing. Leading to a reduced vehicle speed in the simulation. However, this was tried, resulting in inferior results and was therefore neglected.

10.2 Was the behaviour realistic in the interaction between the pedestrians and vehicles?

Something that was considered to be difficult was trying to imitate the reality at the same time as optimising the model, in order to reach the desired result. The aim of obtaining real speed behaviour for the simulated vehicles, while pushing the model to get a drastically increased result was one example on when it became tricky and priorities had to be made. Since the first results indicated that the capacity was greatly underestimated, the main focus was firstly to try to reach the desired real measured results, however it was still important that the vehicles and pedestrians acted in a realistic way during the simulation. For example, it was important that pedestrians were not run over by the vehicles when passing the pedestrian crossing.

Regarding the parameter *desired speed*, to obtain result similar to the reality, we wanted the vehicles to accelerate as fast as possible so that the vehicles had time to drive over the crossing in between the gaps of the pedestrians. To try making the vehicles accelerate faster, without adjusting the desired acceleration, the *desired speed* 70 km/h was tested as well, even though it would not be realistic to have such high velocity at the specific location, where the speed limit is 50km/h. Since most of our focus was on finding ways of increasing the capacity, optimising the model in regards to the behaviour in the interaction became secondary.

However, when visually looking at the simulation, it was noticed that pedestrians occasionally was run over by the vehicles. This was clearly noticeable, when the model was running in 3D, which could be a problem when one of the aims with the software is to visualise the model. Thus, this was only occurring occasionally and it was assumed not to affect the result too much.

10.3 Assumptions and limitations that could have affected the results

Some of the assumptions and limitations done could have affected the result. One that could was the share of pedestrians walking in groups. According to own investigations the share was calculated to be 60% at this specific crossing and it is the number used in the model. However, since the share affects how large the volume of pedestrians is, it can also affect how much the pedestrians will disturb the vehicles and therefore also the result. This can be connected to the investigation of how the volume of pedestrians affects the result. When the pedestrian volume is increased, the gap between the pedestrians becomes very small, making it impossible for the vehicles to pass the pedestrian crossing. This means that if the share of pedestrians walking in groups would change, it will likely change the result. However, the share of 60% is very high, so if it would change, the share would in that case be lower, leading to a higher volume of pedestrians in the model and a worse result. An assumption made was also that all the pedestrian walking in group are pairs, which not need to be true, a group could also be bigger and therefore take up less space. This is however harder to simulate in Vissim, since there are no 3D figures of such groups.

The input data used for the model was collected from the report *Rörelsemönster och trafikflöden vid korsvägen, Göteborg* (Viscando, 2017a). The data chosen was from one of the recorded hours in order to be able to compare the results from the simulations with reality. This could make the data unreliable, since it was not an average of several hours. However, the used hour was chosen carefully and represents an hour with data that was assumed to be reliable. One limitation in the data from the video analysis was that it had a weakness in the tracking of the vehicles, where 1.3% from the three days seem to drive in the opposite direction even though the road was one-directional. This has a small influence on the volume and was neglected.

A limitation that was made was not to optimise the bicycles in the model. They were included in the model so that the model was representing the reality, however, the bicycles were all on default settings. This may affect the result, however since the cyclists and vehicles are following the same behaviour model and are both link-based, they were assumed to be able to handle the interaction at the crossing. Thus, the same problem with the interaction occurs at spaces where there is a conflict between cyclists and pedestrians, this was assumed not to affect the result since it was not happening close by the actual crossing. Another reason to why we did not adjust the settings for cyclists was because the numbers of cyclists passing the crossing at the selected hour were too few. If the numbers of cyclists had been higher it would have been a good idea to include it in the sensitivity analysis.

One thing that could be seen from the video analysis was that pedestrians also walked on the bicycle lane, thus the pedestrians utilized a wider area than the crossing. With a wider pedestrian crossing, the time for the pedestrian to pass the crossing could take less time and more vehicles could manage to drive by. However, this was hard to simulate since the area-based pedestrians cannot use the link-based bicycles lane.

Regarding to find the optimised value for each parameter, we have only looked at the parameter alone and not in combination with other parameters. It was noticed that the result sometimes differed when parameters were combined, as if they were affecting each other. Combinations could also have been investigated thoroughly with the help of COM, to find an even better result. This was though neglected because the changes only seemed to be a few vehicles more or less. This changes could equally well depend on other things for example, number of trucks in the model or number of pedestrians run over by the cars etc.

To validate the model and the results, the beginning of all simulations done were observed, however far from every simulation second were watched. This could have resulted in small errors in the model without any knowledge and therefore changed the results. Especially when looking at *alternating priority* this could be a problem, where we saw some errors depending on where the priority for vehicles was implemented.

The volumes used for pedestrian and bicycles in the case study were taken from the report, *Rörelsemönster och trafikflöden vid korsvägen, Göteborg* (Viscando, 2017a). However, the volume for the vehicles was set to 1500 vehicles per hour. This number was chosen since having a saturated system was desired and the value 1500 was slightly higher than the reality. For example, therefore the result for case study 6*: the decreased volume* of pedestrians gave a higher result than reality.

When the matrices were created, the simulations done for each volume setting was only simulated for one random simulation run, instead of simulating 20 random runs for each value, which was done in the sensitivity analysis for most of the parameters. This was because of the simple reason that it would have required unreasonable long simulations. This can however give an uncertainty to the result.

10.4 Applying the optimised solution

The result regarding the heatmaps, see chapter 8.3.4, shows the volume combinations for when the model is working correctly. This was when the result matches the numbers of vehicles that were being fed into the model. Comparing the base-model with the optimised solution, it clearly shows that more volume combinations can be used when the optimised solution was applied. This occurs both for conflict areas and for priority rule. However, the largest difference between the models occurs when conflict areas was used. This agrees with the previously results, saying that there was a larger range in the result between the base-model and the optimised model, using conflict areas.

These heatmaps was also used to see if the optimised solution can be used more general, or if it only applies for our specific pedestrian crossing at Korsvägen, this by using other study areas and simulating them in the same way. Finding the extreme points of the volume combinations was found to be relevant, since it was at those points the model stops working correctly.

Thus, finding the extreme points of the heatmap at relevant locations in Gothenburg was found to be difficult. This is probably because pedestrian crossings with requirements such as having high pedestrian or vehicle volumes often are signalised. This is illustrated in the heatmaps in chapter 9, where the dots, representing the different study areas, have been placed closely together, indicating that the locations volumes are relatively similar to each other.

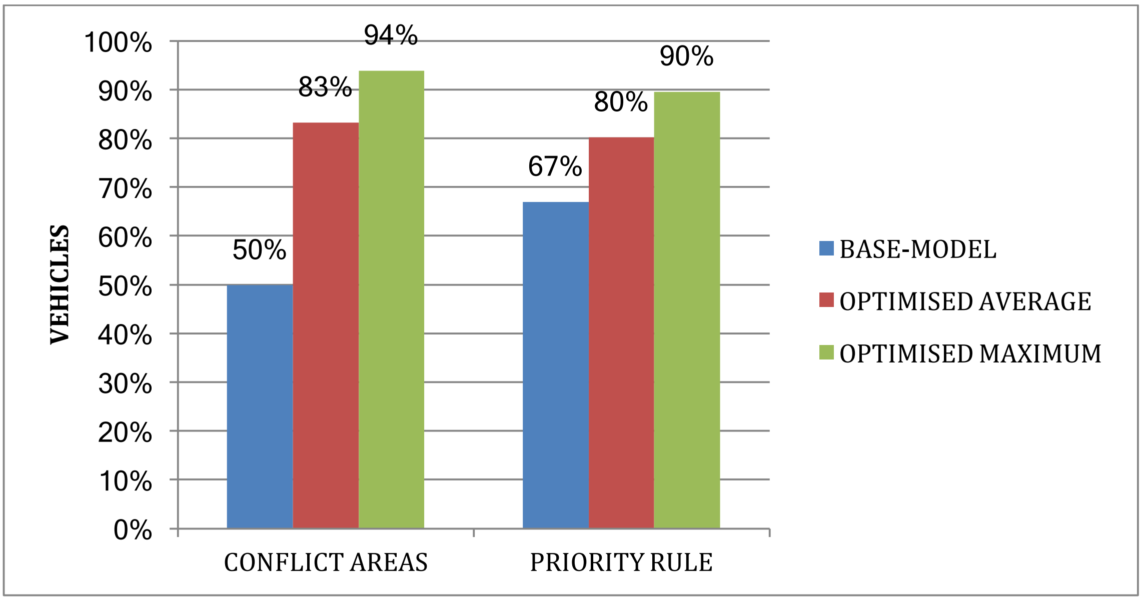
The result showed that many of the chosen study areas worked by only using the base-model, since the flows where relatively low. On the study areas that were closer to the border, using the base-model did not always work. However, when the optimised solution was applied they all worked, except from the extreme point where the pedestrian volume was increased to 4236 pedestrians (in both directions).

Setting the vehicle volume with steps of 100 vehicles and the pedestrian volume with step of 200 created the heatmaps. Each square in the heatmap therefore represents a large range of values (100 vehicles x 200 pedestrians), this makes the values regarding the volumes close to the border uncertain and cannot be used as exact values, but more roughly.

To summarize, the points close to the border could be problematic to simulate and even though the optimised solution increased the volume combination that could be used, there are still many combinations that do not give a realistic result. Thus, it should be said that the combinations with a large pedestrian and vehicle flow probably are impossible to reach 100%, and it should be considered that all of the volume combinations have not been validated to work and problems could occur in the reality when the volumes are extremely high.

11. Conclusion and recommendations

It can be concluded that simulating the specific selected pedestrian crossing at Korsvägen proved to be challenging and the result shows an underestimation regarding the vehicles capacity, see Graph 25. It can also be concluded that after adjusting the model, there was no large difference in the usage of conflict areas or priority rule. Priority rule requires knowledge and time to make the function work correctly, meanwhile conflict areas are easier to use, thus, the parameters included in the function needs to be modified for every simulated scenario.



Graph 25. Shows the result, number of vehicles passing the pedestrian crossing, in percentage compared to reality from simulating the base-model and the optimised model.

The results from the graph above show the difference between using conflict areas and priority rule. The optimised result using conflict areas was found when:

- Using five *pedestrian links* with *alternating priority*
- Changing *front gap* and *rear gap* to zero seconds
- Changing all three *pedestrian behaviour parameters* (VD = 40, lambda = 1, react to n = 1)
- Changing the *vehicles desired* speed to 50 km/h

However, the parameters with the largest effect on the result were the use of five *pedestrian links* with *alternate priority* and adjusting *front gap* and *rear gap* to zero. The optimised result using priority rule was found when:

- Using six *pedestrian links*
- Using *min. headway* 3.5 meter
- Changing all three *pedestrian behaviour parameters* (VD = 40, lambda = 1, react to n = 1)
- Changing the *vehicles desired* speed to 50 km/h

The parameter with the greatest effect on the result was changing the *min. headway* to 3.5 meter and using six *pedestrian links*.

The optimised solution was also tested on other study areas similar to the case study. The solution turned out to be working for them as well and gave good results.

When simulating a non-signalised pedestrian crossing our recommendation is to use the heatmaps presented in the report to check if the volume combinations of vehicles and pedestrians are within the dark blue area. If they are not, the result should be taken carefully into consideration. The heatmap for the base-model could be used firstly, and if the combinations are not within the dark blue area the heatmap for the optimised solution could be used. However, it requires that the settings are adjusted according to the recommendations.

The recommendations are:

- Using more than one *pedestrian link* to create the pedestrian crossing
- If possible, use *alternate priority* (conflict areas)
- Adjusting *front gap* and *rear gap* (conflict areas)
- Using more *stop lines* and *conflict markers* (priority rule)
- Adjust the *min. headway* to the width of the vehicle lane (priority rule)

12. Further studies

There are many areas that have come up during this study that may require further work, for example the methods found in the literature study, where solutions to the problem in question are presented could be further studied. However, since they were too complex and time consuming, they could not be tested in this report. The method presented by (Gibb, 2015), was tried, since we considered the COM Interface to be a useful tool. However even though Gibb presented the script used to replace the vehicles with pedestrians in his report, the grid that was required to be build was considered to be too complex for this study.

One parameter that was excluded from this study was the acceleration. Since it is concluded in the report that it was very hard to reach the real capacity when simulating models with a high number of pedestrians, an attempt could be to investigate if the acceleration of the vehicles will make any difference.

Giving priority in a conflict zone can also be studied more. In Sweden pedestrians always has priority at a non-signalised pedestrian crossing, which this study proceeded from. This may not be the case in other countries. In this study, it was concluded that when using conflict areas, giving alternate priority gave an increased result. This can be studied further but also what happens if the vehicles are given priority. When using conflict areas at a pedestrian crossing and priority is given to the vehicles, the vehicles will stop when a sufficient large number of pedestrians have gathered in front of the crossing. Leading to that the pedestrians get priority and can pass the crossing.

The result in this study only took the vehicles capacity into consideration. However, the pedestrians capacity could also be studied, one way could be to study the pedestrian travel time between the two pedestrian areas further.

13. References

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Appendix I – Investigations

Table 11. Shows the number of pedestrians passing the crossing divided in single and grouped, and the result of the share of the pedestrians walking in group.

	Single pedestrian	**Grouped pedestrians**	**Share of pedestrians walking in group**
3:30-4:00 PM 2017-02-15	64	100	60%
8:00-8:30 PM 2017-02-24	88	26	30%

Appendix II - Results case study

* TIMEINT: TimeInt, Time interval
* V(ALL): Vehs(All), Vehicles (All) (Count of vehicles of the data collection measurement in the interval)
* S(ALL): SpeedAvgArith(All), Speed (arithmetic average) (All) (Arithmetic mean of the speed of all vehicles of this data collection measurement for this interval) [km/h]

		CONFLICT AREAS		**PRIORITY RULE**	
EVALUATION	*TIMEINT*	*V(ALL)*	*S(ALL)*	*V(ALL)*	*S(ALL)*
AVG	1800-2700	155	14,8	215	12,15
AVG	2700-3600	177	15,12	228	12,54
AVG	3600-4500	182	15,57	242	13,48
AVG	4500-5400	171	15,28	235	13,25
STDDEV	1800-2700	19	0,93	19	0,83
STDDEV	2700-3600	17	0,92	16	0,94
STDDEV	3600-4500	16	0,92	15	0,8
STDDEV	4500-5400	19	1,04	19	1,27
MIN	1800-2700	114	12,81	177	10,47
MIN	2700-3600	142	13,98	202	10,78
MIN	3600-4500	152	13,42	220	12,08
MIN	4500-5400	133	13,29	205	11,44
MAX	1800-2700	182	16,02	242	13,54
MAX	2700-3600	219	16,72	263	14,46
MAX	3600-4500	209	17,1	278	14,88
MAX	4500-5400	216	16,94	278	15,9

Appendix III - Results sensitivity analysis

CONFLICT AREAS

* TIMEINT: TimeInt, Time interval

* V(ALL): Vehs(All), Vehicles (All) (Count of vehicles of the data collection measurement in the interval)

* S(ALL): SpeedAvgArith(All), Speed (arithmetic average) (All) (Arithmetic mean of the speed of all vehicles of this data collection measurement for this interval) [km/h]

NUMBER OF PEDESTRIAN LINKS USED TO CREATE THE PEDESTRIAN CROSSING

		ONE PEDESTRIAN LINK		**TREE PEDESTRIAN LINKS**		**SIX PEDESTRIAN LINKS**	
EVALUATION	*TIMEINT*	*V(ALL)*	*S(ALL)*	*V(ALL)*	*S(ALL)*	*V(ALL)*	*S(ALL)*
AVG	1800-2700	113	13,69	134	14,5	164	14,89
AVG	2700-3600	126	14,28	155	14,91	187	15,29
AVG	3600-4500	142	14,78	162	15,36	190	15,76
AVG	4500-5400	133	14,58	155	15,11	182	15,45
STDDEV	1800-2700	15	1,19	16	1	20	0,97
STDDEV	2700-3600	16	1,35	16	1,15	20	0,85
STDDEV	3600-4500	15	1,13	14	0,87	15	0,89
STDDEV	4500-5400	19	1,37	18	1,08	19	1,12
MIN	1800-2700	83	10,67	96	12,34	121	12,44
MIN	2700-3600	101	12,52	123	13,14	148	13,93
MIN	3600-4500	114	11,92	139	13,34	156	13,64
MIN	4500-5400	102	12,67	122	13,65	145	13,96
MAX	1800-2700	135	16,06	155	15,85	196	16,39
MAX	2700-3600	164	17,61	190	17,39	233	17,04
MAX	3600-4500	167	16,44	191	16,97	220	17,36
MAX	4500-5400	182	17,52	192	16,93	225	17,54

		SEVEN PEDESTRIAN LINKS		**NINE PEDESTRIAN LINKS**	
EVALUATION	*TIMEINT*	*V(ALL)*	*S(ALL)*	*V(ALL)*	*S(ALL)*
AVG	1800-2700	166	14,9	158	14,73
AVG	2700-3600	188	15,39	180	15,4
AVG	3600-4500	194	15,84	185	15,64
AVG	4500-5400	184	15,46	177	15,59
STDDEV	1800-2700	18	0,83	18	0,87
STDDEV	2700-3600	18	0,89	18	1,07
STDDEV	3600-4500	15	0,77	17	1,01
STDDEV	4500-5400	20	1,02	19	1,04
MIN	1800-2700	123	13,19	119	12,64
MIN	2700-3600	151	14,26	144	13,82
MIN	3600-4500	167	14,05	151	13,21
MIN	4500-5400	152	14,14	143	14,17
MAX	1800-2700	192	16,66	180	15,9
MAX	2700-3600	227	17,28	219	17,38
MAX	3600-4500	226	17,21	226	17,08
MAX	4500-5400	237	17,06	224	17,46

ALTERNATE PRIORITY FOR PEDESTRIAN LINKS

		ALTERNATE PRIORITY, BASE-MODEL		**ALTERNATE PRIORITY, THREE LINKS**		**ALTERNATE PRIORITY, SIX LINKS**	
EVALUATION	*TIMEINT*	*V(ALL)*	*S(ALL)*	*V(ALL)*	*S(ALL)*	*V(ALL)*	*S(ALL)*
AVG	1800-2700	218	15,05	172	14,75	215	14,37
AVG	2700-3600	247	15,73	197	14,83	242	15,05
AVG	3600-4500	242	16,06	201	15,74	238	15,67
AVG	4500-5400	229	15,4	188	15,32	229	15,02
STDDEV	1800-2700	15	0,83	14	0,78	15	0,78
STDDEV	2700-3600	16	0,97	18	1,11	18	0,88
STDDEV	3600-4500	16	0,92	14	1,02	17	0,85
STDDEV	4500-5400	22	1,02	23	1,21	19	1,05
MIN	1800-2700	184	13,51	137	13,32	180	13,07
MIN	2700-3600	212	14,34	166	13,44	195	13,22
MIN	3600-4500	211	13,99	173	13,82	210	14,27
MIN	4500-5400	197	13,94	147	13,08	192	12,48
MAX	1800-2700	243	16,37	198	16,15	235	16,12
MAX	2700-3600	271	17,24	231	17,21	276	16,41
MAX	3600-4500	269	18,93	230	17,45	270	17,5
MAX	4500-5400	271	18,07	239	18,19	274	16,3

		ALTERNATE PRIORITY, SEVEN LINKS		**AVOID BLOCKING 30 %**	
EVALUATION	*TIMEINT*	*V(ALL)*	*S(ALL)*	*V(ALL)*	*S(ALL)*
AVG	1800-2700	200	13,03	155	14,83
AVG	2700-3600	223	13,59	178	15,15
AVG	3600-4500	223	14,27	182	15,59
AVG	4500-5400	219	14,21	172	15,28
STDDEV	1800-2700	15	0,81	19	0,9
STDDEV	2700-3600	14	0,78	17	1
STDDEV	3600-4500	14	0,89	17	0,9
STDDEV	4500-5400	21	1,21	20	1,12
MIN	1800-2700	169	11,18	114	12,81
MIN	2700-3600	197	11,64	142	13,98
MIN	3600-4500	205	12,75	152	13,42
MIN	4500-5400	181	12,6	143	13,38
MAX	1800-2700	220	14,44	186	16,02
MAX	2700-3600	248	14,88	219	17,38
MAX	3600-4500	250	15,99	209	16,87
MAX	4500-5400	263	16,24	223	17,25

AVOID BLOCKING *COM RESULTS*

VALUES	*BASE-MODEL*	*ALTERNATE PRIORITY*
0	684	942
5	684	942
10	684	942
15	684	942
20	684	941
25	686	943
30	686	945
35	686	945
40	686	944
45	686	943
50	686	943
55	686	943
60	684	942
65	684	942
70	683	941
75	683	941
80	683	941
85	683	941
90	682	941
95	682	940
100	682	940

FRONT GAP AND REAR GAP

		FRONT GAP 0 S		REAR GAP 0 S		FRONT GAP 0 S AND REAR GAP 0 S	
EVALUATION	*TIMEINT*	*V(ALL)*	*S(ALL)*	*V(ALL)*	*S(ALL)*	*V(ALL)*	*S(ALL)*
AVG	1800-2700	189	15,52	168	14,81	205	15,42
AVG	2700-3600	210	15,78	191	15,28	225	16,05
AVG	3600-4500	213	16,21	197	15,54	232	16,33
AVG	4500-5400	206	16,04	185	15,31	223	16,12
STDDEV	1800-2700	21	0,85	19	0,89	20	0,83
STDDEV	2700-3600	19	0,78	17	0,79	18	0,76
STDDEV	3600-4500	17	0,85	15	0,73	18	0,91
STDDEV	4500-5400	21	0,91	18	0,99	23	0,87
MIN	1800-2700	142	13,88	129	12,8	160	13,73
MIN	2700-3600	179	14,48	160	14,24	197	14,85
MIN	3600-4500	187	14,07	166	13,84	207	14,41
MIN	4500-5400	166	14,75	149	13,93	183	14,75
MAX	1800-2700	219	17,03	195	16,34	238	16,71
MAX	2700-3600	255	17,53	236	17,04	265	17,78
MAX	3600-4500	256	17,66	233	16,65	279	17,71
MAX	4500-5400	254	17,76	229	17,01	270	17,75

COM RESULTS

	FRONT GAP		REAR GAP	
VALUES	*BASE-MODEL*	*ALTERNATE PRIORITY*	*BASE-MODEL*	*ALTERNATE PRIORITY*
0	819	1029	738	991
0,1	792	1009	726	973
0,2	762	1004	713	965
0,3	736	979	703	964
0,4	706	953	695	946
0,5	682	940	682	940
0,6	659	923	672	936
0,7	638	912	666	919
0,8	621	896	655	912
0,9	604	892	649	912
1	587	880	639	895

COMBINATIONS

		FIVE LINKS, ALTERNATE PRIOIRTY, FRONT AND REAR GAP 0 S		**FIVE LINKS, ALTERNATE PRIOIRTY, FRONT AND REAR GAP 0 S, AVOID BLOCKING 30 %**		**SEVEN LINKS, FRONT AND REAR GAP 0 S**	
EVALUATION	*TIMEINT*	*V(ALL)*	*S(ALL)*	*V(ALL)*	*S(ALL)*	*V(ALL)*	*S(ALL)*
AVG	1800-2700	254	15,68	253	15,51	219	15,69
AVG	2700-3600	286	16,56	280	16,35	239	16,25
AVG	3600-4500	277	16,99	277	16,74	248	16,71
AVG	4500-5400	271	16,47	268	16,3	240	16,45
STDDEV	1800-2700	18	0,78	18	0,69	21	0,84
STDDEV	2700-3600	17	0,84	18	0,8	20	0,85
STDDEV	3600-4500	18	0,85	13	0,85	18	0,94
STDDEV	4500-5400	24	0,87	23	0,93	22	0,97
MIN	1800-2700	223	14,43	216	14,63	172	13,74
MIN	2700-3600	252	14,86	243	14,86	207	15
MIN	3600-4500	247	15,1	251	14,68	214	14,47
MIN	4500-5400	236	14,59	237	14,32	207	14,67
MAX	1800-2700	287	17,37	285	16,83	249	16,92
MAX	2700-3600	310	17,97	306	17,57	272	17,51
MAX	3600-4500	316	18,8	305	18,52	288	18,04
MAX	4500-5400	319	17,96	329	17,79	282	17,95

PRIORITY RULE

* TIMEINT: TimeInt, Time interval

* V(ALL): Vehs(All), Vehicles (All) (Count of vehicles of the data collection measurement in the interval)

* S(ALL): SpeedAvgArith(All), Speed (arithmetic average) (All) (Arithmetic mean of the speed of all vehicles of this data collection measurement for this interval) [km/h]

CHANGING NUMBER OF PEDESTRIAN LINKS

		ONE PEDESTRIAN LINK		**TREE PEDESTRIAN LINKS**		**SIX PEDESTRIAN LINKS**	
EVALUATION	*TIMEINT*	*V(ALL)*	*S(ALL)*	*V(ALL)*	*S(ALL)*	*V(ALL)*	*S(ALL)*
AVG	1800-2700	188	12,42	208	12,42	218	11,98
AVG	2700-3600	202	13,02	219	12,65	229	12,58
AVG	3600-4500	217	13,85	236	13,63	245	13,54
AVG	4500-5400	210	13,32	228	13,4	237	13,27
STDDEV	1800-2700	19	1,06	19	0,87	19	0,74
STDDEV	2700-3600	17	0,9	17	0,87	15	1,02
STDDEV	3600-4500	17	1,04	16	0,84	17	0,83
STDDEV	4500-5400	21	1,38	19	1,18	19	1,18
MIN	1800-2700	150	10,25	166	10,72	181	10,31
MIN	2700-3600	173	11,71	189	11,37	204	10,79
MIN	3600-4500	188	11,72	212	12,16	220	12,01
MIN	4500-5400	167	10,96	194	11,75	199	11,17
MAX	1800-2700	215	14,3	234	13,94	249	13,38
MAX	2700-3600	247	14,63	252	14,36	261	14,66
MAX	3600-4500	263	15,36	273	14,85	284	14,93
MAX	4500-5400	252	15,66	266	16,02	276	15,19

		SEVEN PEDESTRIAN LINKS	
EVALUATION	*TIMEINT*	*V(ALL)*	*S(ALL)*
AVG	1800-2700	212	11,99
AVG	2700-3600	225	12,51
AVG	3600-4500	239	13,44
AVG	4500-5400	229	12,99
STDDEV	1800-2700	18	0,9
STDDEV	2700-3600	15	1,01
STDDEV	3600-4500	16	0,75
STDDEV	4500-5400	19	1,29
MIN	1800-2700	167	10,35
MIN	2700-3600	205	10,77
MIN	3600-4500	214	11,82
MIN	4500-5400	189	10,75
MAX	1800-2700	237	13,29
MAX	2700-3600	263	14,78
MAX	3600-4500	275	14,38
MAX	4500-5400	270	15,29

HEADWAY

		HEADWAY 3.5 M AND 3.5 M		**HEADWAY 4 M AND 7 M**		**HEADWAY 7 M AND 7 M**	
EVALUATION	*TIMEINT*	*V(ALL)*	*S(ALL)*	*V(ALL)*	*S(ALL)*	*V(ALL)*	*S(ALL)*
AVG	1800-2700	247	12,81	144	11,04	94	9,26
AVG	2700-3600	262	13,17	159	11,52	101	9,78
AVG	3600-4500	276	14,19	166	12,42	111	10,75
AVG	4500-5400	267	13,8	159	12	105	10,27
STDDEV	1800-2700	19	0,85	15	1,17	12	1,25
STDDEV	2700-3600	16	0,71	14	1,18	13	1,8
STDDEV	3600-4500	15	0,68	12	1,07	12	1,66
STDDEV	4500-5400	18	1,05	19	1,41	19	2,19
MIN	1800-2700	206	10,86	114	9,06	68	7,34
MIN	2700-3600	239	12,23	139	9,89	75	6,57
MIN	3600-4500	253	13,01	144	10,26	83	7,35
MIN	4500-5400	232	11,61	121	9,38	63	5,61
MAX	1800-2700	274	13,93	167	12,95	114	12,38
MAX	2700-3600	302	14,69	191	14,52	120	13,78
MAX	3600-4500	315	15,46	189	14,08	128	13,98
MAX	4500-5400	310	15,62	202	14,59	142	15,22

		ONE STOP LINE		**ADJUSTED CONFLICT MARKERS**		***COMBINATION*** **SIX LINKS, HEADWAY 3.5 AND 3.5 M**	
EVALUATION	*TIMEINT*	*V(ALL)*	*S(ALL)*	*V(ALL)*	*S(ALL)*	*V(ALL)*	*S(ALL)*
AVG	1800-2700	155	13,86	214	12,08	252	12,76
AVG	2700-3600	171	14,35	230	12,63	262	13,26
AVG	3600-4500	180	14,98	243	13,55	279	14,04
AVG	4500-5400	174	14,71	236	13,29	269	13,73
STDDEV	1800-2700	16	0,89	20	0,94	19	0,83
STDDEV	2700-3600	20	0,97	18	0,91	15	0,83
STDDEV	3600-4500	15	0,82	15	0,73	16	0,85
STDDEV	4500-5400	19	1	19	1,11	19	1,09
MIN	1800-2700	122	11,97	171	10,41	211	10,84
MIN	2700-3600	137	13,02	202	11,04	237	12,22
MIN	3600-4500	152	13,18	223	12,2	254	12,22
MIN	4500-5400	136	13,14	203	11,71	244	11,65
MAX	1800-2700	178	15,17	245	13,73	279	13,89
MAX	2700-3600	219	16,84	266	14,22	291	14,74
MAX	3600-4500	218	16,46	280	14,51	314	15,43
MAX	4500-5400	213	16,55	280	15,28	316	15,75

COM RESULTS
WALKING BEHAVIOUR

	VD		**REACT TO N**	
VALUES	CONFLICT AREAS	PRIORITY RULE	CONFLICT AREAS	PRIORITY RULE
0	933	916	940	907
1	937	916	944	917
2	936	919	939	914
3	940	920	938	915
4	935	921	941	915
5	942	920	944	915
6	939	921	938	914
7	944	921	938	915
8	945	920	940	915
9	947	919	939	915
10	940	922	939	915
11	942	920	939	915
12	946	921	939	915
13	938	923	939	915
14	946	920	939	915
15	939	919	939	915
16	945	921	939	915
17	944	923	939	915
18	940	921	939	915
19	948	921	939	915
20	947	919	939	915
21	945	919	939	915
22	940	923	939	915
23	938	918	939	915
24	947	921	939	915
25	940	920	939	915
26	944	921	939	915
27	944	920	939	915
28	943	922	939	915
29	939	921	939	915
30	942	922	939	915
31	946	920	939	915
32	941	922	939	915
33	936	919	939	915
34	941	920	939	915
35	938	920	939	915
36	948	921	939	915
37	939	924	939	915
38	948	919	939	915
39	942	924	939	915
40	952	924	939	915
41	944	922	939	915
42	941	924	939	915
43	944	922	939	915
44	944	923	939	915
45	948	924	939	915
46	946	922	939	915
47	948	923	939	915
48	948	919	939	915
49	947	923	939	915
50	948	924	939	915

COM RESULTS
LAMBDA

VALUES	CONFLICT AREAS	PRIORITY RULE
0	938	905
0,1	943	912
0,2	939	913
0,3	955	916
0,4	944	919
0,5	948	921
0,6	950	918
0,7	952	923
0,8	951	920
0,9	948	927
1	953	925

DRIVING BEHAVIOUR CONFLICT AREAS

		DESIRED SPEED 40KM/H		**DESIRED SPEED 50KM/H**		**DESIRED SPEED 70KM/H**	
EVALUATION	*TIMEINT*	*V(ALL)*	*S(ALL)*	*V(ALL)*	*S(ALL)*	*V(ALL)*	*S(ALL)*
AVG	1800-2700	156	15,54	158	15,7	156	15,51
AVG	2700-3600	181	16,03	181	16,19	181	16,33
AVG	3600-4500	184	16,38	185	16,97	184	16,95
AVG	4500-5400	174	16,17	174	16,34	174	16,34
STDDEV	1800-2700	20	1,09	19	1,35	19	1,48
STDDEV	2700-3600	18	1,5	17	1,63	18	1,93
STDDEV	3600-4500	16	1,23	17	1,48	19	1,54
STDDEV	4500-5400	19	1,33	19	1,56	20	1,58
MIN	1800-2700	110	13,29	112	13,1	112	12,31
MIN	2700-3600	145	14,29	147	14,4	143	14
MIN	3600-4500	151	13,53	153	13,92	151	14,22
MIN	4500-5400	140	14,15	137	14,49	141	14,48
MAX	1800-2700	186	17,05	183	17,4	188	17,43
MAX	2700-3600	223	20,15	218	20,04	222	20,74
MAX	3600-4500	213	18,2	215	19,63	224	19,88
MAX	4500-5400	216	18,79	220	18,92	221	19,03

PRIORITY RULE

		DESIRED SPEED 40KM/H		**DESIRED SPEED 50KM/H**		**DESIRED SPEED 70KM/H**	
EVALUATION	*TIMEINT*	*V(ALL)*	*S(ALL)*	*V(ALL)*	*S(ALL)*	*V(ALL)*	*S(ALL)*
AVG	1800-2700	217	12,58	217	12,74	216	12,71
AVG	2700-3600	231	13,04	231	13,3	231	13,39
AVG	3600-4500	245	14,2	245	14,51	246	14,5
AVG	4500-5400	237	13,88	238	14	237	14,02
STDDEV	1800-2700	19	1,06	19	1,09	19	1,15
STDDEV	2700-3600	17	1,13	17	1,4	17	1,63
STDDEV	3600-4500	16	1,06	15	1,43	14	1,4
STDDEV	4500-5400	20	1,44	20	1,73	21	1,71
MIN	1800-2700	179	10,51	180	10,6	178	10,46
MIN	2700-3600	202	10,83	202	11,12	207	11,16
MIN	3600-4500	223	12,01	225	12,02	223	11,97
MIN	4500-5400	207	11,83	198	11,28	201	11,51
MAX	1800-2700	250	14,15	249	14,5	245	14,58
MAX	2700-3600	269	15,23	265	16,25	272	18,18
MAX	3600-4500	283	15,78	276	17,08	275	17,09
MAX	4500-5400	286	16,9	285	17,58	286	17,87

Appendix IV - Python scripts

Conflict areas

The parameters changed for conflict areas, front and rear gap and avoid blocking have been tested using a python script. The script below was used to change front gap, but the same method was used to change rear gap and avoid blocking to.

```
"""
Created on Mon Apr 10 08:24:40 2017
#------- COM server -------------------------------- #
import win32com.client as com
import numpy as np

# ---- Open Vissim -------------------------------- #
Filename = "\\".join([path, name])
Vissim = com.Dispatch("Vissim.Vissim.900")
# ---- load project -------------------------------- #
projname = ".".join([Filename, 'inpx'])
flag_read_additionally = False
Vissim.LoadNet(projname, flag_read_additionally)
# ---- Load layout ----------------------- #
layname = ".".join([Filename, 'layx'])
Vissim.LoadLayout(layname)
#-----Data------------------------------------------ #
Gap = np.linspace(0,1, num=11)
# ---Define boundaries ------------------------- #
A = []
# ----Changing VD -------------------------------- #
for i in range(11):
new_gap = Gap[i]
Vissim.Net.ConflictAreas.ItemByKey(3).SetAttValue('FrontGapDef', new_gap)
Vissim.Net.ConflictAreas.ItemByKey(4).SetAttValue('FrontGapDef', new_gap)
Vissim.Net.ConflictAreas.ItemByKey(5).SetAttValue('FrontGapDef', new_gap)
Vissim.Net.ConflictAreas.ItemByKey(6).SetAttValue('FrontGapDef', new_gap)
Vissim.Net.ConflictAreas.ItemByKey(7).SetAttValue('FrontGapDef', new_gap)
Vissim.Net.ConflictAreas.ItemByKey(8).SetAttValue('FrontGapDef', new_gap)
Vissim.Net.ConflictAreas.ItemByKey(9).SetAttValue('FrontGapDef', new_gap)
Vissim.Net.ConflictAreas.ItemByKey(10).SetAttValue('FrontGapDef', new_gap)
Vissim.Net.ConflictAreas.ItemByKey(13).SetAttValue('FrontGapDef', new_gap)
Vissim.Net.ConflictAreas.ItemByKey(14).SetAttValue('FrontGapDef', new_gap)
Vissim.Net.ConflictAreas.ItemByKey(15).SetAttValue('FrontGapDef', new_gap)
Vissim.Net.ConflictAreas.ItemByKey(16).SetAttValue('FrontGapDef', new_gap)
# ---- Start simulation --------------------------- #
Vissim.Simulation.RunContinuous()
# --- Collecting results ------------------------- #
ped_measurement_number = 2
```

```
ped_measurement =
Vissim.Net.DataCollectionMeasurements.ItemByKey(ped_measurement_number)
result = ped_measurement.AttValue('Vehs(Avg,Total,All)')
A.append(result)
# --- Plotting results -------------------------- #
np.savetxt('vector.frontgap.base.model.CA.txt', A, delimiter=',', fmt='%4d')
np.hstack(A)
```

Pedestrian behaviour settings

The script used for changing the selected pedestrian parameters are seen below, this specific script was used to change the parameter VD, however the same script was used for lambda and react to n as well, but with some changes.

```
"""
Created on Mon Mar 27 14:31:25 2017
#------- COM server ------------------------------- #
import win32com.client as com
import matplotlib.pyplot as plt
import numpy as np
import sys
# ---- Open Vissim -------------------------------- #
Filename = "\\".join([path, name])
Vissim = com.Dispatch("Vissim.Vissim.900")
# ---- Load project ------------------------------- #
projname = ".".join([Filename, 'inpx'])
flag_read_additionally = False
Vissim.LoadNet(projname, flag_read_additionally)
# ---- Load layout ---------------------- #
layname = ".".join([Filename, 'layx'])
Vissim.LoadLayout(layname)
#-----Data----------------------------------------- #
VD = np.arange(51)
# ---Define boundaries ------------------------ #
A = []
# ----Changing VD -------------------------------- #
for i in range(51):
WalkingBehaviourNo = 1
new_VD = VD[i]
Vissim.Net.WalkingBehaviors.ItemByKey(WalkingBehaviorNo).SetAttValue('VD', new_VD)
# ---- Start simulation -------------------------- #
Vissim.Simulation.RunContinuous()
# --- Collecting results ------------------------ #
ped_measurement_number = 2
ped_measurement =
Vissim.Net.DataCollectionMeasurements.ItemByKey(ped_measurement_number)
result = ped_measurement.AttValue('Vehs(Avg,Total,All)')
```

```
A.append(result)
# --- Plotting results --------------------------- #
np.savetxt('vector.VR.base.model.PR.txt', A, delimiter=',', fmt='%4d')
np.hstack(A)
```

Correlation between numbers of vehicles and pedestrians

The script used to change the volumes for vehicles and pedestrians for the selected pedestrian crossing at Korsvägen is shown below.

```
"""
Created on Tue Mar 21 09:02:43 2017
#------- COM server ----------------------- #
import win32com.client as com
import matplotlib.pyplot as plt
import numpy as np
import sys
# ---- Open Vissim ----------------------- #
Filename = "\\".join([path, name])
Vissim = com.Dispatch("Vissim.Vissim.900")
# ---- Load project ---------------------- #
projname = ".".join([Filename, 'inpx'])
flag_read_additionally  = False
Vissim.LoadNet(projname, flag_read_additionally)
# ---- Load layout ----------------------- #
#layname = ".".join([Filename, 'layx'])
#Vissim.LoadLayout(layname)
#-----Data-----------------------------------#
minped = 0
maxped = 3000
minveh = 0
maxveh = 2500
sizeped = 31
sizeveh = 26
 # ---Define boundaries  --------------  #
ped = np.linspace(maxped, minped, num=sizeped)
veh = np.linspace(minveh, maxveh, num=sizeveh)
A=[[[] for j in range(len(veh))] for i in range(len(ped))]
# ----Set pedestrian input ------------- #
for j in range(len(veh)):
        veh_number = 1
        new_vehvolume = veh[j]
        Vissim.Net.VehicleInputs.ItemByKey(veh_number).SetAttValue('Volume(1)',
new_vehvolume)
        for i in range(len(ped)):
        ped_number = 1
```

```
        ped_number2 = 2
        new_volume = ped[i] # pedestrian per hour
        Vissim.Net.PedestrianInputs.ItemByKey(ped_number).SetAttValue('Volume(1)', 
new_volume)
        Vissim.Net.PedestrianInputs.ItemByKey(ped_number2).SetAttValue('Volume(1)', 
new_volume)
# -----Set vehicles input-----------------#
# ---- Start simulation --------------------------------- #
        Vissim.Simulation.RunContinuous()
# --- Collecting results ---------------------  #
        ped_measurement_number = 2
        ped_measurement                                                          = 
Vissim.Net.DataCollectionMeasurements.ItemByKey(ped_measurement_number)
        result  = ped_measurement.AttValue('Vehs(1,Total,All)')
        A[i][j]=result
# --- Plotting results ---------------------  #
np.savetxt('matrisen.txt', A, delimiter=',', fmt='%4d')
fig, b =plt.subplots(figsize=(6, 6))
b = plt.imshow(A, extent=(minveh, maxveh, minped, 6000), cmap='Blues', 
interpolation='nearest', aspect='auto')
plt.colorbar(b, orientation='vertical')
plt.xlabel('Vehicles')
plt.ylabel('Pedestrians')
plt.title('Numbers of vehicles passing the pedestrian crossing')
plt.show()
```

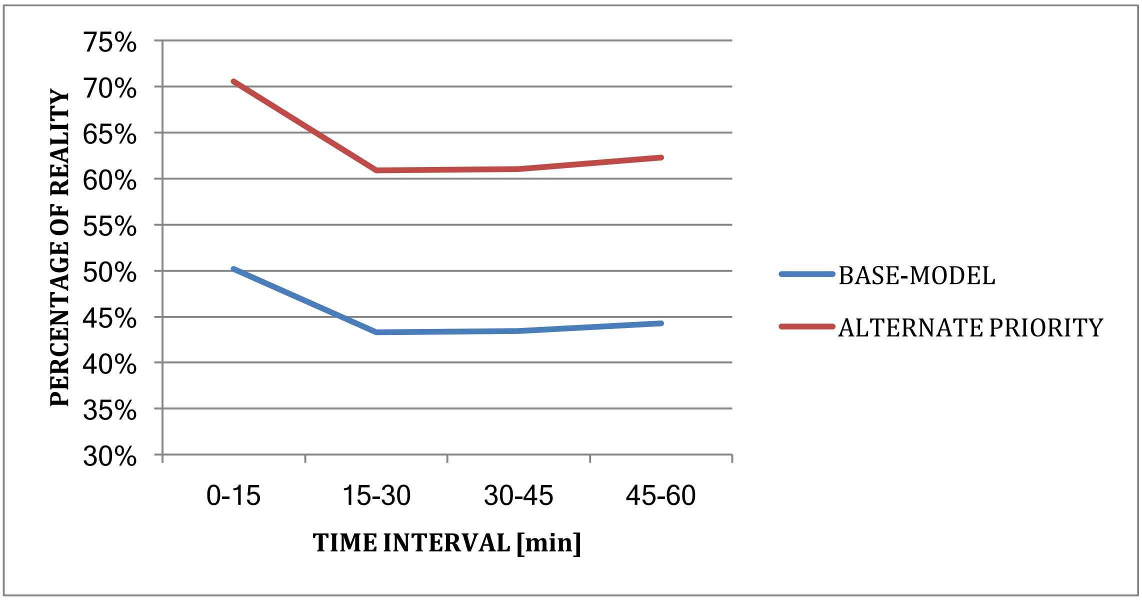
Appendix V – Result graphs sensitivity analysis

Results that gave a small improvement on the sensitivity analysis, by using the function conflict areas and priority rule.

Conflict areas

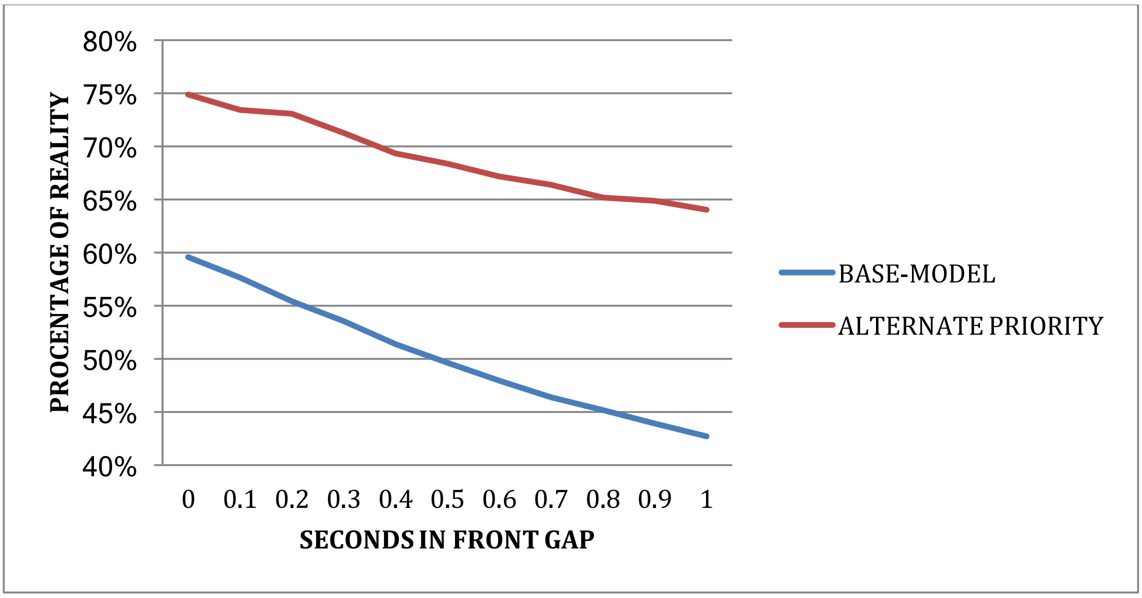
The parameter alternate priority for pedestrian links gave a high result and was therefore compared for the three other results, front gap, rear gap and avoid blocking. The latter parameters were studied by using COM interface scripts in Python.

Alternate priority for pedestrian links



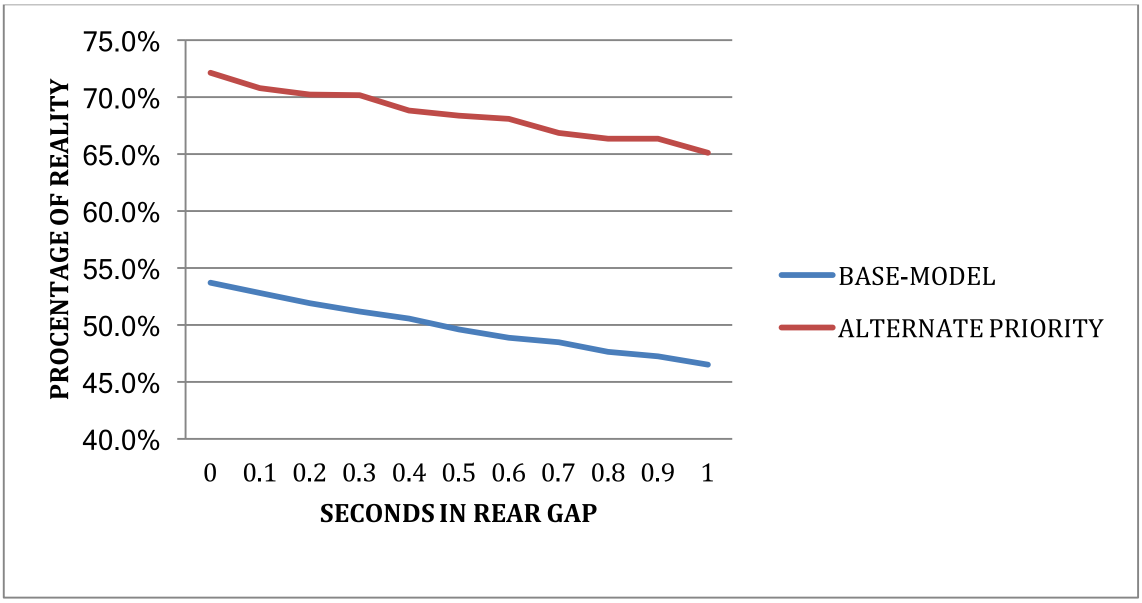
Graph 26. Alternating priority for the pedestrian links for base-model with five pedestrian links.

Front gap



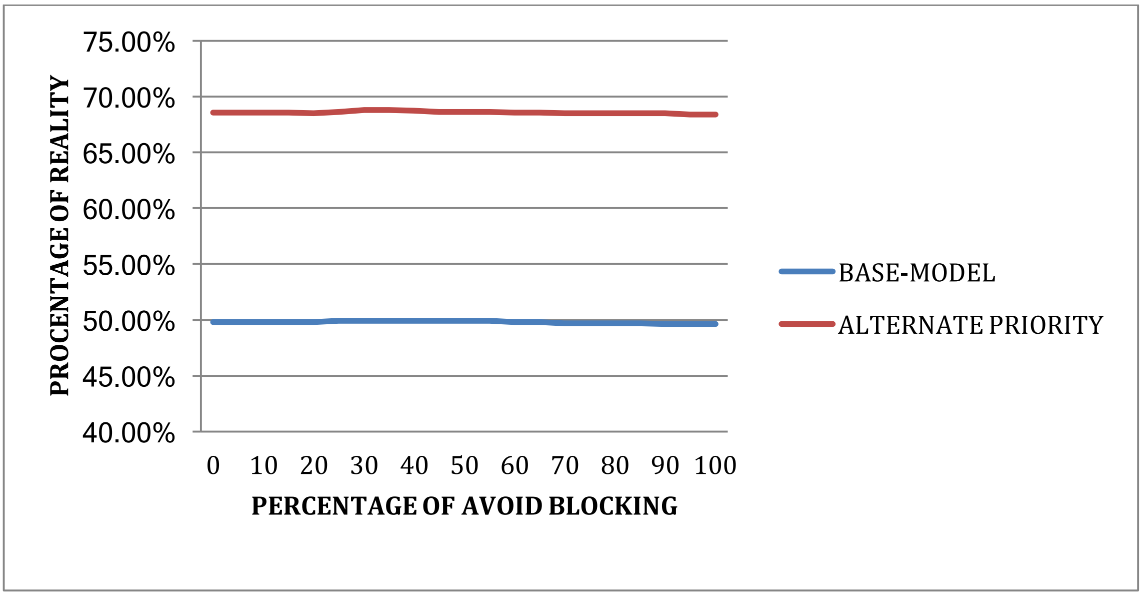
Graph 27. The parameter front gap was tested for values 0-1 seconds for base-model and alternating priority.

Rear gap



Graph 28. The parameter rear gap was tested for values 0-1 seconds for base-model and alternating priority.

Avoid blocking

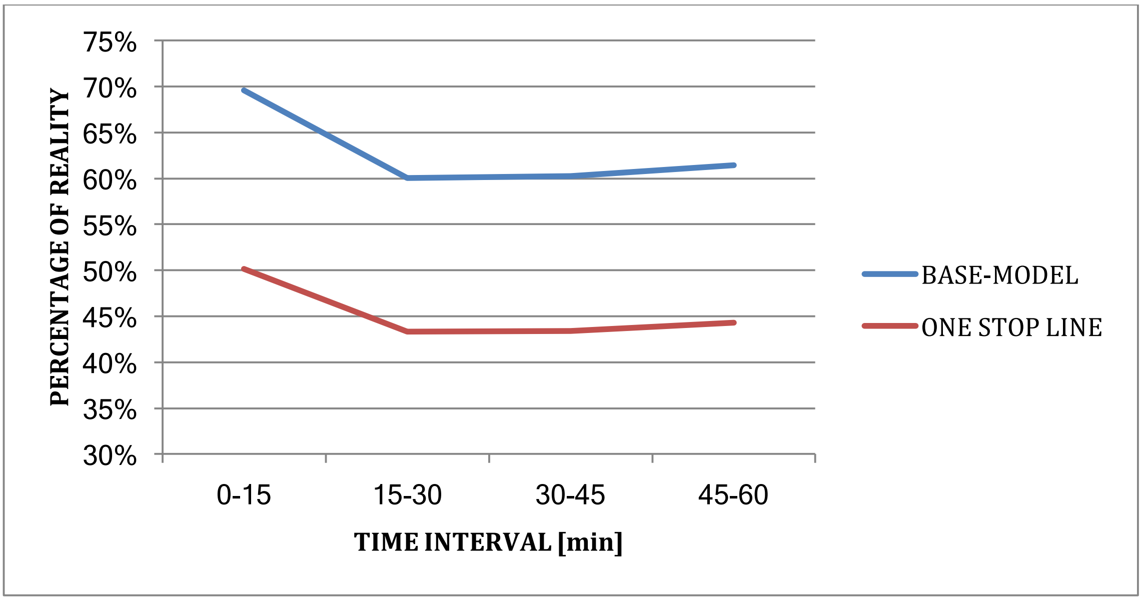


Graph 29. The parameter avoid blocking was tested for the percentage 0-100 for both base-model and alternating priority.

Priority rule

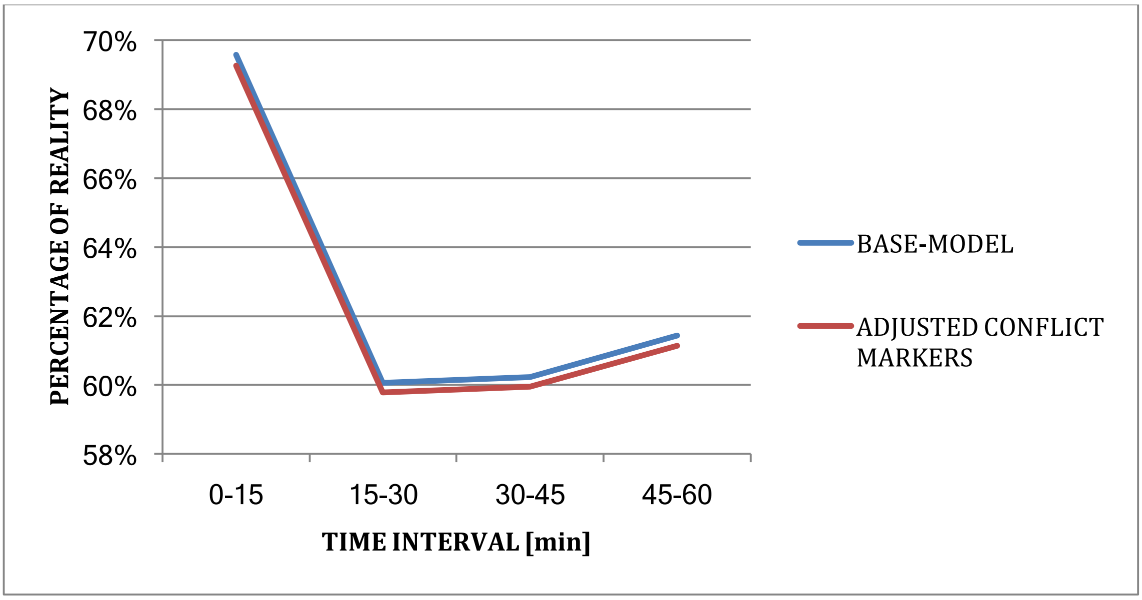
The base-model was compared to the studied parameters one stop line and adjusted conflict markers.

One stop line



Graph 30. Comparison between one-stop line and five stop lines as for base-model.

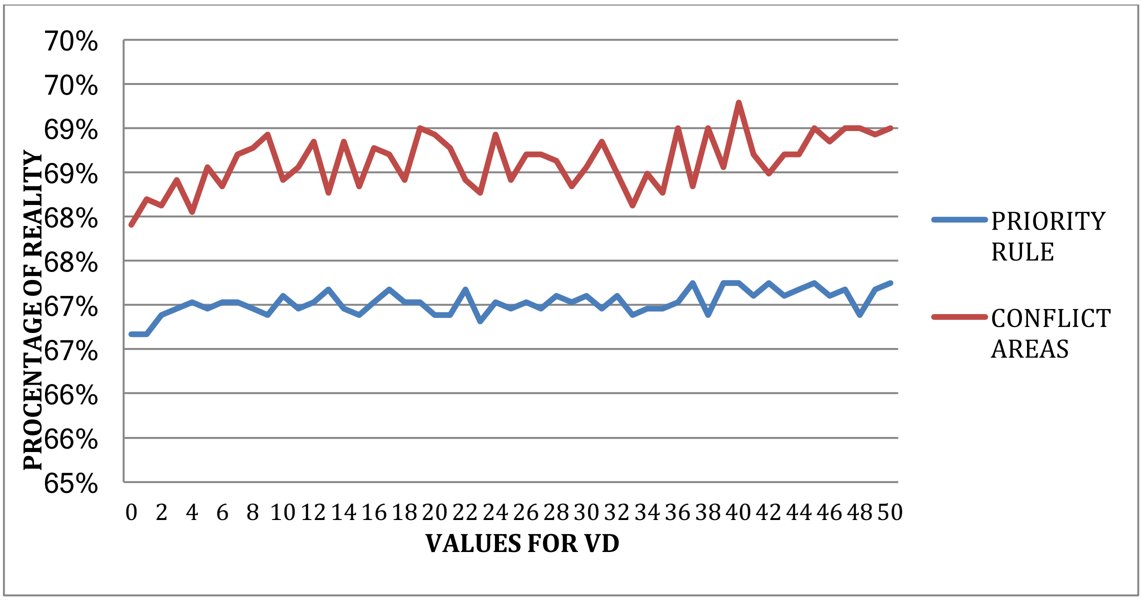
Adjusted conflict markers



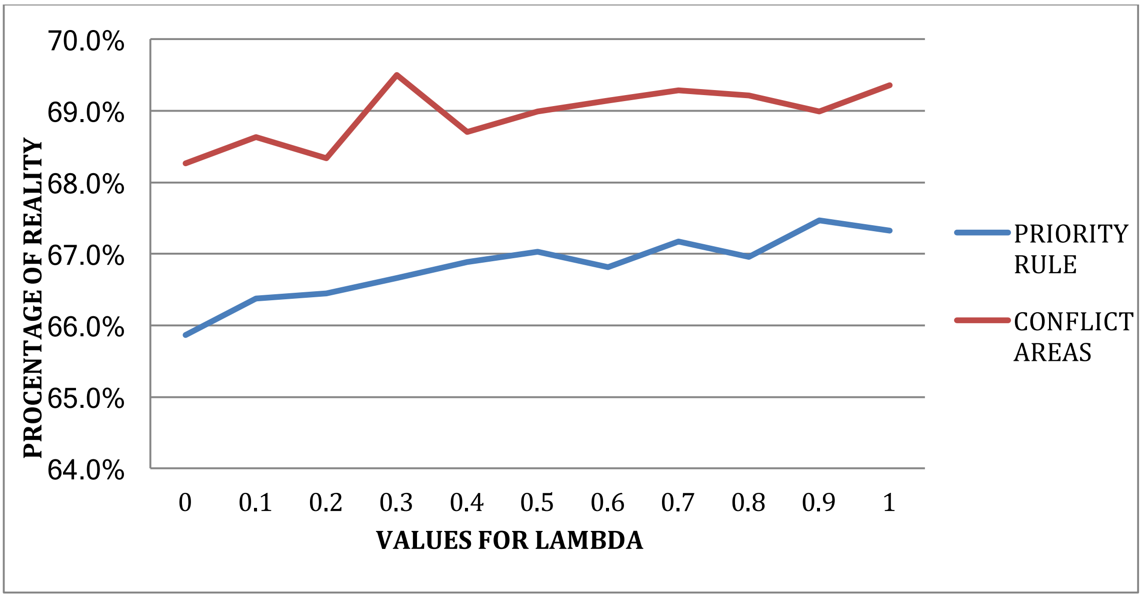
Graph 31. Adjusted conflict markers compared with base-model for priority rule.

Walking behaviour

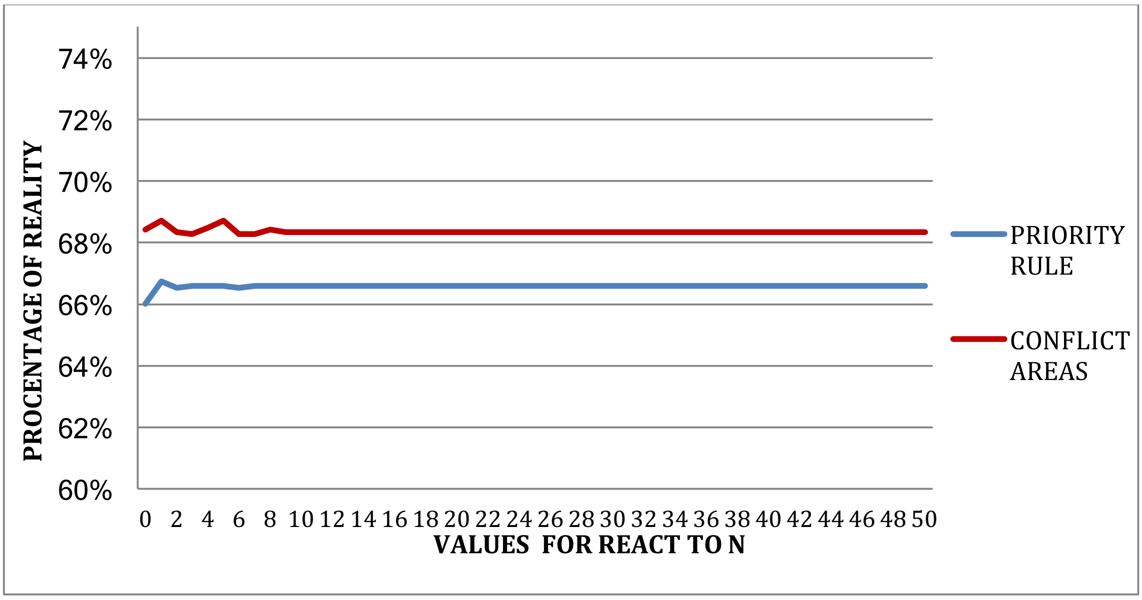
The parameters for walking behaviour were studied by a COM interface script in Python.



Graph 32. Walking behaviour parameter VD tested from 0-50, for priority rule and conflict areas.



Graph 33. Walking behaviour parameter lambda tested for values 0-1 for priority rule and conflict areas.



Graph 34, Walking behaviour parameter react to n simulated for values 0-50 for priority rule and conflict areas.

Appendix VI – Changed volume

Inputs for simulation of decreased and increased pedestrian volume for the investigated pedestrian crossing at Korsvägen, can be seen in Table 12 and 13. The data was taken from the report *Rörelsemönster och trafikflöden vid korsvägen, Göteborg,* (Viscando, 2017a)

Table 12. Passenger distribution for increased pedestrian volume in 15 minutes interval for Saturday 17th of December 2016 between 4:45-5:45 PM, with 60% share of grouped people.

Increased pedestrian input					
Type of road user	Bicycle		Vehicle	Pedestrian	
Direction/ Time interval	Toward Liseberg	Toward travel centre	Toward Liseberg	Toward Liseberg	Toward travel centre
0-15 [min]	5	9	297	487	557
15-30 [min]	2	9	232	431	663
30-45 [min]	7	9	191	262	719
45-60 [min]	4	8	220	434	683
Total [60 min]	18	35	940	1614	2622

Table 13. Passenger distribution for decreased pedestrian volume in 15 minutes interval for Thursday 15th of December 2016 between 7:15-8:15 AM, with 60% share of grouped people.

Decreased pedestrian input					
Type of road user	Bicycle		Vehicle	Pedestrian	
Direction/ Time interval	Toward Liseberg	Toward travel centre	Toward Liseberg	Toward Liseberg	Toward travel centre
0-15 [min]	7	20	300	29	75
15-30 [min]	11	24	300	37	56
30-45 [min]	14	49	356	37	84
45-60 [min]	7	32	290	18	67
Total [60 min]	39	125	1246	121	282

RESULTS CHANGED VOLUME

* TIMEINT: TimeInt, Time interval

DECREASED PEDESTRIAN VOLUME

		CONFLICT AREAS		PRIORITY RULE	
EVALUATION	*TIMEINT*	**BASE-MODEL**	**OPTIMISED MODEL**	**BASE-MODEL**	**OPTIMISED MODEL**
AVG	1800-2700	367	369	370	370
AVG	2700-3600	381	374	372	371
AVG	3600-4500	350	376	377	379
AVG	4500-5400	403	383	382	382
STDDEV	1800-2700	18	15	16	16
STDDEV	2700-3600	18	21	17	16
STDDEV	3600-4500	23	20	23	23
STDDEV	4500-5400	20	20	20	19
MIN	1800-2700	329	345	345	348
MIN	2700-3600	347	332	341	342
MIN	3600-4500	304	330	315	318
MIN	4500-5400	369	353	349	347
MAX	1800-2700	397	398	403	411
MAX	2700-3600	427	414	407	403
MAX	3600-4500	389	406	416	421
MAX	4500-5400	436	423	424	421

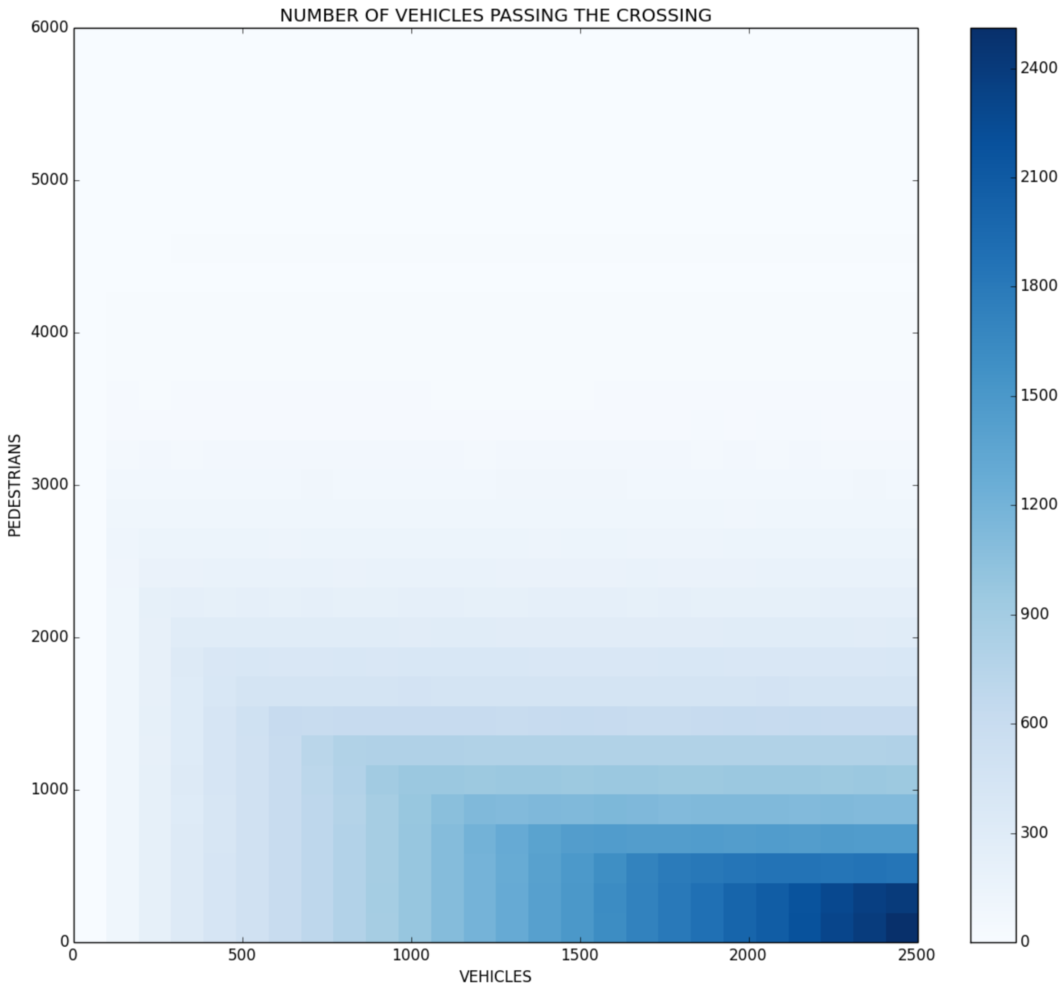
INCREASED PEDESTRIAN VOLUME

		CONFLICT AREAS		PRIORITY RULE	
EVALUATION	*TIMEINT*	**BASE-MODEL**	**OPTIMISED MODEL**	**BASE-MODEL**	**OPTIMISED MODEL**
AVG	1800-2700	3	28	34	66
AVG	2700-3600	2	19	27	59
AVG	3600-4500	3	21	28	66
AVG	4500-5400	2	19	24	58
STDDEV	1800-2700	2	4	5	4
STDDEV	2700-3600	1	5	3	6
STDDEV	3600-4500	2	5	5	5
STDDEV	4500-5400	2	5	4	6
MIN	1800-2700	1	23	25	58
MIN	2700-3600	0	12	21	48
MIN	3600-4500	0	14	17	59
MIN	4500-5400	0	10	17	45
MAX	1800-2700	8	35	47	73
MAX	2700-3600	5	29	32	70
MAX	3600-4500	8	29	35	78
MAX	4500-5400	6	29	36	71

Appendix VII - Pedestrian and vehicle volume

Conflict areas

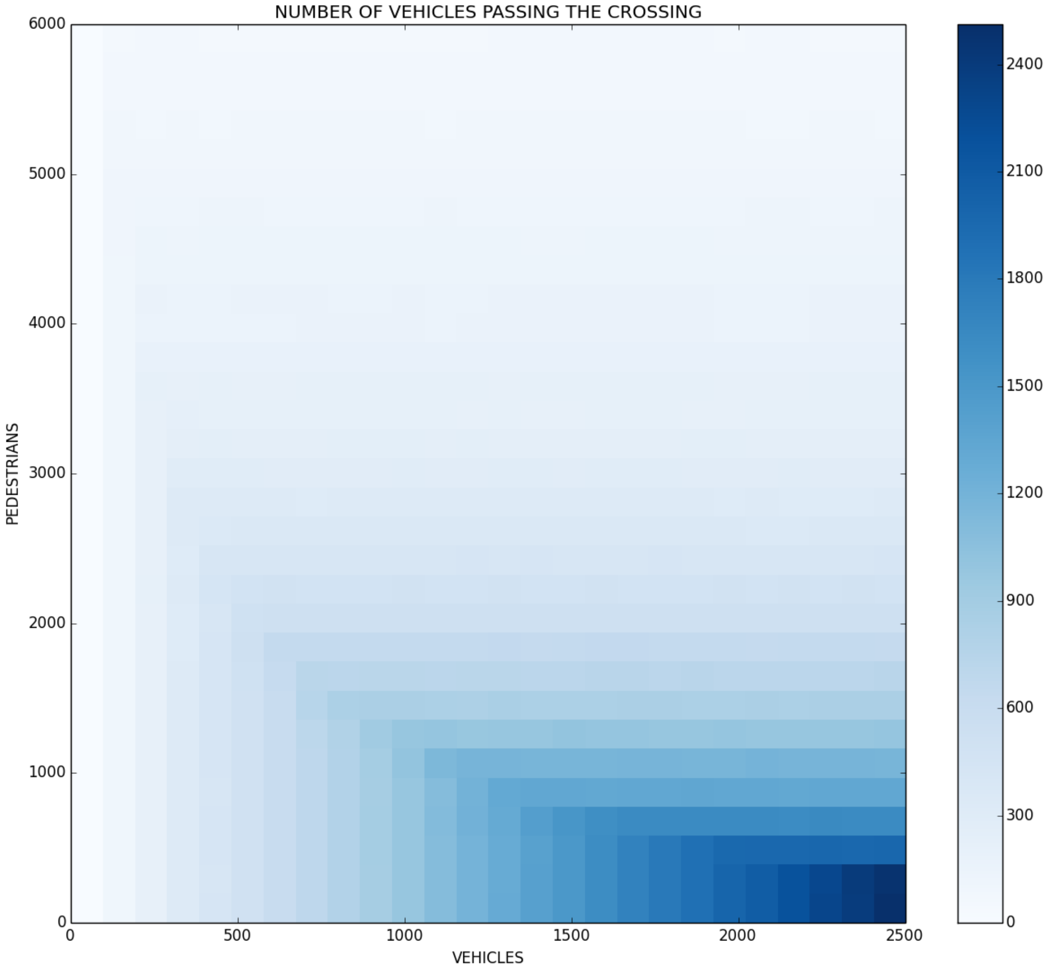
The result from simulate each pedestrian and vehicle volume stepwise can be seen in Graph 35, where the colour represents the number of vehicle passing the crossing. The highest result was obtained when the pedestrian volume was set to zero.



Graph 35. Heatmap with increasing pedestrian and vehicle volume results in number of vehicles passing the crossing. Using conflict areas with a grid size of 100x200.

Priority rule

The same as for conflict areas was done for priority rule and can be seen in Graph 36.



Graph 36. Heatmap with increasing pedestrian and vehicle volume results in number of vehicles passing the crossing. Using priority rule with a grid size of 100x200.

Appendix VIII – Results optimised solution

RESULTS OPTIMISED SOLUTION

* TIMEINT: TimeInt, Time interval

* V(ALL): Vehs(All), Vehicles (All) (Count of vehicles of the data collection measurement in the interval)

* S(ALL): SpeedAvgArith(All), Speed (arithmetic average) (All) (Arithmetic mean of the speed of all vehicles of this data collection measurement for this interval) [km/h]

		CONFLICT AREAS		***PRIORITY RULE***	
EVALUATION	*TIMEINT*	*V(ALL)*	*S(ALL)*	*V(ALL)*	*S(ALL)*
AVG	1800-2700	270	18,02	260	13,45
AVG	2700-3600	296	18,6	272	14,16
AVG	3600-4500	295	19,52	289	15,56
AVG	4500-5400	283	18,2	281	14,93
STDDEV	1800-2700	19	1,37	17	0,99
STDDEV	2700-3600	20	1,49	15	1,26
STDDEV	3600-4500	19	1,62	17	1,28
STDDEV	4500-5400	25	1,42	21	1,77
MIN	1800-2700	235	15,38	221	11,34
MIN	2700-3600	244	15,84	243	12,41
MIN	3600-4500	263	16,6	264	12,6
MIN	4500-5400	244	16,05	252	12,17
MAX	1800-2700	302	20,49	284	15,43
MAX	2700-3600	328	21,23	297	17,64
MAX	3600-4500	327	22,53	319	17,4
MAX	4500-5400	333	20,42	331	18,17

Appendix IX – Investigated study areas

The results from the investigated crossing were studied on other study areas which are explained here. All study area was tested for base-model and optimised model for both conflict areas and priority rule, this is accounted in tables.

Södra Strandgatan

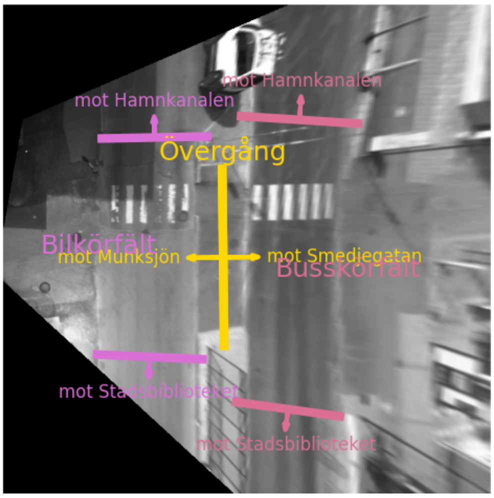


Figure 22. Illustrating the pedestrian crossing at Södra Strandgatan, and the model in Vissim was built from the figures specifications (Viscando, 2017a).

Table 14. Passenger distribution for Södra Strandgatan in 15 minutes interval for 25th of June 2015 between 4-5 AM (Viscando, 2017a).

Södra Strandgatan						
Type of road user	Bicycle		Vehicle		Pedestrian	
Direction/ Time interval	Toward Munksjön	Toward Smidjegatan	Towards Hamnkanalen	Towards Stads-biblioteket	Toward Munksjön	Toward Smidjegatan
0-15 [min]	3	3	93	67	36	29
15-30 [min]	1	1	86	87	33	28
30-45 [min]	4	3	96	81	40	26
45-60 [min]	0	3	111	69	45	32
Total [60 min]	8	10	386*	304*	154	115

*Since the vehicle input was 1500 vehicles per hour in the original model of Korsvägen, the same was used for this model.

RESULTS SÖDRA STRANDGATAN

* TIMEINT: TimeInt, Time interval

* V(ALL): Vehs(All), Vehicles (All) (Count of vehicles of the data collection measurement in the interval)

* S(ALL): SpeedAvgArith(All), Speed (arithmetic average) (All) (Arithmetic mean of the speed of all vehicles of this data collection measurement for this interval) [km/h]

CONFLICT AREAS

		BASE-MODEL		**OPTIMISED MODEL**	
EVALUATION	*TIMEINT*	*V(ALL)*	*S(ALL)*	*V(ALL)*	*S(ALL)*
AVG	1800-2700	377	24	378	40
AVG	2700-3600	375	24	375	40
AVG	3600-4500	373	24	373	39
AVG	4500-5400	369	23	370	37
STDDEV	1800-2700	21	1	20	2
STDDEV	2700-3600	15	1	15	3
STDDEV	3600-4500	14	1	15	2
STDDEV	4500-5400	20	1	20	3
MIN	1800-2700	345	22	346	36
MIN	2700-3600	342	23	343	36
MIN	3600-4500	351	22	348	35
MIN	4500-5400	326	21	326	31
MAX	1800-2700	420	25	418	44
MAX	2700-3600	402	26	401	45
MAX	3600-4500	396	26	403	43
MAX	4500-5400	399	25	399	42

PRIORITY RULE

		BASE-MODEL		**OPTIMISED MODEL**	
EVALUATION	*TIMEINT*	*V(ALL)*	*S(ALL)*	*V(ALL)*	*S(ALL)*
AVG	1800-2700	378	25	378	42
AVG	2700-3600	375	25	374	42
AVG	3600-4500	373	25	373	41
AVG	4500-5400	369	24	371	39
STDDEV	1800-2700	21	1	21	2
STDDEV	2700-3600	15	1	15	2
STDDEV	3600-4500	14	1	15	2
STDDEV	4500-5400	20	1	19	2
MIN	1800-2700	345	23	345	39
MIN	2700-3600	341	23	344	37
MIN	3600-4500	350	23	348	37
MIN	4500-5400	326	22	328	34
MAX	1800-2700	420	27	419	46
MAX	2700-3600	402	27	401	46
MAX	3600-4500	398	26	404	44
MAX	4500-5400	398	25	400	44

Sprängkullsgatan

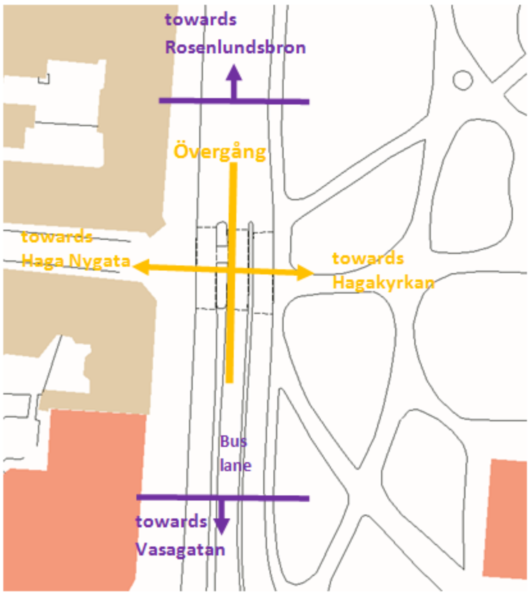


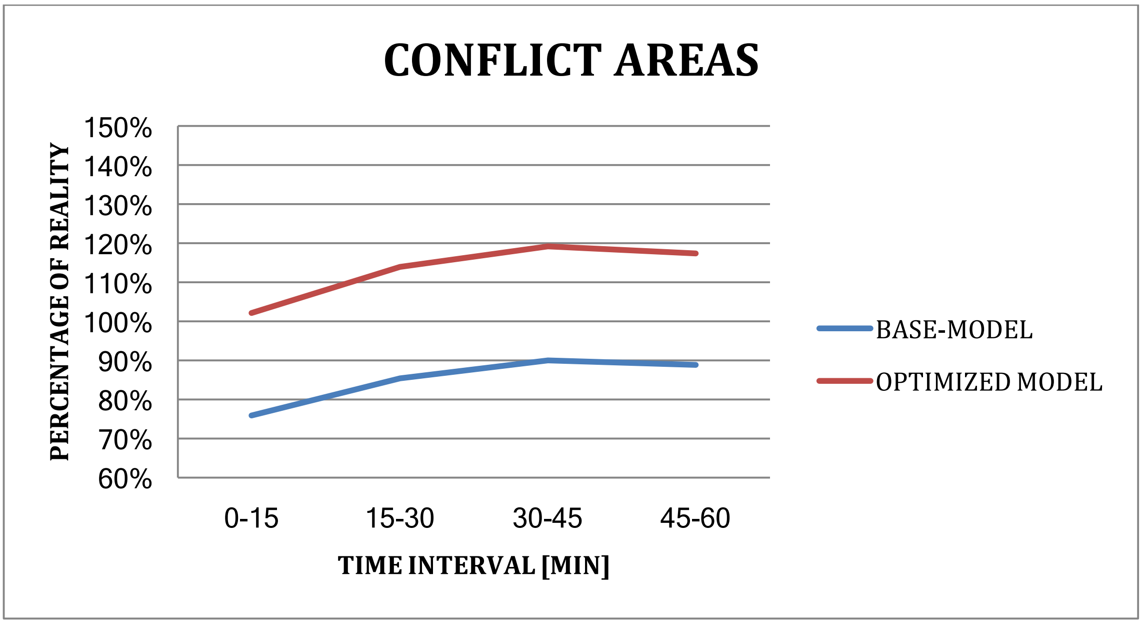
Figure 23. Illustrates the location of the pedestrian crossing for Sprängkullsgatan, and the model in Vissim was built with this as foundation.

Table 15. Passenger distribution for Sprängkullsgatan in 15 minutes interval for 7th of May 2016 between 3-4 PM.

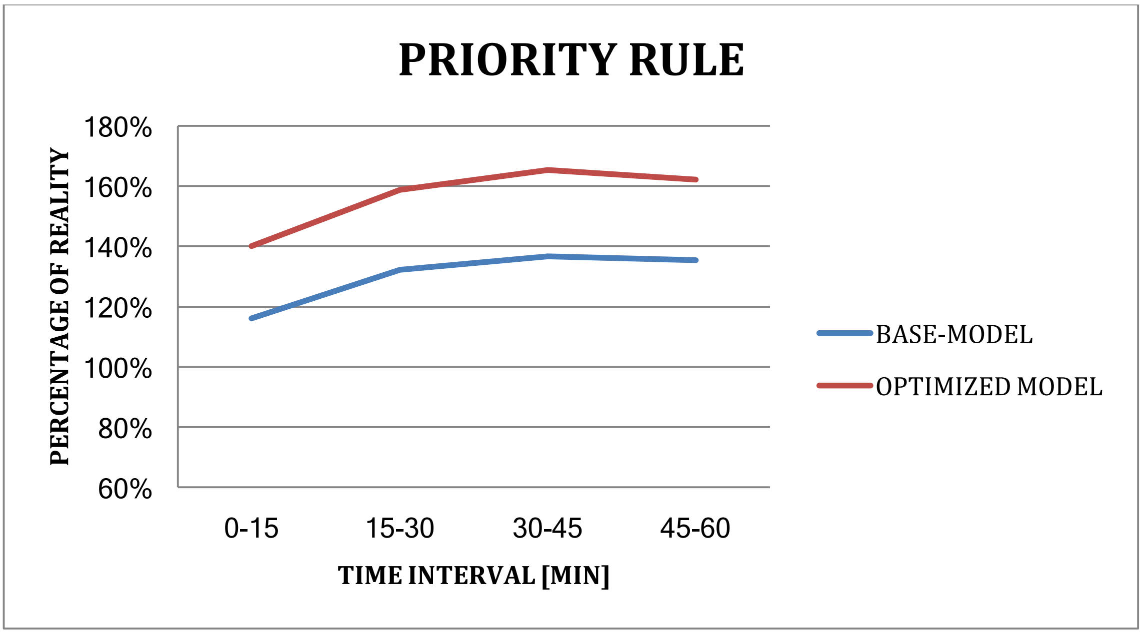
Sprängkullsgatan						
Type of road user	Bicycle		Vehicle		Pedestrian	
Direction/ Time interval	Toward Hagakyrkan	Toward Haga Nygata	Towards Rosenlunds bron	Towards Vasagatan	Toward Hagakyrkan	Toward Haga Nygata
0-15 [min]	-	-	115	72	-	-
15-30 [min]	-	-	95	70	-	-
30-45 [min]	-	-	97	64	-	-
45-60 [min]	-	-	88	73	-	-
Total [60 min]	16**	60**	395*	279*	508	840

*Since the vehicle input was 1500 vehicles per hour in the original model of Korsvägen, the same was used for this model.

**Since there is no bicycle crossing, the vehicles have priority over the bicyclists and the therefore they are not included in the model. It is assumed that they are no interfering with the capacity.



Graph 37. Results from Sprängkullsgatan using conflict areas, comparing base-model with optimised model.



Graph 38. Results from Sprängkullsgatan using priority rule, comparing base-model with optimised model.

RESULTS SÖDRA STRANDGATAN

* TIMEINT: TimeInt, Time interval

* V(ALL): Vehs(All), Vehicles (All) (Count of vehicles of the data collection measurement in the interval)

* S(ALL): SpeedAvgArith(All), Speed (arithmetic average) (All) (Arithmetic mean of the speed of all vehicles of this data collection measurement for this interval) [km/h]

CONFLICT AREAS

		BASE-MODEL		**OPTIMISED MODEL**	
EVALUATION	*TIMEINT*	*V(ALL)*	*S(ALL)*	*V(ALL)*	*S(ALL)*
AVG	1800-2700	142	11	191	13
AVG	2700-3600	141	11	188	13
AVG	3600-4500	145	11	192	13
AVG	4500-5400	143	11	189	12
STDDEV	1800-2700	14	1	16	1
STDDEV	2700-3600	13	1	16	1
STDDEV	3600-4500	14	1	16	2
STDDEV	4500-5400	20	2	22	2
MIN	1800-2700	114	9	163	10
MIN	2700-3600	112	9	154	9
MIN	3600-4500	120	8	162	10
MIN	4500-5400	105	8	144	10
MAX	1800-2700	166	13	217	15
MAX	2700-3600	161	13	220	16
MAX	3600-4500	170	13	219	16
MAX	4500-5400	184	14	227	17

PRIORITY RULE

		BASE-MODEL		**OPTIMISED MODEL**	
EVALUATION	*TIMEINT*	*V(ALL)*	*S(ALL)*	*V(ALL)*	*S(ALL)*
AVG	1800-2700	217	13	262	14
AVG	2700-3600	218	13	262	14
AVG	3600-4500	220	13	266	14
AVG	4500-5400	218	13	261	14
STDDEV	1800-2700	16	1	18	1
STDDEV	2700-3600	17	1	18	1
STDDEV	3600-4500	17	1	18	1
STDDEV	4500-5400	19	1	23	2
MIN	1800-2700	183	11	224	12
MIN	2700-3600	187	11	226	11
MIN	3600-4500	191	11	236	12
MIN	4500-5400	171	11	200	12
MAX	1800-2700	241	15	290	17
MAX	2700-3600	252	14	293	18
MAX	3600-4500	250	15	299	17
MAX	4500-5400	248	15	301	17

Västra Sjöfarten

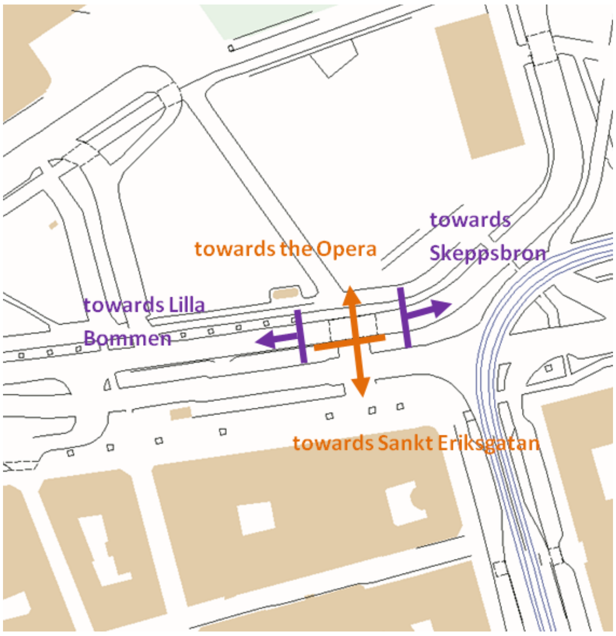


Figure 24. Illustrates the location of the pedestrian crossing at Västra Sjöfarten, and the model in Vissim was built with this as foundation.

Table 16. Passenger distribution for Västra Sjöfarten from Monday 24th of April 2017 between 3:55-4:25 PM. The results were multiplied by two to become an hour.

Västra Sjöfarten						
Type of road user	Bicycle		Vehicle		Pedestrian	
Direction/ Time interval	Towards the opera	Towards Sankt Eriksgatan	Towards Skeppsbron	Towards Lilla Bommen	Towards the opera	Towards Sankt Eriksgatan
Total [60 min]	132	214	104*	248*	20	26

*Since the vehicle input was 1500 vehicles per hour in the original model of Korsvägen, the same was used for this model.

RESULTS VÄSTRA SJÖFARTEN

* TIMEINT: TimeInt, Time interval

* V(ALL): Vehs(All), Vehicles (All) (Count of vehicles of the data collection measurement in the interval)

		CONFLICT AREAS		*PRIORITY RULE*	
		BASE-MODEL	**OPTIMISED MODEL**	**BASE-MODEL**	**OPTIMISED MODEL**
EVALUATION	*TIMEINT*	*V(ALL)*	*V(ALL)*	*V(ALL)*	*V(ALL)*
AVG	1800-2700	378	377	378	378
AVG	2700-3600	376	375	375	374
AVG	3600-4500	373	373	373	373
AVG	4500-5400	370	371	371	372
STDDEV	1800-2700	21	21	21	21
STDDEV	2700-3600	13	13	13	13
STDDEV	3600-4500	15	16	15	15
STDDEV	4500-5400	20	20	20	21
MIN	1800-2700	346	346	348	346
MIN	2700-3600	355	354	355	350
MIN	3600-4500	349	348	349	348
MIN	4500-5400	329	330	329	330
MAX	1800-2700	420	422	422	422
MAX	2700-3600	402	399	402	398
MAX	3600-4500	403	404	403	403
MAX	4500-5400	400	399	401	401

Bergslagsgatan

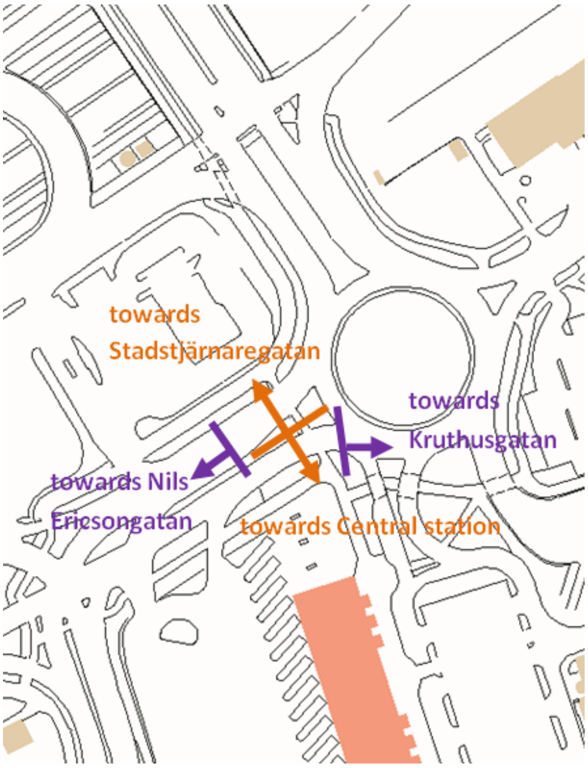


Figure 25. Illustrates the location of the pedestrian crossing at Bergslagsgatan, the model in Vissim was built with this as foundation.

Table 17. Passenger distribution for Bergslagsgatan from Monday 24th of April 2017 between 3:00-3:30 PM. The results were multiplied by two to become an hour.

Bergslagsgatan					
Type of road user	Bicycle	Vehicle		Pedestrian	
Direction/ Time interval	Both directions	Towards Kruthusgatan	Towards Nils Ericsonsgatan	Towards the central station	Towards Stadstjänaregatan
Total [60 min]	14	484*	220*	440	54

*Since the vehicle input was 1500 vehicles per hour in the original model of Korsvägen, the same was used for this model.

RESULTS BERGSLAGSGATAN

* TIMEINT: TimeInt, Time interval

* V(ALL): Vehs(All), Vehicles (All) (Count of vehicles of the data collection measurement in the interval)

		CONFLICT AREAS		***PRIORITY RULE***	
		BASE-MODEL	**OPTIMISED MODEL**	**BASE-MODEL**	**OPTIMISED MODEL**
EVALUATION	*TIMEINT*	*V(ALL)*	*V(ALL)*	*V(ALL)*	*V(ALL)*
AVG	1800-2700	379	378	379	378
AVG	2700-3600	374	373	374	374
AVG	3600-4500	372	373	372	373
AVG	4500-5400	370	371	372	372
STDDEV	1800-2700	20	20	20	19
STDDEV	2700-3600	16	15	15	15
STDDEV	3600-4500	15	15	14	15
STDDEV	4500-5400	19	20	19	20
MIN	1800-2700	347	344	347	345
MIN	2700-3600	346	346	345	347
MIN	3600-4500	347	348	349	351
MIN	4500-5400	332	329	331	330
MAX	1800-2700	413	413	416	413
MAX	2700-3600	403	400	401	400
MAX	3600-4500	396	402	401	403
MAX	4500-5400	400	398	398	401

Östra Hamngatan

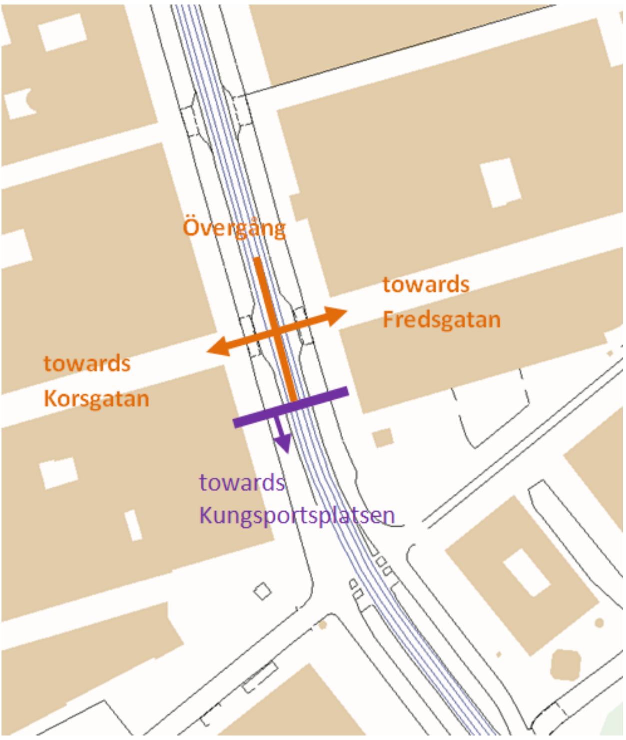


Figure 26. Illustrates the location of the pedestrian crossing at Östra Hamngatan, the model in Vissim was built with this as foundation.The optimised model was built with three pedestrian links.

Table 18. Passenger distribution for Östra Hamngatan from 27th of April 2017 between 4:30-4:45 PM. The results were multiplied by four to become an hour.

Östra Hamngatan				
Type of road user	Bicycle	Vehicle	Pedestrian	
Direction/ Time interval	Towards Kungsportsplatsen	towards Kungsportsplatsen	towards the Korsgatan	towards Fredsgatan
Total [60 min]	144*	100**	828	910

*The road is a cycle-speed road and therefore was the bicycle inputs combined in the vehicle lane.
**Since the vehicle input was 1500 vehicles per hour in the original model of Korsvägen, the same was used for this model.

RESULTS ÖSTRA HAMNGATAN

* TIMEINT: TimeInt, Time interval

* V(ALL): Vehs(All), Vehicles (All) (Count of vehicles of the data collection measurement in the interval)

		CONFLICT AREAS		PRIORITY RULE	
		BASE-MODEL	OPTIMISED MODEL	BASE-MODEL	OPTIMISED MODEL
EVALUATION	*TIMEINT*	*V(ALL)*	*V(ALL)*	*V(ALL)*	*V(ALL)*
AVG	1800-2700	40	86	74	129
AVG	2700-3600	41	92	77	135
AVG	3600-4500	42	88	78	131
AVG	4500-5400	42	88	77	131
STDDEV	1800-2700	12	10	8	10
STDDEV	2700-3600	12	12	11	11
STDDEV	3600-4500	10	9	8	11
STDDEV	4500-5400	10	10	8	9
MIN	1800-2700	23	72	61	110
MIN	2700-3600	18	72	60	117
MIN	3600-4500	21	67	58	115
MIN	4500-5400	18	75	64	110
MAX	1800-2700	68	103	88	142
MAX	2700-3600	64	110	101	156
MAX	3600-4500	63	102	92	158
MAX	4500-5400	67	108	91	148

High vehicle volume from Korsvägen

Table 19. Passenger distribution for Östra Hamngatan from 16th of December 2016 between 12-1 PM (Viscando, 2017a).

Higher vehicle input					
Type of road user	Bicycle		Vehicle	Pedestrian	
Direction/ Time interval	Toward Liseberg	Toward travel centre	Toward Liseberg	Toward Liseberg	Toward travel centre
Total [60 min]	22	39	1521*	413	332

*Since the vehicle input was 1500 vehicles per hour in the original model of Korsvägen, the same was used for this model.

RESULTS HIGH VEHICLE VOLUME

* TIMEINT: TimeInt, Time interval

* V(ALL): Vehs(All), Vehicles (All) (Count of vehicles of the data collection measurement in the interval)

		CONFLICT AREAS		***PRIORITY RULE***	
		BASE-MODEL	**OPTIMISED MODEL**	**BASE-MODEL**	**OPTIMISED MODEL**
EVALUATION	*TIMEINT*	*V(ALL)*	*V(ALL)*	*V(ALL)*	*V(ALL)*
AVG	1800-2700	288	369	363	370
AVG	2700-3600	275	366	353	365
AVG	3600-4500	284	374	358	380
AVG	4500-5400	282	370	366	378
STDDEV	1800-2700	28	27	22	21
STDDEV	2700-3600	25	23	15	16
STDDEV	3600-4500	31	33	21	23
STDDEV	4500-5400	22	26	27	21
MIN	1800-2700	235	321	314	339
MIN	2700-3600	228	325	330	331
MIN	3600-4500	223	307	329	338
MIN	4500-5400	239	323	322	338
MAX	1800-2700	342	410	409	425
MAX	2700-3600	305	423	379	400
MAX	3600-4500	326	427	396	429
MAX	4500-5400	313	410	409	427

Table 20. Results from investigated study areas, including the used volumes for pedestrians and vehicles.

		Pedestrians	Vehicles	Result conflict areas [vehicles]		Result priority rule [vehicles]	
Nr	Roads			Base-model	Optimised model	Base-model	Optimised model
1	Södra Strandgatan	269	690	1494	1496	1495	1496
2	Sprängkullsgatan	1348	647	571	760	873	1051
3	Västra Sjöfarten	46	352	1497	1496	1497	1497
4	Bergslagsgatan	494	704	1495	1495	1497	1497
5	Östra Hamngata	1738	100	165	354	306	526
6	Decreased pedestrian volume	403	1246	1501	1502	1501	1502
7	Increased pedestrian volume	4236	940	10	87	113	249
8	Increased vehicle volume	719	1521	1129	1479	1440	1493