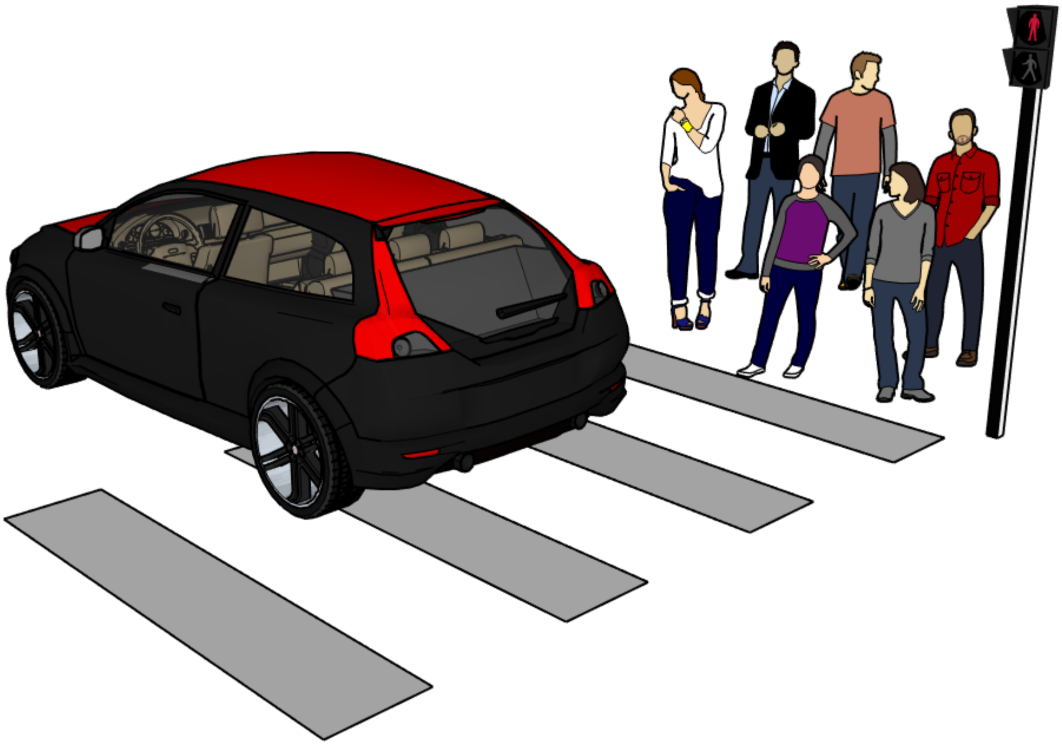


Pedestrian delays at Artillerigatan

A multi-method analysis of a select crosswalk in Gothenburg

Master's Thesis in Infrastructure and Environmental Engineering

JOHANNA GREGER
LINUS WREDE

Department of Architecture and Civil Engineering
CHALMERS UNIVERSITY OF TECHNOLOGY
Master's Thesis ACEX30-19-24
Gothenburg, Sweden 2019

MASTER'S THESIS ACEX30-19-24

Pedestrian delays at Artillerigatan

A multi-method analysis of a select crosswalk in Gothenburg

Master's Thesis in the Master's Programme Infrastructure and Environmental Engineering

JOHANNA GREGER
LINUS WREDE

CHALMERS
UNIVERSITY OF TECHNOLOGY

Department of Architecture and Civil Engineering
Chalmers University of Technology
Gothenburg, Sweden 2019

Pedestrian delays at Artillerigatan
A multi-method analysis of a select crosswalk in Gothenburg
Master's Thesis in the Master's Programme Infrastructure and Environmental Engineering

JOHANNA GREGER
LINUS WREDE

Supervisors: Sebastien Rauch, Department of Architecture and Civil Engineering
Maria Löfving, ÅF, Traffic Management
Examiner: Sebastien Rauch, Department of Architecture and Civil Engineering

Examensarbete ACEX30-19-24
Institutionen för arkitektur och samhällsbyggnadsteknik
Chalmers tekniska högskola, 2019

Master's Thesis ACEX30-19-24
Department of Architecture and Civil Engineering
Water Environment Technology
Chalmers University of Technology
SE-412 96 Göteborg
Sweden
Telephone +46 (0)31-772 1000

Cover: Sketch of pedestrians experiencing delay, made in SketchUp.

Gothenburg, Sweden, 2019

Pedestrian delays at Artillerigatan
A multi-method analysis of a select crosswalk in Gothenburg
Master's Thesis in the Master's Programme Infrastructure and Environmental Engineering
JOHANNA GREGER
LINUS WREDE
Department of Architecture and Civil Engineering
Chalmers University of Technology

Abstract

The city of Gothenburg is estimated to grow with approximately 150,000 inhabitants by year 2035. A goal is that Gothenburg should become a greener and more coherent city by then. One of the ways to manage this is to increase the share of travel on foot, which means that pedestrians as a means of transport need to be further emphasized. The aim of the thesis was to analyse the pedestrian situation in a specific crosswalk at Artillerigatan, primarily in terms of delay. The work was carried out with a multi-method analysis, involving manual investigation, video analysis through the software Flowity and traffic simulations through PTV Vissim 11. The current situation was quantified, and adjustments were made in the simulation software to make the traffic point more pedestrian prioritised. During an on-site investigation, it was established that many pedestrians crossed prematurely, before the signal had switched to green. It is later confirmed through video analysis that about 66% cross at red signal. It was concluded in the thesis work that Flowity, in its development stage at the time of use, was less adequate for the analysis. Because of struggle in retaining specific identities of pedestrians in view, only about 27% of the total sample size was able to be used. Through the video analysis, the average delay of 13.71 seconds was retrieved for pedestrians crossing at green signal.

Three predefined scenarios were structured as simulation models; a real-world scenario, a scenario with signal adjustments and a scenario where the vehicle speed limit was reduced. With the signal adjustments made in the second scenario, involving lowered signal cycle time, the average delay value for pedestrians was significantly reduced by 3.84 seconds. The share trips with delays above 25 seconds were also reduced. As the vehicle delays were only changed within the margin of error, the adjustments seem reasonable and Scenario 2 is thus a recommended suggestion for pedestrian traffic improvement.

Keywords: pedestrians, delay, crosswalk, video analysis, Flowity, traffic simulation, microscopic simulation, Vissim.

Gångtrafikanters tidsfördröjningar vid Artillerigatan
En multimetod-analys av ett specifikt övergångsställe i Göteborg
Examensarbete inom Mastersprogrammet Infrastruktur och Miljöteknik
JOHANNA GREGER
LINUS WREDE
Institutionen för Arkitektur och Samhällsbyggnadsteknik
Chalmers Tekniska Högskola

Sammanfattning

Göteborg beräknas öka sin folkmängd med ungefär 150,000 invånare till år 2035. En målsättning är att Göteborg skall bli en mer grön och sammanhållen stad tills dess. En förutsättning till att klara av det på är att öka andelen resor till fots, vilket betyder att fotgängare behöver bli mer prioriterade som transportslag. Syftet med arbetet var att analysera situationen för fotgängare vid ett specifikt övergångsställe på Artillerigatan, främst sett till fördröjningar. Arbetet utfördes med en multimetod-analys, innehållande manuell undersökning, videoanalys med programvaran Flowity samt trafiksimuleringar med PTV Vissim 11. Dagsläget blev fastställt och justeringar gjordes i simuleringsprogrammet för att prioritera fotgängare mer än vad som görs på platsen idag. Vid utredningarna på plats kunde det konstateras att många fotgängare korsar övergångsstället innan det slagit om till grönt. Det blev senare bekräftat genom videoanalysen att cirka 66% gick mot röd signal. I arbetet konstaterades det även att Flowity, i dess dåvarande utvecklingsstadium, var mindre adekvat för den aktuella analysen. På grund av svårigheter med att behålla specifika identiteter hos fotgängarna i bild kunde bara ungefär 27% av den totala insamlade datan användas. En genomsnittlig fördröjning på 13.71 sekunder för gångtrafikanter som gick vid grön signal togs fram med hjälp av videoanalysen.

Tre fördefinierade scenarion strukturerades upp som simuleringsmodeller; ett nutida scenario, ett scenario med justerat signalschema och ett tredje scenario där gatans hastighetsbegränsning sänktes. Med signaljusteringarna som gjordes i det andra scenariot, som innefattade en kortare omloppstid, förkortades gångtrafikanternas fördröjningar med hela 3.84 sekunder. Andelen resor med en fördröjning högre än 25 sekunder sänktes också. Eftersom fordonens tidsförluster inte påverkades märkbart kan justeringarna antas vara rimliga och Scenario 2 är således ett rekommenderat förslag till gångtrafiksförbättring.

Nyckelord: gångtrafikanter, fördröjning, övergångsställe, videoanalys, Flowity, trafiksimulering, mikroskopisk simulering, Vissim.

Acknowledgements

The thesis has been carried out at ÅF offices at Grafiska Vägen 2, Gothenburg. First we would like to thank the employees at the traffic management department for having us and providing support and insightful thoughts for the work. A special thanks to our supervisor Maria Löfving for being there and assisting in brainstorming and decision making. The video analysis part of the thesis was made in cooperation with Flowity developers Roger Tedblad and Per Brendelökken from the AI-department at ÅF. Without their help, the analysis would not have been possible. Appreciations are also directed towards Bengt Halling and Maria Olsson at the Traffic and Public Transport Authority in Gothenburg for assisting with suggestions for the choice of crosswalk.

We want to thank PTV Group for lending us an academic PTV Vissim 11 license. The simulation software was a central part of the thesis topic.

Next, we have a number of people from Chalmers to thank. First and foremost, thanks to Sebastian Rauch, who despite being professor in a different field of expertise, agreed to be the thesis' supervisor and examiner. Thanks to Alexander Erlandsson from Fote '19 who helped us capture photos of the crosswalk with the use of a drone. Lastly, our sincere gratification towards Alma Sjöö and Lina Sköldberg, who have been the opponents of the thesis and have provided useful feedback and discussion.

Gothenburg, May 2019

Glossary of Terms

Amber	The yellowish colour used in traffic signals to indicate that a signal switch is soon to come.
Artificial intelligence	Computer systems able to perceive its environment and perform tasks normally requiring human intelligence.
Cycle time	The time it takes to go through the signal sequence and return to its original state.
Delay	The additional time beyond what is required to perform a travel at the desired speed.
Footfall	A hypothetical line that measures the amount of people passing.
Green wave	A signal timing technique that coordinates a row of traffic signals to cooperate in a "wave" with green light.
GUI	Graphical User Interface, a user-friendly interface which permits easier interactions with computers through visual or graphical indicators, rather than text-based.
Traffic island	Pedestrian refuge area between the vehicle lanes of each direction. Common in Swedish crosswalks.
VAP	Vehicle actuated programming, where signals are actuated based on for example push buttons or buried sensors.
VTTS	Value of Travel Time Savings, a measurement used to compare travel time and travel costs of different travel modes.

English - Swedish translations

Swedish Transport Administration	Trafikverket
The Trade Market Institute	Handelns Utredningsinstitut HUI
Traffic and Public Transport Authority in Gothenburg	Trafikkontoret, Göteborgs Stad
Transport Analysis	Statliga förvaltningsmyndigheten Trafikanalys

Table of Contents

1. Introduction

Today's society faces continuously growing challenges related to traffic. As cities grow in population, more people have the need to travel using various means of transport. The city of Gothenburg is estimated to grow with approximately 150,000 inhabitants by year 2035 (Trafikkontoret, 2018). A goal is that Gothenburg should become a greener and more coherent city by then. This vision relates a lot to how the city is perceived by the citizens traveling on foot. In order to reach the goal, and for Gothenburg to become a more active city where the citizens can thrive, further knowledge about pedestrians is required. One of the ways to achieve this is to investigate the possibility of redesigning existing traffic sites to prioritise pedestrians as a means of transport (Trafikkontoret, 2018). In this thesis, a crosswalk at Artillerigatan was researched by the use of video analysis and traffic simulations, in order to investigate the validity of the software use as well as the possibility of improvement for pedestrians. The result will allow for reflection over how intersections could be changed, depending on which priorities are set.

1.1 Background

Almost 1,500,000 trips are made daily in the city of Gothenburg (Göteborgs Stad, 2019a). The share of private vehicles in the distribution of travel modes, see Figure 1, has declined in favour of public transport in the most recent years (Göteborgs Stad, 2019b).

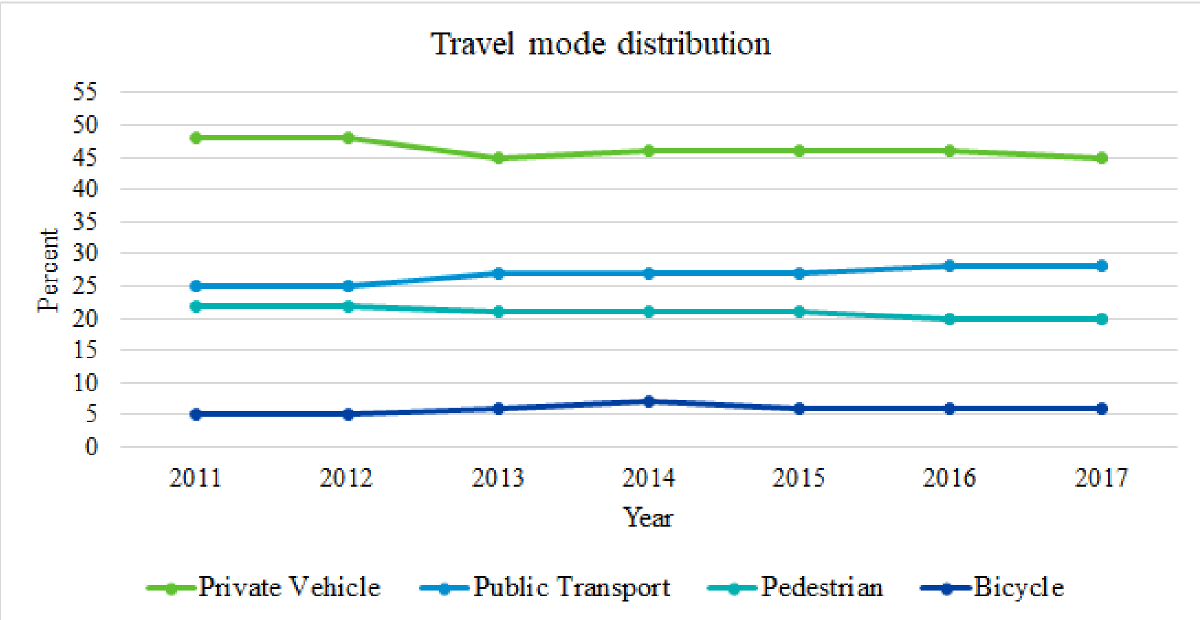


Figure 1: Travel mode distribution over recent years based on travel surveys issued by the Traffic and Public Transport Authority in Gothenburg (Göteborgs Stad, 2019b).

A referral was released in February 2018 with goals regarding an increased proportion of travel on foot and to increase the walkability, meaning walking-friendliness, of the city in general (Trafikkontoret, 2018). One goal is to increase the amount of trips made on foot from today's 22% to 28% in 2035. Nearly everyone is a pedestrian daily. For example, people using public transport are considered pedestrians both to and from the station. Walking, driving and using public transport are different means of transport but even though walking is its own transport mode, it is not sufficiently prioritised against the others. Traveling on foot is crucial for some people's daily travel. As has been mentioned, Gothenburg is expected to grow quite rapidly in population by year 2035 and thus increase the demand for trips. There are numerous benefits for cities where more people choose to walk, not only in an environmental perspective but also for public health and the contribution to a more active city. Examples of advantages are better air quality, less congestion, a decrease in noise pollution and a reduced rate of sick leave. Furthermore, walking is more space efficient than other transport modes and is therefore a strong argument to why more trips should be done on foot (Trafikkontoret, 2018).

When designing a traffic network for pedestrians, it is necessary to include and appeal to all users (Trafikkontoret, 2018). Pedestrian as a traffic mode is very broad and varying, since it also includes joggers, strollers and wheelchair-users among others. The ages also vary a lot, from children to elderly. In conclusion, the process is more complex than meets the eye. Because of the vehicle traffic generally being more prioritised than the pedestrian, pedestrians experience delays and limited accessibility relative to their general travel speed. This raises the question about whether they should be prioritised, at least in crossings where they have a high flow and thus high green signal demand. Crosswalks are especially interesting, as delays are generated here (Trafikkontoret, 2018). In a study conducted in China, 25% of responding pedestrians were refusing to use signalised crossings, and about 60% of them said it was because of delays (Anciaes & Jones, 2017). Delays are described as the additional time beyond what is required to perform a trip at the desired speed (Fi & Igazvölgyi, 2014). If the delays become too great, pedestrian patience wears out and they tend to cross on red signal if they find space between vehicles. This is dangerous, especially with limited vision (Trafikkontoret, 2018).

In a study, pedestrians were interviewed regarding a few selected crosswalks in New Zealand (Beca, 2009). When asked how long they had to wait before they could cross, the average perceived waiting time was much longer than the actual waiting time. In some cases even as much as double, proving that the subjective experience is quite difficult to quantify. The study concluded that waiting times beyond about 20-30 seconds makes the level of frustration associated with delays grow disproportionately, thus increasing the risk of red signal crossing.

A more comprehensive way to assess pedestrian delay importance is to apply a concept called value of time, or more specifically Value of Travel Time Savings, VTTS. Value of time is a measurement that can be used to value travel time and travel costs in comparison between different travel modes. According to a study conducted by CTS (2012), commuting and school trips have about 30% more valuable travel time than other private trips in Stockholm. It also showed that high variability in travel time, like with high congestion levels, the value of time also becomes higher. If the trips are of a very high value, self-selection will choose a fast and expensive mode of travel, such as car over bus, cycling and walking. This is the case for regional trips. But the study also states that theoretically there is a “split point”, where above travellers will choose car and below will choose another mode. The better cycling, walking and public transport are, the higher the split point will be. That translates to a lower share of motorised vehicle travellers. Thus, by reaching this split point with alternatives to vehicle travel, Gothenburg could go a long way for a more sustainable city life (Centre for Transport Studies, 2012).

1.2 Aims and Objectives

The aim of the thesis is to analyse the pedestrian situation on a specific crosswalk at Artillerigatan, primarily in terms of delays. If possible problems are identified, the magnitude of them is to be quantified and the situation should then be evaluated in scenarios where the pedestrian traffic is more prioritised. The summarised objectives are structured accordingly:

- The research should include literature study to increase the knowledge of pedestrians and walking as a means of travel in order to gain an understanding of how delays affect people.
- By attempting to collect data through video analysis, the full circumstances of the location should be quantified and evaluated using the software Flowity.
- Using compiled data from the video analysis, a real-world traffic model is to be created in the traffic simulation software PTV Vissim 11. The real-world model will be altered to become more beneficial to pedestrians, in order to provide suggestions for improvements.

1.2.1 Hypothesis

The impression of the crosswalk at Artillerigatan is that a lot of pedestrians are exposed to delays which probably will lead to a number of pedestrians crossing at red signal. The video analysis platform Flowity can possibly assist in measuring traffic flows as well as more complex parameters, such as delays, and produce a representative result of the situation. A factor that can become a challenge is that the detection software is perhaps less perceptive than the human eye, and may struggle distinguishing individual pedestrians. Further on, as the traffic simulation software PTV Vissim is well known on the market and its use is widespread, there is reason to assume that it would give a realistic result if done well. The notion is that the specific traffic point at Artillerigatan can be improved in delays, inter alia, for pedestrians through the simulation software use and that any adjustments made are justifiable and applicable to the reality.

1.2.2 Problem and Question Formulation

In order to assess the subject thoroughly and clarify its purpose, a set of problems shaped as questions are made to later be answered through the research:

1. By the use of video analysis software Flowity, can the current state be quantified? If so, how large are the delays for pedestrians that cross?

2. In theory, as mentioned in the background, when pedestrians experience large delays in traffic they tend to cross on red signals. How large of a quantity of people cross red signal at the chosen crosswalk?
3. Is it possible to improve the crosswalk for pedestrians with the use of PTV Vissim 11, and how?

1.3 Delimitations

The project will have the following delimitations set:

- The research will focus on primarily pedestrian traffic, and other traffic types will only be considered in comparison.
- Research area is concentrated to only one crosswalk in Gothenburg.
- The parameters considered will mainly be pedestrian delay and those closely related.
- On-site observations and measurements are subject to change depending on the day, weather and other factors. The thesis will only analyse the current scenario and circumstances of the day that is measured, and only two measured hours. An annual comparison is too extensive and redundant for the purpose of the thesis.
- Economical costs as well as emissions will be disregarded.
- The simulation will be simplified to only use fixed time in signal control. Adequacy of this simplification will be discussed.

2. Literature Study

In order to further assess today's pedestrian situation and gain an understanding of related systems and the means of being a pedestrian, the following chapter will contain relevant literature research. The study will be used in consideration while making decisions and choices for the latter parts of the thesis, where it will be referred to.

2.1 Pedestrians

Pedestrians often encounter obstacles when it comes to crossing busy roads (Kronborg, 2007). If the crossings are too few, too complicated or misplaced it will lead to detours and time losses for pedestrians. A benchmark for the density of crossings is that it should not be more than 100 meters between them. It is important to remember that pedestrians also want to arrive to their destinations quickly. However, pedestrians have a limited physical speed and is therefore also limited in possibilities to increase their travel speed. The average speed of all pedestrians is about 1.6 m/s, where the fifth percentile is slower than 1.2 m/s (Kronborg, 2007). Young men under 30 walk the fastest, while elderly and those with physical handicap are slower (Herrstedt, 2012). Due to that, the design of an intersection will affect pedestrians observably, and need to be well thought-out.

The most important factors for pedestrians is availability, perceived security and traffic safety (Kronborg, 2007). As pedestrians are more prone to cross red signals than other road-users, they are also heavily overrepresented in lethal traffic accidents. About 80% of all fatal pedestrian accidents in traffic was due to crossings at red signal. This can be explained through various reasons. The perceived risk is not correspondent with the objective risk, to which pedestrians cross the red signal thoughtlessly. Often the pedestrians themselves do not realise they are road-users, or that crossing red signal is an illegal action. Other reasons could be that pedestrians have less rules. They can be under the influence of mind-altering substances and they are not required to have a driving license or to pay attention in the same manner as a vehicle driver.

Statistics show that the most common preconceptions about pedestrian accident victims are true (Kronborg, 2007). They are often older in age. While the older pedestrians are less prone to cross red signal than others, the high representation in lethal accidents could be explained through other means. For example, they are less agile and quick in their movement, they have slower reaction times and have difficulties understanding the signal and traffic systems as a group. Additionally, they are more fragile and thus more likely to pass away in lesser impacts.

2.2 Traffic Signals

A traffic signal is a light or sound signal that control the traffic flow on the road and especially at intersections and pedestrian crossings (Trafiksakerhet, 2019). The three-coloured traffic signal is the most common for vehicles. Red, amber and green light depending on what information that is expressed. Red light means that it is forbidden to pass the stop line, amber light indicates that a signal switch is soon to come and green light means that vehicles are allowed to drive. Amber-red is a signal state that occurs before switching to green signal and all-red means that all traffic modes have red signal at the same time. All-red is used to make sure that all road users have time to complete their trip through the crossing before giving green signal for someone else. Unlike the signals for vehicles, the traffic signals for pedestrians usually consists of only two colours, red and green. Red light shows that they are not allowed to cross the road, but if there are people at the road when the signal is switching they should continue to the other side or wait at a traffic island if possible. Green light means, as mentioned before, that they are allowed to walk.

The signals at crosswalks can be expressed in different ways. In the United States it is common to have down counting traffic signals for pedestrians (Kronborg, 2007), whereas Sweden and its neighbouring countries have tried flashing green lights during the last five seconds of green time at some crosswalks (Lund, 2006). Both methods are aimed to inform pedestrians that a signal switch will soon occur. When people arrive at the crosswalk during the flashing period, they will have the choice between crossing with an increased walking speed or wait until the next green phase. This allows for a higher road capacity, where the all-red time can be decreased. The flashing traffic signals are, however, much disputed. The benefits of flashing traffic signals are not as clear as they were supposed to be and a lot of pedestrians do not know the function of it (Kronborg, 2007).

Traffic signals can be controlled either independent of the prevailing traffic or by detectors, cameras and push buttons (NTF, 2019). When detection is made through the latter options, the system becomes aware of the road users and looks to give way when possible. Pedestrian crossing signals are often on fixed-time or with push buttons while for vehicles it is common with sensors or cameras. Traffic signals are mainly designed to function smoothly for vehicles and it is therefore unusual to have pedestrian friendly signals (Städje, 2015). An example of this is the green wave. Green wave is a signal timing technique that coordinates a row of traffic signals to cooperate in a "wave" with green light. Based on the existing speed limit and the distance between the signals, a green wave can be set up. This technique is almost exclusively programmed for vehicles while all other traffic have to comply with the prioritised green wave. According to Peter Kronborg (2007), an abolishment of green waves would be better for pedestrians and let the signal cycle be as short as possible. He claims that it is a common misunderstanding that long green times should be better for pedestrians. Long green times results in even longer red times and due to that increased waiting times. Short green times on the other hand are better if it is long enough to let pedestrians with mobility impairments pass. A preferred signal technique for this purpose is to let the vehicles come in clusters rather than an even flow of single vehicles. The demand for green signal for vehicles becomes less frequent, giving pedestrians more opportunities to cross while also providing safety as pedestrians would be less likely to find gaps between vehicles to cross while their signal is red. He also claims that fixed time signals should be implemented during high traffic hours (Kronborg, 2007).

According to research done by Beca (2009) at crossings in New Zealand, a desired signal design should be engineered with consideration to all users of the intersection, and not just the vehicle count. By distributing the road space more evenly between its users, the system will have a fairer and more positive effect on the delay per person. Network performance is probably not measured with equal value of delay between traffic modes. Further on, their report suggested that in some areas with high pedestrian flows, the pedestrians contributed extensively to the generated per person delay, with total pedestrian delay sometimes being more than double that of the vehicle delay. The research showed that it is sometimes possible to improve the performance of the signals in a crossing without affecting the vehicle traffic notably. The time period that is outside of vehicle peak periods, and most commonly lunch time which is traditionally busy for pedestrian traffic alone, can sometimes have unused capacities to use for improvement (Beca, 2009).

2.3 Geometry and Design

There are numerous factors and parameters to adjust when designing a good traffic environment for pedestrians. While traffic signals can play a very important role, one must also look towards the general geometry and design of pedestrian lanes and crossings.

The importance of the placement of the traffic signal posts themselves can easily be overlooked. However, there are different ways to do this. The most common way in Sweden is to place the signal post on either the traffic island between the car lanes, or on the opposing side from where you stand (Kronborg, 2007). Besides that, the traffic island is a good place to mount both primary and secondary signals. Primary signals are most commonly those assigned for vehicles, while secondary are those assigned for bicycles and pedestrians. With this design, pedestrians are expected to see the signal while they are crossing and stop at the traffic island to wait for the next green signal, if it switches to red midway. Another way is to use the Puffin design which, according to Kronborg (2007), works well in Great Britain. This design instead uses a nearside signal, meaning that pedestrians only see the signals on the push box on their side of the road. The system also has sensors, making the green signal length vary depending on the pedestrian’s walking speed. Advantages of this design is that the green signal can be very short, followed up by an all-red signal of safety until the pedestrian has come across. This makes for shorter cycles, and thus a more continuous pedestrian flow where waiting times are lower. It is also possible to place the signal in such way that pedestrians can have an oversight of approaching vehicles. One of the major downsides, however, is that it would not work well with crossings containing traffic islands (Kronborg, 2007).

There were some problems related to the push button boxes commonly used at Swedish crossings in the report *Fotgängarvänliga Trafiksignaler* (2007). It was established that many pedestrians either did not press the button or pressed the button even though passage has already been called for. That means that the pedestrians either did not understand the function of the box’ indicator light, or that it was not visible. This led to the development of a new box which indicator light could be seen more clearly and from every angle around it, see Figure 2. Unfortunately, this had little impact on the issue.

Figure 2: A push button box with indicator light visible all around it.

Other important design choices can be based in other transport modes. Traffic situations are a correlation between different traffic modes, so one's benefit often comes at a cost of another's. If the focus is to prioritise pedestrians, certain design strategies can be done to "hinder" vehicle traffic. By for example installing the signal detectors for vehicles closer to the crossing so that the vehicle is detected later, the system will be less prone to give way for vehicles (Kronborg, 2007). Another way to prioritise pedestrians is to reduce the speed of the vehicles. In Sweden, the speed limit is commonly 50 km/h in cities. The Swedish government agency Transport Analysis had investigated and suggested that the speed limit ought to be reduced to 40 km/h, in response to the Vision Zero programme. Their investigation showed that a speed limit reduction would decrease the potential severity of accidents and reduce lethal accidents by 17 per year (Nordén et al., 2018). By introducing speed bumps in connection to the crossings or thinning the road, vehicles are forced to a lower speed. This can also be achieved by designing green waves to be slower purely with the use of signals (Kronborg, 2007).

The purpose of pedestrian design comes to action through its intended users. As has been said, this involves all people who travel on foot. This provides a sizable challenge, as the system has to accommodate for visually impaired among others. Some basic details from *Fotgängarvänliga trafiksignaler* (2007) with this in mind are:

- Simplistic design which cannot be misinterpreted, with few signal groups.
- Clear visibility with signs and markings, possibly traffic islands and also tactile markings leading up to the crossing, indicating where the crossing is.
- To create some distance for safety and comfort, the stop line for vehicles ought to be up to five meters away from the crossing. This also improves vision.

- Pedestrians and cyclists should be well kept apart.
- The push box has to have tactile markings with adequate information about the crossing, and fully functional acoustics.
- It is advantageous to have a short crossing, with as few vehicle lanes as possible. The crosswalk should be perpendicular to the street.

2.4 Pedestrian Flow Measurements

Common methods to collect data of pedestrian flows in traffic situations are on-site measurements using pen and paper or hand held clicker counters (Bjerhem, 2019). These methods have not changed much in the recent decades. Manual measurements can also be performed by looking at a recorded video from the site and using the same equipment. A video that has no disturbance can contribute to a high accuracy due to the possibility to watch the same sequence several times (Karlsson & Nilsson, 2017). Another, not as qualitative, method that has been used for this purpose is travel surveys (Bjerhem, 2019). By letting people answer questions regarding their travel habits, useful information can be collected. On-site measurements usually last for 15, 30 or 60 minutes.

When doing traffic analysis and flow measurements, an important factor is to decide when to do it. Traffic behaviour and flow volumes are highly dependent on factors such as the time of day, or period of the year (Federal Highway Administration, 2016). The daily variations patterns are dependent on the trip purposes, such as commuting or recreational, and land use in the area. This can be seen per direction too, where a high flow of commuters travel into the city at morning and return home in the afternoon. Recreational traffic, such as shopping, is instead more common on weekends. Therefore, the results from the area of research is dependent on location, if it is close to offices and workplaces, or perhaps a shopping mall. The flows also heavily fluctuate depending on season. During summer for instance, the share of recreational trips is larger due to holidays. It is most common to take measurements during peak hours (Roess & Prassas, 2014). However, even though traffic points are being designed for peak hour demand, fluctuations within the hour itself can surpass the designed capacity. As such, if deemed necessary, studies and flow measurements ought to be done in smaller increments to assure the absolute maximum and prevent breaching capacity limit.

For pedestrian traffic, there is a relation between weather and the total flow volumes. In a study conducted by Aultman-Hall et al. (2009) in Vermont, it was established that precipitation as well as winter seasons decreased the pedestrian flows, and made road users more prone to choose driving over walking or biking. The authors also had the notion that the perception of the weather could be more of a deterrent than the weather itself (Aultman-Hall et al., 2009).

Pedestrian flows are rarely measured within the municipalities and pedestrian traffic itself is not as established in research as bicycle and vehicle traffic (Bjerhem, 2019). But there is a lot of technology development in the category. The trade market institute, HUI, and the general trade market itself are driving the technology the most at the moment. Cameras inside some shopping malls can capture exactly how one moves, what shelves one sees and where one looks. This is incredibly important for the trade market itself and the techniques they use can be of great value for municipalities. According to Joakim Bjerhem (2019) this trend is clear, the demand for more and qualitative data has increased due to the desire of building pedestrian-friendly cities.

A new method for measuring pedestrian flows is to detect mobile phones searching for Wi-Fi (Bjerhem, 2019). This method has recently been used successfully in the city centre of Kristianstad. When phones are detected, the system is able to track them and map out the movements of the owners, creating walking patterns and flows in a large scale. Another advanced method is the video analysis. The video analysis has encountered problems with ethics, but in the current situation, new technology can de-identify people in such an early stage that performing the measurements are easier. There are cases where a permission for the law of camera surveillance is not needed. A third method is Space Syntax which is a theoretical model that is based on the street network instead of actual behaviour.

2.5 Flowity

Flowity is a flow and movement analysis platform that detects humans and other types of objects such as cyclists and vehicles (Tedblad & Brendelökken, 2019). It uses artificial intelligence to find specific objects in an image and return its coordinates, and is then able to track them. Its development began in 2018 by the company ÅF's artificial intelligence division, and is predicted to have a constant development to always fit the customers demand. According to the developers, the technique of artificial intelligence provides greater opportunities than conventional computer vision technology that has been more uncertain of what it counts due to mainly detecting movements and the differences between various movements. Flowity on the other hand is able to confirm the type of object, and is less sensitive to image noise and lighting variations in video. Beyond that, a video can be recorded with almost any camera equipment since Flowity is very adaptable (ÅF Digital Solutions, 2019).

Flowity can be used as a real-time system based on the information it sees or as a tool for analysis of pre-recorded videos (Tedblad & Brendelökken, 2019). The fields of application are mainly in traffic and real estate. Flowity makes it possible to see how people and other vehicles move and form the basis for decisions of where, for example, crosswalks or billboards should be placed. The result can be presented in numerous ways. Commonly the results can be directly integrated into the customers own systems where they can access the information. From there, the customer can choose how their systems will react to the information in real-time, like for example increase the heat, open a door or turn off the lights. Other ways are to return and present the results in various types of logs or store it in databases. Should the customer prefer, the results can also be returned as a map of movements in real-time, rather than raw data.

When running Flowity in real time, every image frame is processed instantly, and then immediately discarded (Tedblad & Brendelökken, 2019). The only information kept by Flowity is the relative location of the object in the camera view and an anonymous identifier for each object. Flowity is well suited to be used in settings where it is crucial to collect fully anonymised data to conform with data regulations, such as GDPR.

2.6 Traffic Simulation

Traffic simulation is a powerful tool when it comes to mimicking the actual road traffic and enables recreating and running different traffic scenarios that can form the basis for decision making. Traffic simulations can be divided into three categories; Macroscopic, Mesoscopic and Microscopic (WSP, 2016). The major difference between the categories are the size of the traffic network and the level of detail required in the model. A macroscopic simulation is used when a large traffic network will be analysed, like a city, region or a country. If the purpose is to analyse a smaller city, a mesoscopic simulation can be used instead where the level of detail is higher than for a macroscopic simulation. The highest level of detail is possible in a microscopic simulation there every single vehicle, bicycle and pedestrian can be simulated individually in a crossing or small district.

PTV Vissim is a microscopic, time step and behaviour based simulation tool developed by the German company Planung Transport und Verkehr AG, PTV AG (PTV Group, 2017). It is the world leading program when it comes to performing traffic and transport simulations and has more than 16500 users worldwide (PTV Group, 2019). A reason for this is the opportunity to build up a detailed model that generates a realistic overview. Over and above vehicle traffic, pedestrian and public transport traffic can be modelled and simulated as well. The fields of application are, among other things, traffic design comparisons, capacity analysis and traffic control system analysis (PTV Group, 2018). PTV Vissim enables comparisons between different traffic scenarios which can form the basis for decision-making.

The following chapters will present how a traffic network can be set up in PTV Vissim. Network objects relevant for this thesis are in focus and explained below. The network setup guidelines are based on the PTV Vissim 11 User Manual released in 2018.

2.6.1 Links and Areas

One of the first things to do when setting up a model is to add links. Links constitutes the basis for transportation. There are lots of possible settings for the links that enable modelling a large selection of different road types. Examples of possible link behaviours are: urban motorised, freeway and footpath among others. If a link is aimed to be a footpath exclusively, the attribute “Use as pedestrian area” must be selected. The width of the different links as well as number of lanes can easily be changed in the editor list. Furthermore, the network object “Areas” are used for pedestrians and can be added as a polygon, rectangle or a circle. Areas allow for the use of for example Pedestrian inputs and routes, see Chapter 2.6.4 and 2.6.5.

2.6.2 Conflict Areas

A conflict area occurs when two or more road users approach each other in a manner such that there is risk of collision, like with links crossing each other and roads merging together. The model-creator decides the status of conflict areas, which link that should have the right of way. Figure 3 displays three different conflict area statuses. The yellow markings means that it is a passive conflict area where nobody has right of way. The second and third illustration shows the statuses in colours, green indicates right of way and red indicates yield.

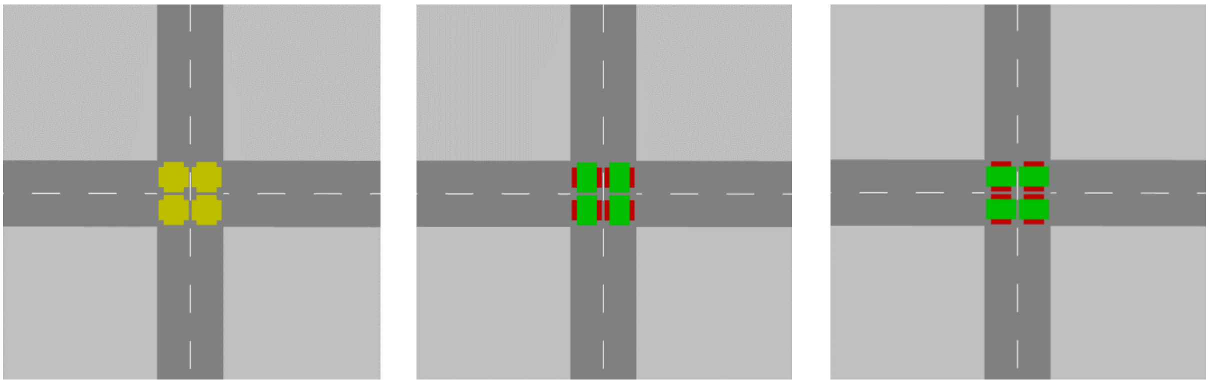


Figure 3: Three different conflict area statuses illustrated in colours.

2.6.3 Traffic Signals

Depending on the size of the PTV Vissim license, the user gets access to a different amount of signal controller types. Fixed time is a common controller type and is available in all sizes of the license. To create a fixed time signal controller, the signal groups must be defined. Signal groups are the signals for each specific traffic mode or direction. There is no limit of how many signal groups that can be added in a signal controller, it depends on the complexity of the network. Only two signal groups are needed for a simple crosswalk, one group for vehicles and one group for pedestrians. When the signal groups are generated, a signal program must be created for each of them. The first step is to define the cycle time and then decide the length of the different signal states. Only then will the associated signal heads make use in the network.

Another signal controller type is vehicle-actuated programming, VAP, which is an add-on module to PTV Vissim. By adding sensors in the network, the signals will be called for if detected. The signal controller can be programmed by defining the program logic in a flowchart editor or in a text file. Signal data can also be made in a text editor or exported from another add-on module called Vissig.

2.6.4 Routes

Routes have to be drawn to define routing decisions for vehicles at road branches. Unlike vehicles that only needs routes if it is more than one routing decision, routes is a requirement for pedestrians to be able to transport themselves. Additionally, the pedestrian route must be drawn from an area to another with a link in between.

2.6.5 Vehicle and Pedestrian Input

Vehicles and pedestrians are added to the network through the input function. The vehicle input can be placed on any road that allows vehicles and the location of the input point can be anywhere along it. However, the vehicles will adjust to the direction of the road. Pedestrian input on the other hand must be added on an area, as mentioned earlier. Another option to add pedestrians into the network is to create an origin-destination matrix, OD matrix. The hourly volume of pedestrians in combination with the origin and the destination area's relations forms the matrix. Hence, by creating an OD matrix, pedestrian inputs and routes do not need to be added to the network separately. Finally, there are several vehicle and pedestrian types available that later on can be grouped into classes to facilitate specific scenarios if desired. Cars, heavy goods vehicles, buses and men, women, wheelchair users are some examples.

2.6.6 Travel Time

Travel time measurements can be done for both vehicles and pedestrians. By adding a start and an endpoint, the time needed to travel between them are measured. It is also possible to get delay measurement through this network object. The difference between the measured travel time and the theoretical travel time without obstacles results in a delay.

2.7 Decision-making for Projects

There are numerous ways to structure a decision's provided advantages and disadvantages. In order to assist decision-making more deeply for a project, three efficiency criteria commonly used in economics can be looked upon; Pareto, Kaldor-Hicks and Little (Pettinger, 2017). In order to satisfy a Pareto criterion, at least one part must see improvement, while no part receives exacerbation. If the Pareto criterion is possible to apply, it could warrant real changes as there would supposedly be no downsides. However, normally in a crossing where two traffic modes meet, one's benefit comes at the cost of another's, so the criterion could be otherwise hard to fulfil. The second criterion, Kaldor-Hicks, instead dictates that as long as the total sum of benefits surpasses the total of losses, it is acceptable. And the more on the plus side the better, however high the losses for one side may be. This would mean, for example, that in a traffic related project, increase of delays for vehicles are allowed, if the delays for pedestrians are significantly lowered, or vice versa. The Kaldor-Hicks criteria regrettably comes with downsides however, the main one being that it capitalises on numeric or economic improvements, and lack moral values being taken into account. It also indirectly assumes that the losing part can be compensated.

In Little's criterion, these downsides are lessened (Shailes, 2019). It is somewhat a compromise between Pareto and Kaldor-Hicks criterions, and dictates that a solution with no downsides is preferable, but downsides for one part is allowed as long as it is within reasonable limits and not too far from the original state. The individuals should be in centre of focus and value assessment. As such, any adjustments for a traffic area could for example be based on benefits for the individuals directly in the traffic network, like comfort and perceived safety, rather than an economical perspective such as road space efficiency for vehicle traffic. Little's criterion is appropriate for decisions looking to not worsen the situation for any part too much, while still making sizable improvements.

3. Study Area

This chapter presents the area of study. In order to investigate the chosen crosswalk more closely, a case study has been conducted. For more information regarding the decision of choice, see Chapter 4.1. The crosswalk was visited for a general understanding of its circumstances, design and geometrics. Further investigation carried on through studying maps and reviewing literature. The Traffic and Public Transport Authority in Gothenburg is aware of the crosswalk being problematic for pedestrians, and had thoughts on improving it.

3.1 Location of Chosen Crosswalk

As has been mentioned, the chosen crosswalk to be studied lies on the street Artillerigatan in northeast of central Gothenburg, see Figure 4. It is denoted by the tram and bus station named "SKF" after the company Svenska Kullagerfabriken, Swedish Ball Bearing Factory, which have their offices nearby in the area.

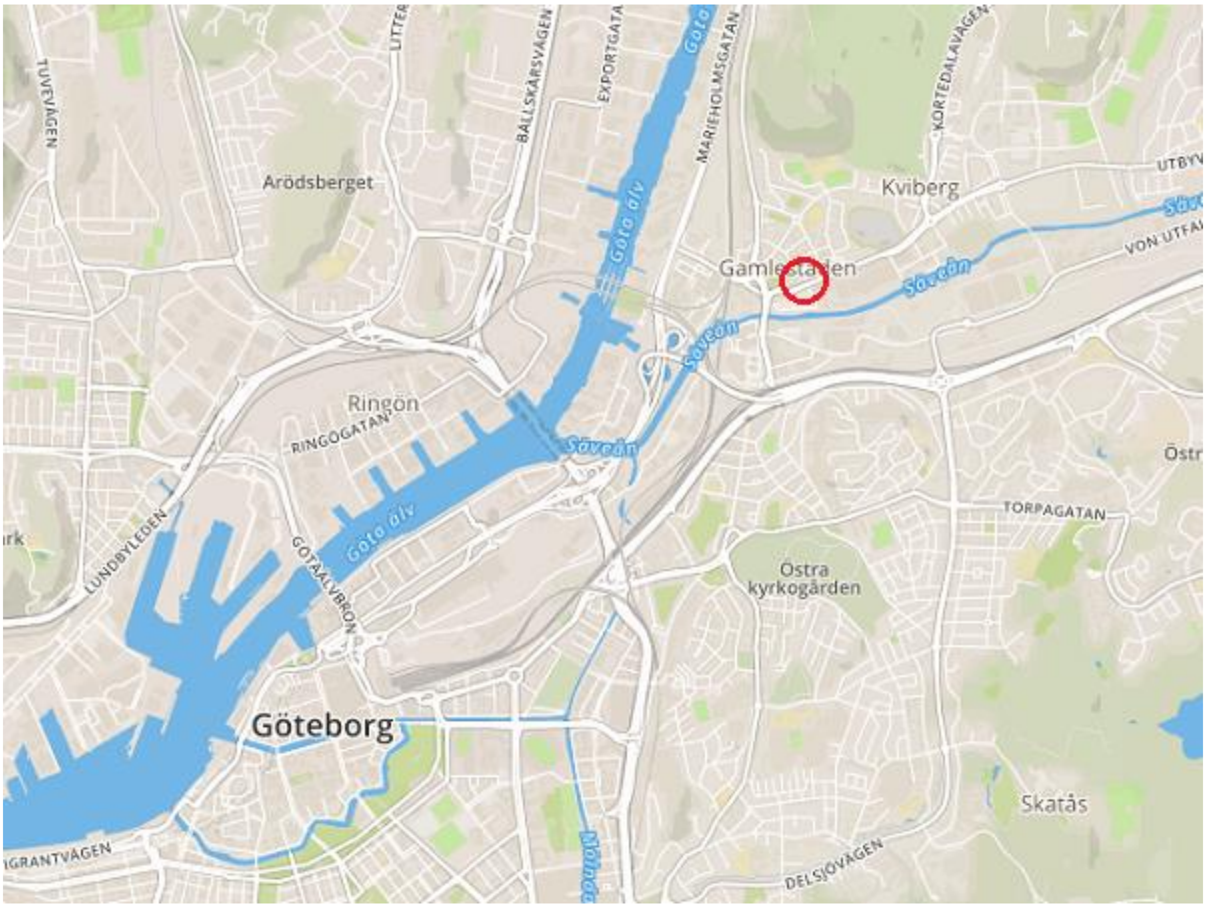


Figure 4: Chosen study area located in Gothenburg (Satellitkarta.se, 2019).

The area sees large quantities of pedestrians daily, since there are many offices to commute to. Recreational usage is high within the area. Plenty of restaurants, cafés, small shops and a grocery store, as well as a gym, drug store and Systembolaget for example. Roughly 350 meters away lies the primary-school Gamlestadsskolan, with about 650 students (Göteborgs Stad, 2019c). There is also a mosque 480 meters away in eastern direction.

The communication opportunities in the area are really good since the tram lines 6, 7 and 11, together with the bus lines 58, 69 and 519, have many departures the whole day at the tram and bus station SKF (Västtrafik, 2019). Between 4 pm and 5 pm, the trams arrive more frequent than one per three minutes in each direction, in total 42 departures both ways. The bus departures are a bit fewer but still 24 during the studied hour.

Figure 5 displays a close up the chosen crosswalk in the middle, together with the tram station at the bottom of the picture as well as a bus stop in the upper right corner.

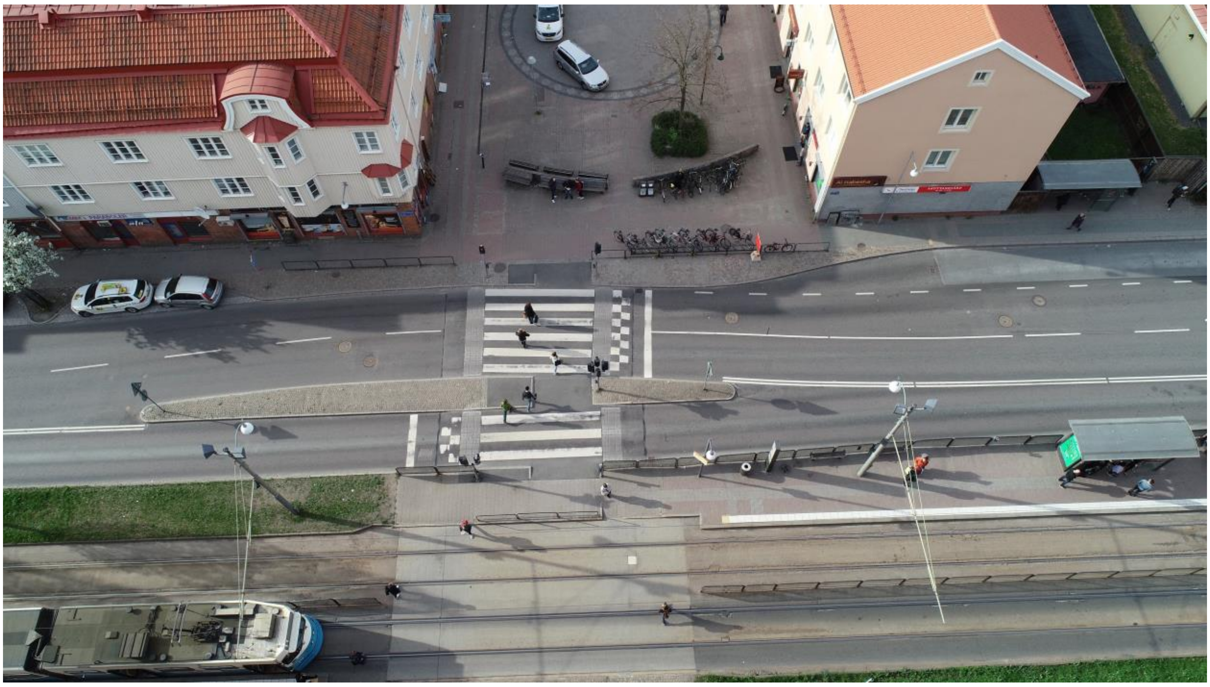


Figure 5: A drone picture of the chosen crosswalk (Erlandsson, 2019).

3.2 The Design of the Crosswalk

The crosswalk itself is placed on top of a speed bump to force vehicles to reduce the speed. A traffic island is located in the middle of the crosswalk and divides the footpath into two parts. The crossing’s curbstone has been removed on one side, making the area flat enough for wheelchair and stroller accessibility. Furthermore, there are one pedestrian signal head on either side of the crosswalk as well as a double-head for each direction in the traffic island. In addition to this there are five pedestrian push buttons that actuate green signal, distributed on either pedestrian or vehicle signal posts. Two on each side of the road and one placed on the signal post in the traffic island. The two boxes on the north side is of the design with a round-going strip of indicator light on top. The location of the signal heads, the geometric dimensions and shape of the crosswalk can be seen in Figure 6, with north pointing upwards.

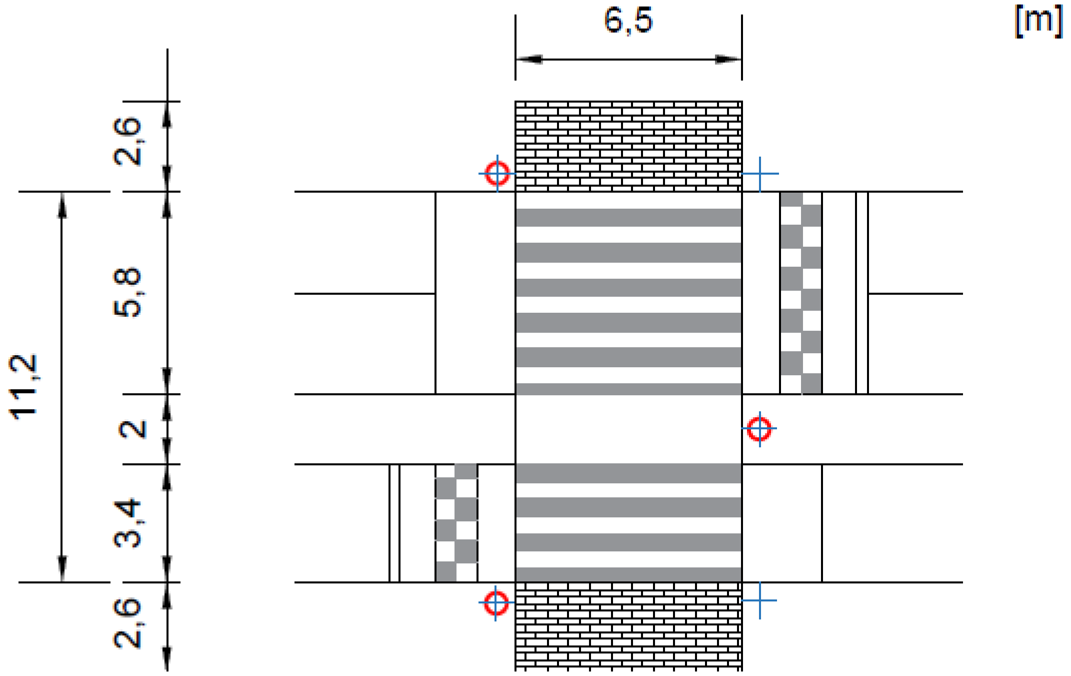


Figure 6: Measured geometric dimensions and layout of the crosswalk.

Figure 6 is a produced design based on collected data, made in AutoCAD. The waiting areas on each side of the road is roughly 6.5 × 2.6 m^2 of paving stone. The total crosswalk area is about 11.2 meters in distance, with a 2 meter long traffic island in the middle. There is one lane going east and two lanes going west. Close to the stop line, chequered road markings indicate the elevation of the speed bump. Red rings mark the location of the pedestrian signal head posts, and blue crosses mark the location of the push button boxes. Beyond that, the distance to the stop lines are 3.35 and 3.80 meters on the north and south side respectively.

3.3 Traffic Signals

The traffic signal is designed with vehicle-actuated programming and is centrally controlled. Based on timing, the cycle time has been found to be roughly 50 seconds with 15 seconds of green time for pedestrians upon demand. A more specific time distribution is 15 seconds green for pedestrians, 2 seconds all-red, 1 second amber-red, 26 green for vehicles, 4 seconds amber and 2 seconds all-red. The time distribution is displayed visually in Chapter 4.3.1. As mentioned earlier, the push buttons are used to actuate green signal.

4. Methodology

The following section will describe the approach and process of the thesis work, from planning state to performance as well as how decisions and limitations were made in order to meet the aims of the thesis.

4.1 Planning and Criteria

The thesis topic was initially a self-invented idea, which expanded through brainstorming and discussions with teachers and consultants in the field. A draft was created and presented to the traffic division at ÅF, which agreed to supervise the work. In order to concentrate the work to a comprehensible size, it was decided that the study should be focused to one crosswalk alone.

The next step was to decide which crossing or crosswalk that was best suited for the topic. The following criteria for the area of focus was concluded to be met:

- The crossing or crosswalk must not be too complex, as it would require extensive simulation work which is outside the scope of the thesis aim.
- There should not be traffic signals programmed for public transport priority, and thereby not contain tram rails or bus-only lanes for same reasons as above.
- The area must see a high flow of pedestrians at the crossing, at least in select critical hours of the day. This will represent the sample size of analysis, and define the importance for the crossing to become more prioritised for pedestrians.

Through discussions with supervisors, employees at ÅF and with Bengt Halling and Maria Olsson at the Traffic and Public Transport Authority in Gothenburg, various crossings and crosswalks have been suggested and looked upon. A day of site investigation for a number of candidate crossings was also conducted. A good example which many contacts suggested was the four way crossing at Sankt Sigfridsgatan near ÅF's offices, where the pedestrian delays were observably large. However, this crossing was deemed too complex. Bengt Halling came up with the suggestion of the crosswalk at Artillerigatan in Gothenburg which fit all the requirements well, and it ended up being the chosen one. For further information about the chosen crosswalk, see Chapter 3.

4.2 Data Collection

Geometric data collection and general observations were done initially, before gathering traffic flow data. The dates when the flow data was collected can be seen in Table 1 below. The choice of hours for data collection was reflected from the literature study. To gather all important data regarding pedestrians, a GoPro camera was set up. A specific scope and angle was needed for the camera to enable further analysis in the software Flowity. Therefore, the camera was mounted approximately four meters above ground level on a lamp post near the crosswalk. The camera was connected to a mobile phone which facilitated the control of it. While the camera was turned on, vehicle flows in both directions was quantified with hand held clicker counters, since Flowity was incapable of detecting other means of traffic the moment the data collection took place. Pedestrian flows were counted while viewing the recordings. Due to file size limitations in the SD-card of the camera, the full-sized videos were split into three parts of separate videos. The video reached file size limit at roughly 21 minutes, meaning that the first two were 21 minutes, and the last video was 18 minutes.

Table 1: Compilation of dates of conducted observations

Date and time	Day of the week	Weather	Temperature
February 5 07-08	Tuesday	Cloudy, windy & drizzle	1°C
February 5 16-17	Tuesday	Cloudy & breezy	1°C

In order to be able to work in road and traffic networks, one must undergo a small course about information and safety called "Arbete på väg", issued by the Swedish Transport Administration. This was required in order to perform the site investigations and camera montage. ÅF issued certificates confirming that this education had been completed.

4.2.1 Video Analysis

When analysing the videos, the morning videos were not able to be used. Because of the weather, rain had covered the camera lens to a large extent, making it too difficult for Flowity to detect pedestrians. Additionally, the camera had shut itself off after roughly 44 minutes of video, thus not yielding the full hour intended to be analysed. The decision was made to continue the analysis with only the videos from the afternoon, which also by manual observations had a better potential and higher traffic flows.

The recorded videos from the afternoon were prepared for analysis by adding shapes and lines in a still image of the video, a more user-friendly implementation to set coordinate limitations. The shapes are programmed as waiting boxes in Flowity and the lines as footfalls, see Figure 7. Per request, the Flowity program has been set up by developer Roger Tedblad to provide the output data needed for the thesis. Once preparations and all necessary elements have been tuned accordingly, the video is then rendered through Flowity with a powerful computer. This results in a video with annotations and an output file containing the necessary data.

Figure 6: The interface of an early iteration of an annotated video produced by Flowity.

The annotated video displayed how Flowity has interpreted the situation and all moving objects. It has a counter for each footfall by each direction, the current traffic signal colour, as well as the content-display for each waiting box, shortened to WB, at the specific time in the video. Pedestrians and vehicles were detected and assigned a specific ID number and detection box, to be individually tracked both in the annotated video as well as in the code of the output file. The footfalls and WB register the detection box at the centre of the bottom line. The annotated video was also analysed in order to control the results legitimacy manually. When a pedestrian disappeared from the camera's field of view, or was covered by other elements, its ID's got replaced or removed after a set amount of time. This time frame is titled as the ID's "age". When an ID has gone missing, Flowity will remember and try to relocate the object until the time frame has passed.

The output file was natively in the file format .json, JavaScript Object Notation. However, in order to compile the results more easily, the file was instead output as an .xlsx which is the file format corresponding to Microsoft Excel. Reading the file, the data was structured as events occurring in columns at set timestamps in rows from the video. The videos were rendered at roughly 33.37 FPS, frames per second, which means that an hour of video was translated into roughly 120 000 timestamps, or rows. The final iteration used to produce the results had a set ID age of 100 frames, or roughly three seconds, to account for pedestrians passing under the traffic heads. This ID age increase, from the original 20 frames, caused Flowity to produce the pedestrian flow values much higher than what the real numbers were. Therefore the analysis carried on with flow values from the manual counting, as the age increase made other important parameters better. The different events, columns, that were recorded can be seen in Table 2.

Table 2: Event categories and description recorded in the output file.

Event	**Description**
Waiting box content	Each waiting box displays the specific IDs it contains at the specific timestamp.
Waiting box length	Length in programming language normally depicts the amount of characters in a string. This is the amount of separate IDs simultaneously contained in the specific waiting box.
Zebra A, Zebra B	Displays the specific IDs that has passed either footfall in direction A or B.
Zebra A length, Zebra B length	In case of pedestrians passing a footfall at the same time, the amount of separate IDs at the specific footfall and direction is displayed.
Colour detect: car_red, car_green	Boolean output returning the state of the vehicle's traffic signal. If the red signal is lit, car_red returns "True" and if the green signal is lit, car_green returns "True". If any signal is not lit, the corresponding function returns "False".
Colour detect: ped_red, ped_green	Same as previous, but instead operates on the pedestrian traffic signal.

4.2.1.1 Method 1

With all data collected and sorted, a plan to reach a result was structured. Microsoft Excel hosts a multitude of ways to reach the goal, and how to interpret if the result is representative or not. As the thesis is looking to evaluate time delays for pedestrians, they were the centre of interest. All traffic flows and their directions could be extracted by simply reading the zebra counters in the annotated video, but they were as mentioned before, incorrect and therefore not used. Extracting the delays however, is a bit more challenging. In order to get a valid delay for each respective pedestrian, the result was filtered through various criteria. The first criterion, C1, was that the pedestrian has to be detected in all waiting boxes and footfalls in the correct order of direction because Flowity detected all people in view, but only the people that fully pass the crossing were of interest. The second criterion, C2, was that the pedestrian traffic light must be green. The thesis are based on a functional system in the intended design, which is that pedestrians only cross for green as on red is illegal. An argument for crossing on red when it was all-red being valid could be made, but it was ultimately ruled out since it is still a traffic hazard. Any scenario where the traffic signal was red while crossing one zebra section but was green while the crossing in the other zebra section was also ruled out, as the pedestrian was deemed to not intentionally pay attention to the signal. Lastly, the result was manually controlled as a criterion 3, C3, to confirm if it was valid or not. The delay is represented as the total time spent in each waiting box summarised. Some reduction in time was made in each waiting box to compensate for the time it takes to travel through the box, as this is not delay itself, see Formula 1. The result would otherwise include for example the time spent in the last waiting box after the pedestrian already made its crossing.

$$Time\ inside\ WB = Travel\ Time\ (TT) + Delay \tag{1}$$

To start off with, the dataset was quite large, so the solutions must be able to operate on large arrays. By separating the data in the waiting box content columns into separate columns per content, the data was converted from strings into numbers. Extracting the data this way was easier and required less computing power than to operate on strings, where specific elements of the string has to be found. From there on the rest of the process carried on using ID number as the row index. Each individual ID's occurrence in each waiting box was quantified using COUNTIF, returning the total number of occurrences. Using an IF statement, where the COUNTIF was larger than zero, the IDs were filtered to the first criterion of existing in all waiting boxes and footfalls. The number of IDs that passed the first criterion can be summarised again using COUNTIF.

After filtering the rows of the IDs that passed the first criterion, the next step was to find which traffic signal occurred when the ID passed both footfalls. This was achieved using VLOOKUP, where the second criterion would be fulfilled only when the green pedestrian signal returned "True" at both footfalls. The remaining IDs that fulfilled both the first and second criterion were then tested in the last control, which was to validate them manually in the video. In case the ID had jumped between different pedestrians, had been outside the boxes or covered excessively much to the point where it cannot represent the crossing, the data was filtered out. The IDs passing respective criterion were referred to as "Legal" with C1, C2 or C3 as index, stating which level of criterion is regarded.

To get the LegalC3 IDs delay, the values produced by the COUNTIF function in the beginning were used. Since the numbers dictated the amount of timesteps in each waiting box, they were converted into real time. Some small adjustments were however needed to be done. By using the average pedestrian travel speed of 1.4 m/s, as well as the geometric measurements of the crossing from the site investigations, it was concluded that roughly six seconds of the time spent in the waiting boxes needed to be deducted. This was split into two seconds, applied to each box individually. This was to account for making a pass through the waiting box. However, if the occurrence in a waiting box was lower than two seconds, the function was set to return a zero, as otherwise it would have given a negative value which would spill over to the other waiting boxes' times. Lastly, as could be seen in the annotated video, the ID tracking tends to "flicker" when pedestrians cover each other in passing. This resulted in the ID not being traced in some timestamps where it should have, and can be seen missing in a few cells in a larger consecutive stream of the ID being detected in the code. To compensate for this, while also making the result more comprehensible, the total delay in the distribution table was rounded up to even seconds with the function ROUNDUP. This was not done while calculating the average, median or standard deviation. Now the result can be sorted after the number of pedestrians experiencing specific amounts of delay in seconds.

When viewing the result from using this method, it was quickly realised that Flowity had limited ability in retaining IDs for specific pedestrians, as a very large amount of data was filtered out, leaving only a very small sample size to remain. Some reasons why this could be, can be viewed in the Discussion, Chapter 6.2. The result was therefore regrettably not representative, both by the numbers produced and the remaining sample sizes compared to the pedestrian count. Because of this, Roger Tedblad came up with a new idea of a method, where more data could be pertained. This method will be referred to as Method 2, or M2.

4.2.1.2 Method 2

Method 2 strives to retain as much of the data as possible, and was therefore more general rather than specific. While not all IDs would become legal in C1 because of them swapping between pedestrians etcetera, the idea was that most of all accumulated waiting time in each box was still delay for pedestrians, regardless of which ID that was held. The first step was to set up a filter, where pedestrians just passing either waiting box 1 or waiting box 3 without the intention of crossing the crosswalk, would be disregarded. The filter was structured to summarise all time generated per ID, as long as the ID was either higher than a set minimum time, or that the ID also crossed a footfall. This was a more simple and forgiving way to apply an occurrence criterion compared to Method 1, where the ID would only be required to occur in either one waiting box or in some cases a waiting box and a footfall. The minimum time was set per box to filter most of the pedestrians not crossing the crosswalk, as they would only have a rather low time being their travel time. This is only required in WB1 or WB3, as all pedestrians in WB2 would have needed to pass the crosswalk.

Taking into account the camera position, the geometries of the waiting boxes in field of view and the pathing of pedestrians passing by, the minimum time is set to six seconds for WB1 and four seconds for WB3. In case the crossing pedestrian had a low occurrence in the box, such that it was green signal upon arrival, its time contribution will still be added because it crossed the footfall. After the filter was applied, the same time reduction used in Method 1 of two seconds for travel time, is deducted for each ID and box. One crucial step in this method was to also manually control and remove some individual IDs, as it was found that WB1 was a common place for pedestrians to hang out and chat for a while. All three videos contained smaller groups of people staying in the box without actively intending to pass the crosswalk, thus generating unnecessary occurrence time.

By summarizing the total remaining amount of time for each waiting box, and dividing with the amount of pedestrians passing the crossing per direction, an average delay was calculated. This delay will however be with green and red crossings mixed, and there is no way to see the distribution of delays for each pedestrian. While Method 2 provides a somewhat realistic result, it was not very specific. When brainstorming about ideas on how to assess this problem, Method 3 was thought out.

4.2.1.3 Method 3

This method looks to combine Method 1 and Method 2, in order to achieve a more realistic result. In Method 1, a major problem coming from its small sample size was that those with longer waiting times were for a larger extent excluded. The longer an ID was in the system, the higher was the risk of it jumping between pedestrians and becoming invalid. Therefore, the IDs that passed Criterion 3 were likely among those having shorter delays. The IDs crossing at red signal is however more likely to be shorter and the sample size for those were also larger. Therefore, Method 3 operated with the use of the calculated average delay for red crossings. By comparing the sample sizes in C3 between green and red crossings, a rough percentage of the distribution between the crossings' signal colours was obtained. Lastly, in Method 2, a total delay was calculated. By using the following Formula 2, a new average for green signal-crossing delay was calculated:

$$AvgGreenDelay = \frac{TotDelay - (AvgRedDelay * PedCount * RedCross)}{(PedCount * GreenCross)} \qquad (2)$$

Where,
AvgGreenDelay = Average delay for green crossings [s]
AvgRedDelay = Average delay for red crossings [s]
TotDelay = Total accumulated delay from Method 2 [s]
PedCount = Total pedestrian count [persons]
RedCross = Share of pedestrians crossing at red signal [%/100]
GreenCross = Share of pedestrians crossing at green signal [%/100]

4.3 Traffic Simulations

An in scale base simulation model with all desired settings, except active traffic signals, was initially created in PTV Vissim. The design and dimensions were based on the collected geometric data as well as satellite photos from Google maps. The first things added in the network were the urban motorised links for vehicles, one footpath for the pedestrian crossing and the tram rails for public transport. Pedestrian areas were placed at the ends of the crosswalk as well as an interconnected waiting area and platform for public transport trams. The status of the conflict area between pedestrians and vehicles was set to passive since traffic signals were installed afterwards. Reduced speed areas were also added at the crosswalk, that forced the vehicles to pass with a speed of 20 km/h in comparison to the rest of the motorized link that had a desired speed of 50 km/h. The amount of speed reduction seemed reasonable and representative compared to the site investigation. However, routing decisions at road branches were defined with the vehicle route network object and the amount of vehicles per hour was added through a vehicle input. Pedestrians on the other hand were added into the network differently, namely through an origin-destination matrix, OD matrix. Both origins and destinations must be defined on pedestrian areas, thereby the area on the plaza side together with the public transport waiting area was selected as both origin and destination, depending on the direction of the pedestrians. A desired speed, based on observations and literature, was set between boundaries of 1.2 to 1.7 m/s for all pedestrians. The generated pedestrians obtain a random value of desired speed between the boundaries. Vehicle and pedestrian inputs were based on the manually generated flows. Furthermore, timetables for bus and tram departures were added to simulate reality as much as possible.

The simulation model was programmed to have 100% green crossings by pedestrians even though it was not the case in reality. This was made in order to get an idea of the size of the delays as well as the capacity of the crosswalk in a case where all pedestrians cross the street at green signal, which is the actual objective. However, as mentioned in Chapter 4.2.1.2, the average delay for Method 2 was a mix of green and red crossings. To be able to imitate a situation like that and to compare the result with Flowity, an alternative solution was made. By using the base simulation model with conflict areas that favours vehicles instead of traffic signals, a situation where pedestrians cross at red signal was created. Combining the result from that simulation with Scenario 1 in Chapter 4.3.1, another delay distribution for the combined scenario was found. The ratio between them are based on the percentage calculated in the video analysis. This distribution is also presented in Chapter 5.2.

Lastly, the different scenarios were structured and simulated in Vissim. Ten number of runs containing 3600 seconds each were simulated for all scenarios and the one with an average delay closest to the total average was used. In addition to this, the data was gathered between 60 and 3660 seconds into the simulation to let the traffic getting started. The simulation results were presented in an output file and delays were then compared. By using the efficiency criteria, explained in the literature, to assist in deciding which adjustments to make, it was established that the focus would be to try to fulfil Little's criterion. The different scenarios are described in more detail in the sections below.

4.3.1 Scenario 1 - Real-world

The real-world scenario strives to imitate the current traffic situation as much as possible when it comes to geometry as well as traffic signals. A copy of the base simulation model was used when programming the signal controller and fixed time was used as the controller type, as was stated in the delimitations of the thesis. Two signal groups were defined, one for vehicles and one for pedestrians. A signal program was created for each signal group, see Figure 8. The cycle time, set to 50 seconds, and the length of the different signal states was based on manual timing from the afternoon video, see Chapter 3.3, and can be seen in Figure 8. The green-time for vehicles was 26 seconds, and 15 seconds for pedestrians.

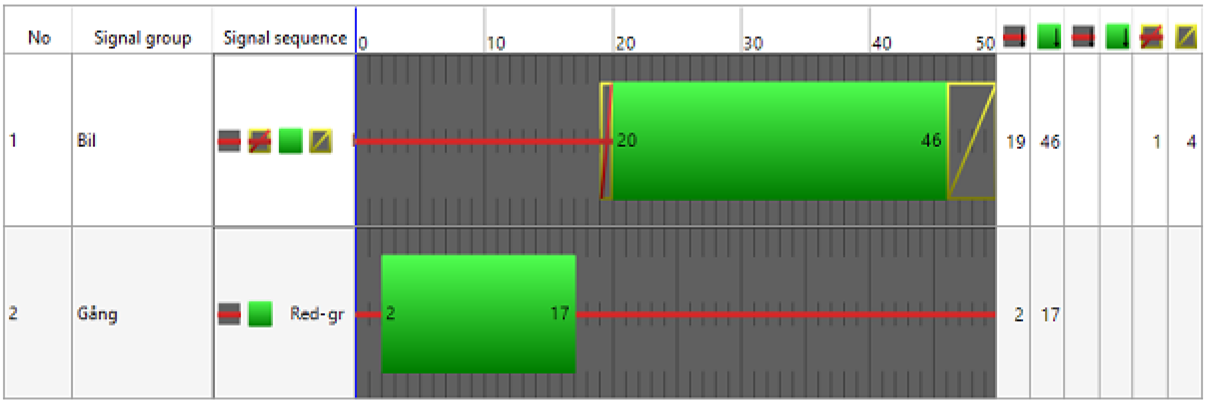


Figure 7: Signal program for vehicles and pedestrians with a cycle time of 50 seconds.

4.3.2 Scenario 2 - Signal Adjustment

The adjusted scenarios aims to reduce delays for pedestrians without increasing the delays for vehicles considerably. Therefore, a lot of simulations with varying cycle times and different length of the signal states were simulated. Each simulation run resulted in a list with parameters such as delays. The average delay generated by pedestrians and vehicles respectively, in both directions, were noted. An increased delay was written with a plus sign (+) and a reduced delay with a minus sign (-), beyond the actual value. By adding up the delays for pedestrians and vehicles, a new value was created. The higher negative the value was, the better, seen from a delay perspective. However, although delays were the primary, it was not the only crucial parameter taken into account. As mentioned in the literature, perceived security is an important factor while designing traffic networks. With this in mind, Scenario 2 was defined according to the following figure, Figure 9. This scenario has eleven seconds shorter cycle time compared to the real-world scenario but the all-red, amber-red and amber signal has the same length as previously. Instead, the green time for vehicles was 18 seconds, a reduction of 8 seconds, and the green time for pedestrians 12 seconds, a reduction of 3 seconds.

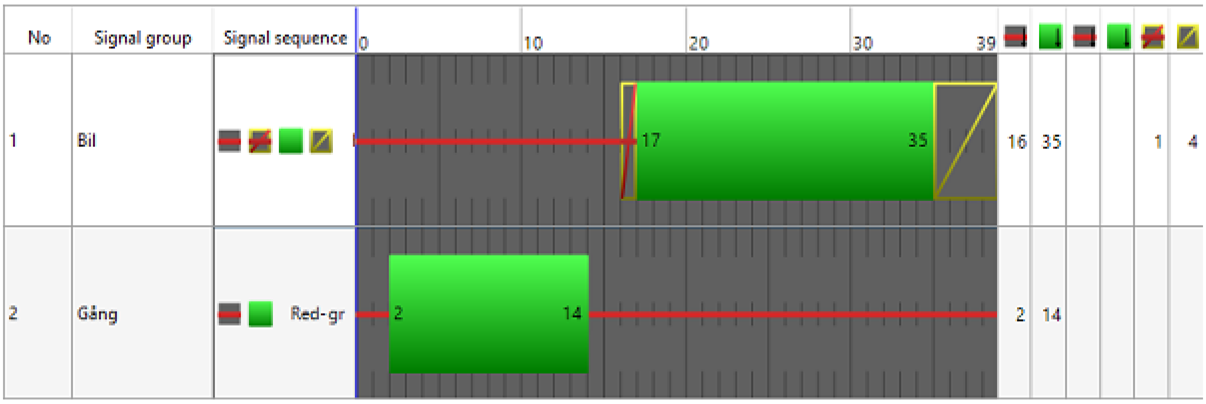


Figure 8: Signal program for vehicles and pedestrians in a cycle time of 39 seconds.

4.3.3 Scenario 3 - Speed Limit Reduction

The idea with the third scenario was to do a more infrastructural change, beyond the traffic signals. Therefore, the speed limit of the road was reduced from 50 km/h to 40 km/h in accordance with the suggestion from Transport Analysis, mentioned in the literature study. In addition to that, one second from the amber signal was taken away since the stopping distance is shorter with a lower speed. As seen in Figure 10, the cycle time was 49 seconds.

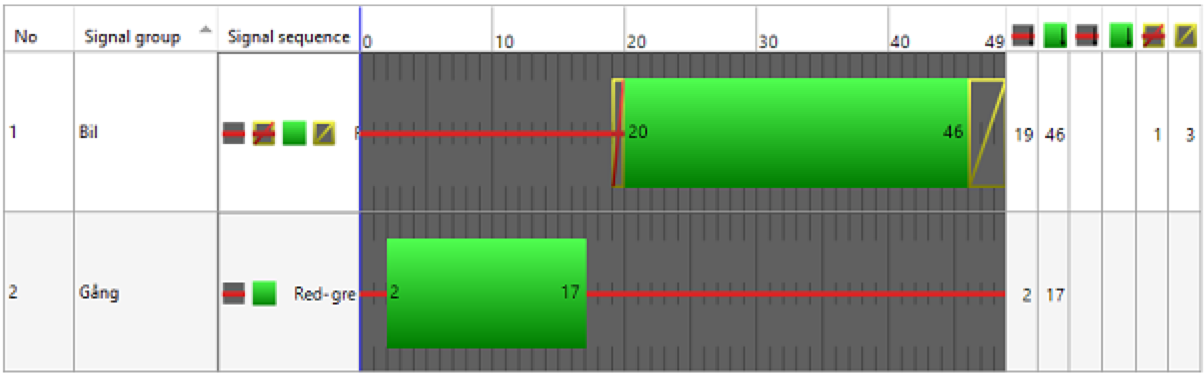


Figure 9: Signal program for vehicles and pedestrians in a cycle time of 49 seconds and a speed of 40 km/h.

5. Result & Analysis

In this section, the results of on-site investigations, video analysis and traffic simulations will be presented, described and compiled. Evaluation, legitimacy and adequacy of the results will be discussed in Chapter 6.

5.1 On-site Investigation and Video Analysis

The pedestrian and vehicle flows measured from the on-site investigation can be viewed in Table 3. As previously mentioned, the morning video was shut off prematurely. It's pedestrian values have therefore been based on the average flow of the 44 minutes of video, and then projected into a full hour's flow, see asterisk mark (*) in Table 3. During the on-site investigation it was observed that the flow of pedestrians was at its highest during the afternoon. The amounts in the morning were higher in the last half of the measured hour, but compared to the afternoon, lower in total. The vehicle flows are as expected, being higher going into town by morning and higher going out of town in afternoon. This is a clear commuting behaviour, and the flow sizes match each other somewhat. The morning's east-flows are a bit lower than the afternoon's west-flows. The total flow of vehicles was higher than the total flows of pedestrians, but this only takes into account the pedestrians passing the crosswalk, and not those walking along the sidewalk.

Table 3: Traffic flows per direction of the measured hours.

	Pedestrian flow	**Pedestrian flow**	**Vehicle flow**	**Vehicle flow**
Direction	North	South	West	East
February 5 07-08	182*	275*	423	277
February 5 16-17	366	382	362	474

Further on, the flow of pedestrians is highly volatile in the north direction, as it mainly comes in small groups exiting the tram station. The pedestrian age distribution consists mainly of adolescents going to school or adults in working age. A few strollers with infants were seen, about six, but a low amount of elderly and disabled pedestrians. Passing the crosswalk at red signal was very common. One of the push button boxes for pedestrians did not work when pressed, but lit up when any of the others were pressed. Lots of drop offs from the vehicles were made, either in the bus pocket or by the crosswalk. The vehicle types were very varied between service vehicles, trucks, private cars, slow moving vehicles and buses.

The results from the video analysis made with Flowity are presented in Table 4. The afternoon hour's three video parts, named PM1 through 3, were analysed separately and a consolidation between them was made. In the consolidation, pedestrian counts are summarised, and percentages and delay times are a calculated average between the three video parts. The total pedestrian flows from both directions, used in the video analysis, are presented in the table in order to compare it with the amounts passing each criterion.

Table 4: Compiled list of results obtained through video analysis performed with Flowity.

Video Analysis	**PM1**	**PM2**	**PM3**	**Consolidation**
Pedestrian flow [persons]	227	313	208	748
Method 1				
Passed C1 [persons]	131	181	103	415
Passed C2 [persons]	35	59	35	129
Passed C3 [persons]	20	35	15	70
Crossing red [%]	70	62	66	66
Crossing green [%]	30	38	34	34
Avg. green delay [s]	5.18	10.57	7.20	7.65
Median green delay [s]	3.84	6.41	4.51	4.92
Stdev. green delay [s]	5.49	10.81	8.28	8.19
Avg. red delay [s]	4.93	6.44	4.44	5.27
Method 2				
Tot. acc. delay [s]	1887	2990	1347	6224
Avg. delay [s]	8.49	9.47	6.44	8.13
Method 3				
Avg. green delay [s]	16.26	14.53	10.41	13.73

The pedestrian amounts are, as previously mentioned, the values counted by hand because the values produced in the footfalls by Flowity became very inaccurate with the last iteration that increased ID age. The amounts that pass the criteria is relatively low, especially between C1 and C2. This is because a very large quantity of pedestrians are crossing red signal, and that C2 is set to also rule out crossings where either footfall-pass was being done on red signal. Many red crossings are made during the all-red signal, meaning that the pedestrians are too quick and cross before the signal has switched over to green. The difference between C2 and C3 should be as close to zero as possible, as this filter strictly removes inaccurate results produced by software limitations. With future software optimisations, this could be improved.

The distribution between red and green signal crossings is consistent between all video parts, being between 60 to 70% crossing at red signal. PM2 is the lowest of the videos, but had the highest sample size so it is likely closest to the reality. This number is also consistent with perceived observations made during the site investigation. In Figure 11, the distribution of the combined result is more clearly visualised.

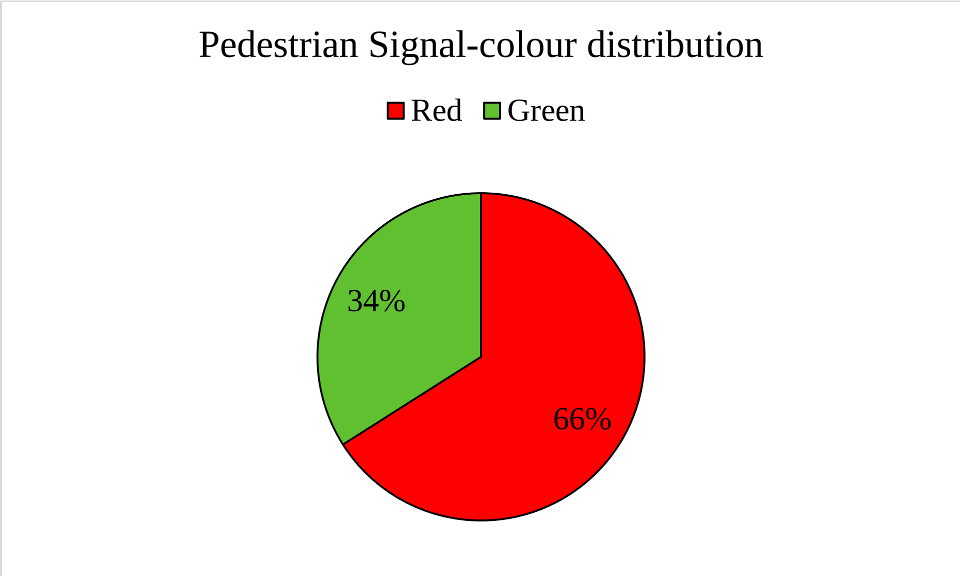


Figure 10: The signal colour distribution for pedestrian crossings in the combined result.

The results of the statistical parameters related to delay in Method 1 are relatively low, the average delay for green crossings are quite close to the red crossings. The values for average green delay was higher in PM2 than the others, and was in video observation much better in detection, but is still quite low. Because of this, the result was deemed not representative, compared to on-site observations. This could be due a number of reasons, but as previously mentioned, primarily the following two. Firstly, the sample size became very small after filtering with all criteria. Secondly, the software struggled to consistently retain its assigned IDs to each pedestrian. This means that pedestrians that stayed longer in the system, such when waiting for green signal, ran a higher risk of losing the assigned ID. While waiting in a stationary position, pedestrians often become covered either by other waiting pedestrians, or pedestrians passing by. This means that the result consists only of primarily the low waiting times of the total sample size, as the longer ones were filtered out. The average red delay seemed much more reliable though, and in line with on-site observations. Realistically, red waiting times ought to be relatively low since pedestrians would only wait for a gap between passing vehicles. Compared to the average waiting time in Method 2, which consists of both red and green signal crossings in a mix, the values were deemed representative. The new calculated average for green delay in Method 3 is however relatively close to the perceived reality of on-site observations, being only slightly lower. One explanation for a low average delay value could be that in case the pedestrians would be stuck in long waiting times, they would be more prone to cross at red signal. Thus, there would be fewer of the higher waiting times contributing to the result.

The last observation that can be done from the table is the total accumulated amount of waiting time. A large portion of this was generated in PM2, and the total was summarised to roughly 1 hour and 44 minutes of total time loss for all pedestrians in this hour. If this is assumed to be the same for all hours during a normal day's working hours, this number would be roughly 13 hours and 50 minutes of time loss per day.

In Table 5, the total sample sizes remaining after all filters were applied, can be viewed. The LegalGreenC3 are all green signal crossings which passed C1, C2 and C3, and the LegalRedC3 are all red signal crossings which passed C1 and C3, but with any of the red crossing combinations, rather than a green crossing, in C2. When divided by the total amount of pedestrians during the hour, the percentage of successfully gathered samples is found. The remaining missing percentages are data which was not able to be used due to software inaccuracies. As only roughly 27% of the sample size in Method 1 is being used, this analysis suggests that further software development and improvement is needed.

Table 5: The sample sizes and software accuracy in percent.

LegalGreenC3	LegalRedC3	Total flow	Rate (%)
70	132	748	27.01

In Figure 12, the total delay distribution of the 70 green signal crossings obtained from all video parts combined is presented. The values of delay has been rounded upwards to even numbers. As can be seen, the distribution has more weight on the lower side of the spectra, due to reasons previously stated in this chapter. There are however some values which are rather high, surpassing recommended values from the literature when looking to minimise pedestrian agitation.

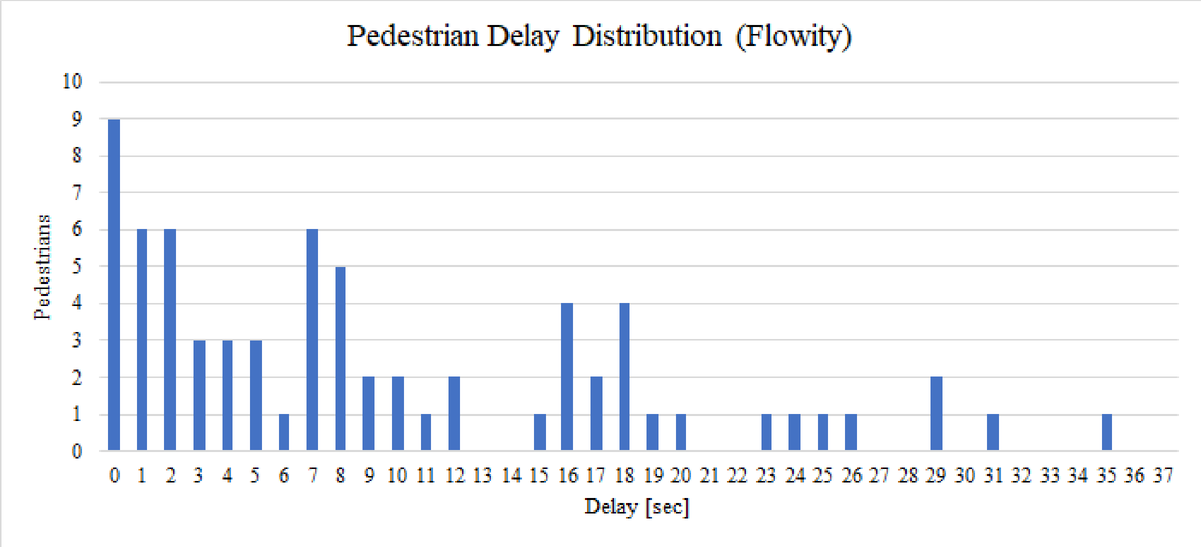


Figure 11: Graph of pedestrian delay distribution obtained through the video analysis with Flowity.

5.2 Traffic Simulation

The result from the on-site investigation and the video analysis formed the basis for the inputs in Vissim. The result of that is now presented in this chapter. Firstly, the created base simulation model turned out to be quite similar to reality when it comes to the infrastructural part, which was the purpose. The visual result of the base simulation model can be seen in Figure 13 and 14. Red and green markings at the road in Figure 13 shows all conflict areas in the network except the ones at the crossing that were set to passive. The yellow rectangles are reduced speed areas and the red rectangles are public transport stops. Furthermore, the tram stop consists of a waiting area, blue, and a platform, pink.

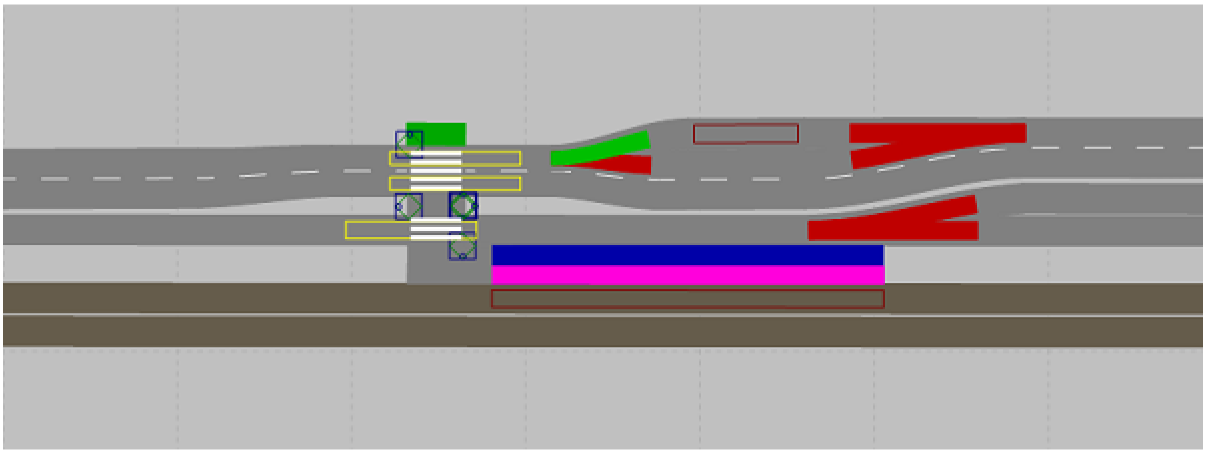


Figure 12: A close up of the base simulation model with some of the network objects visible.

The traffic signal heads are visible in the 3D view, Figure 14. The 3D view also shows that some pedestrians are queuing behind others which causes some smaller delays due to throng and differences in reaction time as well as walking speed while switching to green signal.

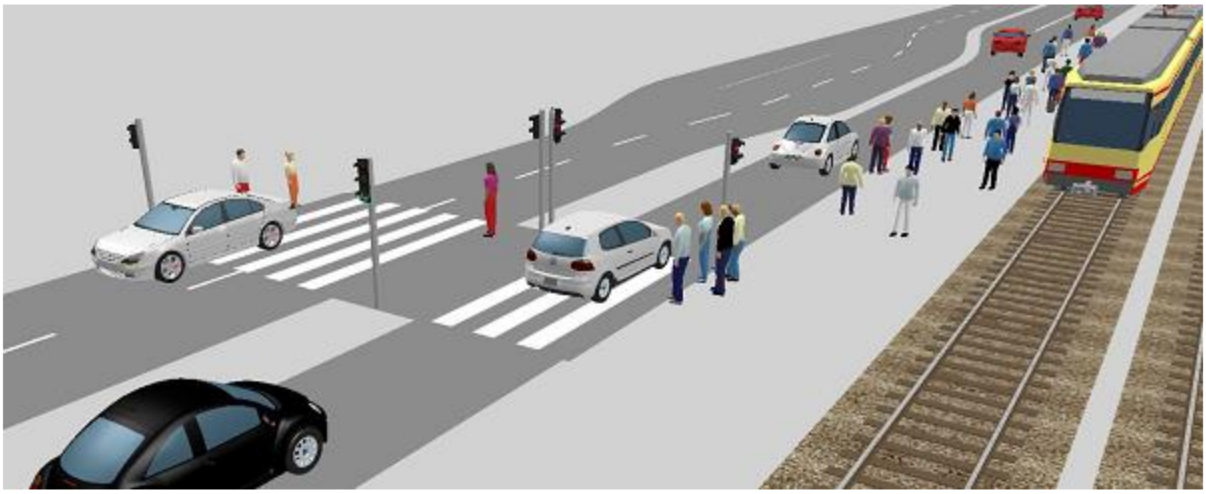


Figure 13: The base simulation model running in 3D.

As mentioned in the methodology, ten simulation runs of one hour each were made for all scenarios since Vissim uses a stochastic distribution which means that every run will be different from one another. The differences were quite clear between the ten runs, both in the generated number of road-users entering the system but also the returned delay data. Therefore, the most fair and representative delay results were expressed by selecting the simulation run which values were closest to the average values between them. Figures 15, 16 and 17 present the delay distribution graphs for pedestrians from the most representative runs in each scenario, and Table 6 and 7 shows the compiled statistical parameters for pedestrians and vehicles separately. All chosen runs contained 768 pedestrians each, which is 20 pedestrians more than the input value. The choice of starting the data collection 60 seconds into the simulations made it possible to start in a system that already contained pedestrians instead of an empty system, which is a reason to the greater pedestrian flow.

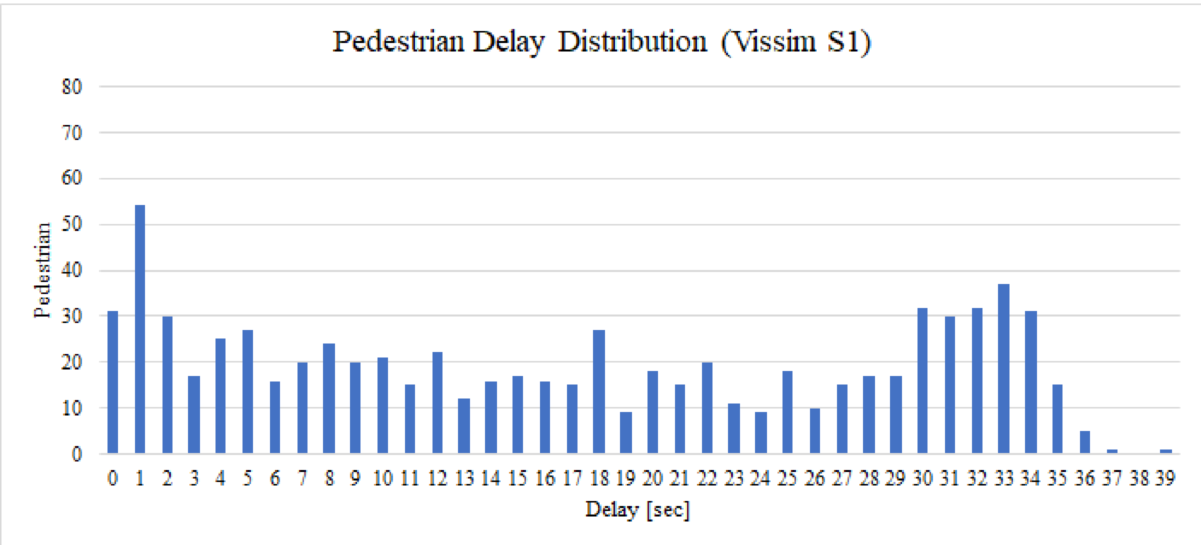


Figure 14: Delay distribution graph for pedestrians in Scenario 1.

The graph, Figure 15, shows high quantities of pedestrians with a very low delay of roughly zero to two seconds. This is due to the fact that all pedestrians that arrive to the crosswalk during green signal are not subjected to delays caused by traffic signals. Even though the signal is green, pedestrians are commonly exposed to other causes of delay anyway. This can be due to for example throng, which explains why there are lots of one and two seconds delays seen in the graphs. This is also a reason as to why there exists delays higher than 35 seconds, which is the highest red signal time for pedestrians. Furthermore, there are noticeable high quantities at the end of the graph compared to the middle part. For discussion of possible explanations for this, see Chapter 6.3.

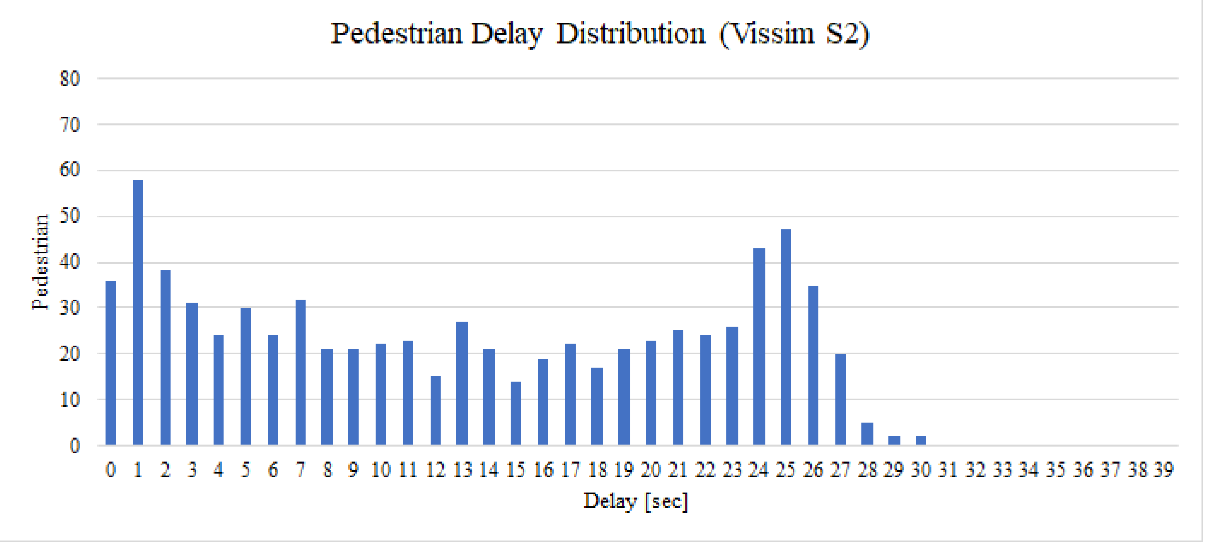


Figure 15: Delay distribution graph for pedestrians in Scenario 2.

In similarity with the previous graph, Figure 16 has the same appearance at the low delays as well as at the end. Since the number of pedestrians that entered the system was the same in all three scenarios, Scenario 2 thus handles the same amount of road-users distributed on fewer posts. It is also shown that, due to the reduced cycle time, the highest achieved delay was 30 seconds. The adjustments made in Scenario 2 has cut off all delays between 31 to 39 seconds visible in the first scenario.

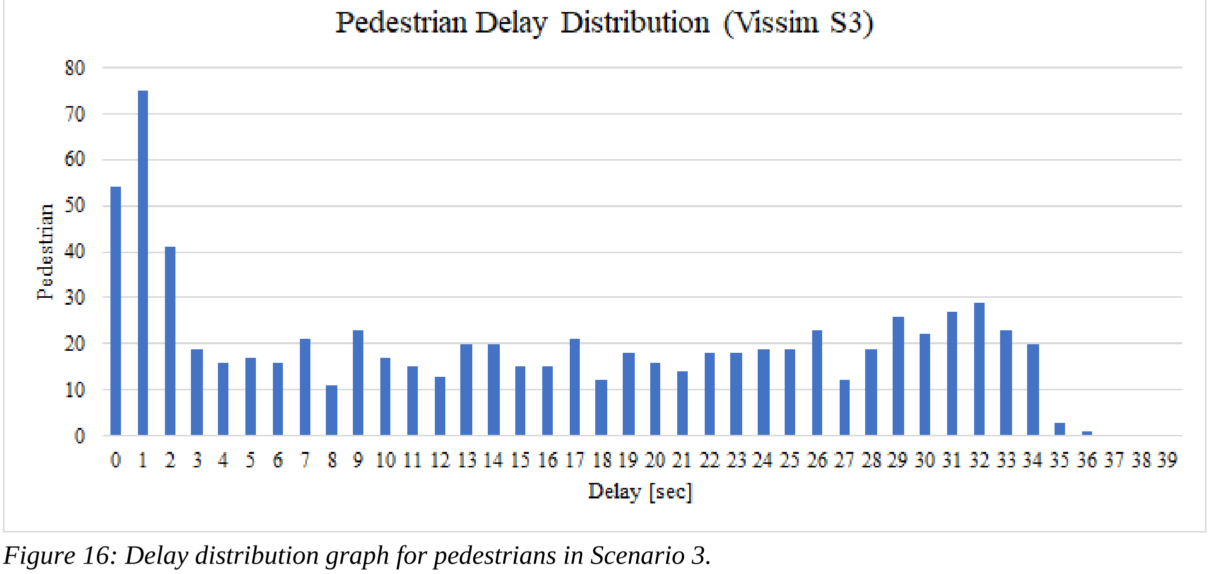


Figure 16: Delay distribution graph for pedestrians in Scenario 3.

The adjustments made in Scenario 3 led to an equalisation of the delays, except from the quantity of pedestrians exposed to zero to two seconds of delay that in this case is more distinct than in previous graphs, see Figure 17.

As can be seen in Table 6, the average delay for pedestrians in the real-world scenario, Scenario 1, is 16.97 seconds. By comparing this scenario with scenario 2 and 3, it is clear that both scenarios led to a reduction of the average delay. A delay reduction of 3.84 seconds was reached by making the traffic signal adjustments in Scenario 2. The percentages of pedestrians being subjected to high delays are, in addition to that, much lower in comparison. Scenario 2 lowers the delays equal or higher than 25 seconds with 20% and the delays equal or higher than 20 seconds with 10%. The reductions for the third scenario are 3 respectively 5%. It is also clear from Table 7 that the average delay for vehicles are slightly lower, even though vehicles driving in eastern direction are subjected to nearly a second of increased delay. Scenario 3 is more similar to the first scenario, but still an improvement.

Table 6: Compiled table of statistical parameters for pedestrian delays.

Pedestrians	**Scenario 1**	**Scenario 2**	**Scenario 3**
Avg. delay [s]	16.97	13.13	15.81
Med. [s]	16.50	12.90	15.45
Stdev. [s]	11.68	9.01	11.35
≥ 20 s delay [%]	43	33	40
≥ 25 s delay [%]	34	14	29

Table 7: Compiled table of statistical parameters for vehicle delays.

Vehicles	**Scenario 1**	**Scenario 2**	**Scenario 3**
Avg. delay West [s]	8.07	7.75	7.61
Avg. delay East [s]	9.55	9.78	9.64
Avg. total delay [s]	8.91	8.87	8.72

Finally, as mentioned in the methodology, a combined result with both green and red crossings was made using Scenario 1 in addition to the three main scenarios. The signal colour distribution produced by the video analysis' Method 1, 34% green crossings and 66% red crossings, led to the result shown in Figure 18 and Table 8.

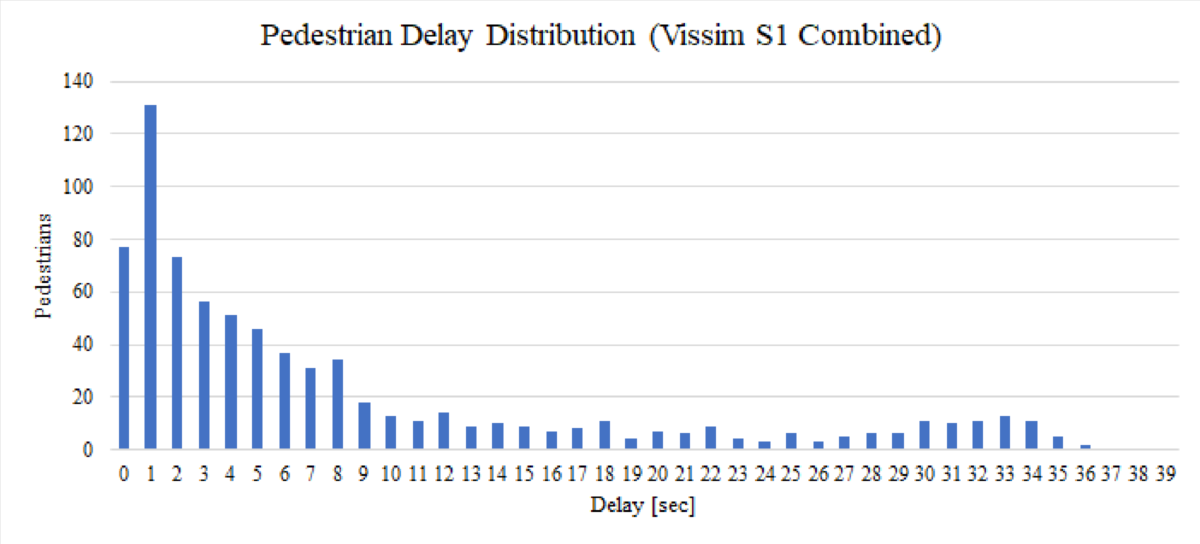


Figure 17: Delay distribution graph for green and red crossings combined.

The graph, Figure 18, has high quantities at low delays followed by a de-escalation. The quantities are, however, increasing towards the end. Table 8 shows the differences between the average delays for pedestrians crossing at green respectively red signal as well as a combined average delay. For delay distribution and statistical parameters corresponding to the red crossings, see Appendix I. Since pedestrians cross red signal at a rate of 66%, the average combined delay of 8.42 seconds is numerically closer to the average red, rather than the average green delay. The distribution table for the red crossings alone can be found in Appendix I.

Table 8: Average delay for green, red and combined crossings based on Scenario 1 and the signal colour distribution.

Pedestrians	
Avg. green delay	16.97
Avg. red delay	4.01
Avg. combined delay	8.42

6. Discussion

In the following section, the results and other select topics relating to the work will be discussed. The work, its difficulties, choices and goals will be reflected upon in a personal perspective, in order to provide deeper knowledge of the subject.

6.1 On-site Investigation

The result showed that the pedestrian flow was lower in the morning than in the afternoon. This could mean that commuting as pedestrian is not the dominant contribution, or this would be reflected onto the afternoon flows. A sizable portion of the pedestrian flows in the afternoon is instead probably visiting the site for recreational purposes. It could also be that since it was worse weather and a bit darker in the morning, more people would avoid being outdoors or perhaps get a lift on their way to work, but walk home when the weather was better. When you commute to work in the morning, the value of time might be higher than in the afternoon, when you are less pressed for time. The vehicle flows matched each other quite well, with the exception of the mornings east-flows being slightly lower than the afternoons west-flows. This difference could be made up of a portion of drivers going into town in their leisure time.

One observation made during our visits was that many pedestrians started crossing during the all-red signal, before it had switched to green. They would simply wait for the vehicles to stop, and realise that the signal would turn pretty soon, and walk prematurely. This is something that was clearly showing during our video analysis and Flowity output data, while not being covered due to hardcoded rules in Vissim. When thinking about this concept in generality, this seems to be quite normal in bigger cities, and perhaps not as dangerous as if crossing while vehicles had green signal. It is possible that perhaps one second of the all-red time could be removed in the signal control for the simulations, which could then improve the crosswalks efficiency. However, this could have other safety related issues for some cases which are less apparent. There needs to be a some margin, which depends on the standard deviation of for example reaction times for the road-users, and has probably been carefully calculated before. There are most likely strong reasons to why the crossing is configured and designed specifically the way it is, but traffic behaviours could also change in time compared to how it was when the crossing was designed. Thus, it could be wise to still reanalyse and investigate traffic points regularly, perhaps each ten years, to see how the situation has changed over the years.

One clear observation during the on-site investigation was that many pedestrians did not push the button when looking to cross. As the signals running at Artillerigatan are configured, this means that pedestrians will never get green signal, yet some still wait and experience unnecessary delays. This problem is thus the same as in the report *Fotgängarvänliga Trafiksignaler* (2007), as the crossing at Artillerigatan also using the same push box with indicator light visible every angle around it. In accordance with their research, our on-site investigation showed that this solution is not sufficient enough, at least not with only two of them on one side. The question remains of what else can be done to improve this system and encourage people to pay closer attention to the push button boxes. The same study suggested that using traffic signals with fixed time at pedestrian-rich crossings, where signals switch automatically without the need of a box, is a good choice. Thus, our use of fixed time in simulation is justified when looking to improve for pedestrians. A factor could be maintenance and sanitation, as people would for example be less willing to press on a dirty button box. Our notion was that the maintenance had been insufficient at the time of visitation, because of there being some graffiti and stickers on the signal heads, and one push box that did not work. The latter could also have affected the results of data collection for the video analysis, as the pedestrians would have had to walk over to the one further away to call for green signal.

6.2 Video Analysis

As previously mentioned in the result section, some of the issues that arose while working with Flowity in its current state of development was that the software often failed to retain specific IDs to select pedestrians. When discussing this matter more deeply with the developers, there are a number of factors not yet mentioned which could possibly affect it. With the sample date being in winter, most pedestrians have larger and thicker jackets and winter clothes, which alters the shape of the human body. It becomes harder to for example distinguish separate arms and legs. This could be a contributing reason to why pedestrians are more likely to become covered by one another, together with a high pedestrian flow. Flowity also seemed to struggle with bigger bags, umbrellas or backpacks, and in some cases partially interpret grocery bags as a minor holding the adult's hand. Another reason could be that, as current winter fashion goes, a large quantity of used clothing was in black or darker colours, creating a more homogenous pedestrian flow in terms of appearance. In summer and spring times, pedestrians tend to use more colourful, and colour variating clothing.

In a few cases there were pedestrians, either younger or with a smaller body size, who were partially covered by poles and other structural elements at the crosswalk while waiting. By standing very still in conjunction with this, Flowity was unable to detect these pedestrians. Their rather stationary behaviour as well as clothing in similar colours to the structures possibly had Flowity believe they were part of the structure. This could partially be mitigated with the choice of camera positions or angles, but for our research it was crucial to also be able to see and extract traffic signal data, limiting the choices. Some issues with structures or cars temporarily covering pedestrians were mitigated with the iteration using 100 frames as age, compared to the native 20, but this setting caused other issues such as the ID being retained in the system in cases when it should not, and thereby pass it on to another pedestrian. As previously mentioned, it also cause the footfalls to miscalculate to a high degree. Therefore, the optimal choice of age is also dependant on area and camera position choices, requiring fine tuning. Depending on budget and time, setting up two cameras could also be an option, where they could be positioned on either side of the crosswalk. This could also assist Flowity in cases where detection distance becomes an issue, or that pedestrians are far enough away that their frames are very small and can more easily intertwine. The cameras must then be configured to run at the same time intervals.

Lastly, the results of the analysis is very dependent on input material. One large potential source of error is of course the video sampling, in a multitude of factors. To begin with, it is more reliable to analyse flow and behaviour with an annual perspective, and with more frequent sampling. It is not feasible to do this for this research since it is only running in spring, or either way because of the high time consumption required. In a possible future, video analysis as a tool could potentially be used to improve in this manner, as one could set up a camera that records for a set program by itself, and thus not require many man hours. Other factors that comes with fewer sampling dates is the current situation. We did the sampling in February in accordance with a planned schedule, when the ground was still partially snow covered. In better weather, more daylight and warmer temperatures, it is more likely to see a higher pedestrian flow which could generate different results.

As was mentioned in the chapter about Flowity in the literature study, the software is compatible with GDPR. As such, it is legal and does not require the pedestrians consent. By being present while recording the videos, the law of surveillance in Sweden is also surpassed, as it is then considered private recording in a public place. The method of tracking people's phones through their Wi-Fi function to map their movements does not require consent either. But is it really okay to continue to push the limits of personal integrity? And how does this apply in other countries and places in the world? Integrity is an important factor to keep in mind as new technology and methods are being developed, if it is to fit into Sweden's democratic and liberal society. While the developers and entrepreneurs would prefer to have easier rules and regulations, perhaps it should not be. It is of our opinion that this type of research in smaller scales would result in more good than bad, and that the majority of people would not feel their integrity being interloped. It is however good to be open and spread information on exactly how the functionality works, and that their identity is not being kept in data. Lastly, perhaps the future will hold new and harsher laws, further increasing the difficulty of performing research in this way.

The idea of using video analysis instead of other methods such as manual counting is for a number of reasons. We mentioned in the hypothesis that it ought to make it easier when analysing more complex parameters, such as delays, crossing red or green signal, frequency of button pushing etcetera. Another would be to be able to collect larger sample sizes for a more accurate result. As such, the key to achieve the purpose lies in making the analysis method easy to use and readily available. While we do not know much about the costs involved, they ought to be lowered by reducing the amount of working hours needed for data collection, depending on the thoroughness of the analysis. In future the output data needs the option to use a graphical user interface, GUI, that can calculate the required information by itself rather than just raw data.

6.3 Traffic Simulation

As seen in the traffic simulation result, Scenario 2 has the lowest delays for pedestrians. One reason to the decreased average delay is the reduced cycle time that, in accordance with the literature study, favours pedestrians. Another reason may be the fact that the ratio between pedestrian green time and vehicle green time has increased a little compared to the real-world scenario. The adjustments made in Scenario 3 were not that dramatic when it comes to the cycle time, as only one second was removed, and therefore the result is not that astounding either. The security for pedestrians is on the other hand higher in this case since the motorised traffic drives 10 km/h slower than before, which can save lives. Another important factor when comparing the results from the three scenarios is to look at the percentage of delays exceeding 20 or 25 seconds since this is the limit when people tend to become disproportionately agitated. Getting irritated is a negative experience and we think that if Gothenburg want to become a more pedestrian friendly city, these negative experiences must be reduced. The reason to why we chose 20 and 25 seconds instead of 20 and 30 seconds, which was the interval mentioned in the background, is because we were interested in a middle value of the interval as well as the “lowest” limit.

The three graphs with delays presented in Chapter 5.2 have, as mentioned earlier, different appearance. However, a common thing between them is that the three first columns, representing zero, one and two seconds delay, are the greatest. The reason to this is, as mentioned in the result, the fact that all pedestrians that arrive to the crosswalk during green signal are not exposed to delays caused by traffic signals but rather other factors such as throng. The two first scenarios have also high columns close to the ends of the graphs, between 30 to 35 seconds for Scenario 1 and between 24 to 26 seconds for Scenario 2. A reason to this might be the number of pedestrians that get stuck at the traffic island during red signal and are therefore exposed to the highest possible delay. Depending on where the pedestrian was when the traffic signal switched, the delay at the traffic island can vary with a few seconds, as seen in the graphs. It is more difficult to interpret why Scenario 3’s graph, Figure 17, is an equalisation of the delays. We do not have an answer to how one second of reduced cycle time induce this appearance, but one possible reason could be the choice of the specific simulation run. As was described in the methodology, the simulation runs analysed were chosen between ten simulation runs for each configuration. Even though the average values of the chosen run matched the total average well, it does not say anything about whether this particular runs’ distribution was representative. In order to know for sure, all ten runs had to be further analysed in depth, which is excessively time consuming.

As mentioned in the methodology, Scenario 2 was aimed to be a traffic signal adjustment and Scenario 3 a more infrastructural adjustment. The purpose of the adjustments made to the base simulation model in Vissim was to mainly improve for pedestrians. The delay for vehicles are, in line with the scope of the thesis, just a secondary prioritisation. However, if any solution is to possibly be introduced to the existing network in reality, it has to be feasible. Therefore, we have ruled out some of the very radical solutions to pedestrian improvement, such as removing one car lane of the double-lane going in western direction. Scenario 2 was based on multiple test simulation runs to get an understanding of what changes that affects the delays the most. While doing these test runs, we saw some output delays that were lower than the final Scenario 2’s delays. As mentioned earlier, delays were not the only crucial parameter taken into account. One test simulation that was done, with eight seconds green time for pedestrians and fifteen seconds green time for vehicles, generated a lower average delay for pedestrians in comparison to the presented Scenario 2. These adjustments were however abolished since the traffic signal is going to switch from green to red before reaching the other side which will lead to stress and reduced perceived security among pedestrians. We know that all pedestrians that enter the crosswalk during green signal will reach the other side or at least the traffic island before vehicles would have green signal. The pedestrians themselves might not be as informed or receptive to this, and might believe they are in danger if they are in the middle of the road as the signal switches to red. Hence, the responsibility of the traffic signal programmer is to counteract this and still retain a safe traffic point.

Additionally, we used the efficiency criteria mentioned in the literature study to assist our decisions on which adjustments we ought to do. Initially we had the notion that we needed to keep in line with Little's criterion, as in improving for pedestrians while only marginally worsen for vehicles. The pedestrian delays would become much better, but that it perhaps would become slightly worse for vehicles. This criterion was achieved successfully. However, as was shown during the simulation iterations, we had the possibility to also instead fulfil a Pareto criterion, which as mentioned, is the more preferable outcome according to Little as well. With the specific adjustments described in the presented Scenario 2, the pedestrian delays became lower, as well as the vehicle delay when compared to average values. When looking per lane however, one lane direction for the vehicles received slightly higher delays, so with this point of view, only Little's criterion was fulfilled. Scenario 3 had less focus on the efficiency criterions, but also managed to fulfil a Pareto criterion with the exception of one lane's delays. The differences for this particular lane are very small, and is within the margin of error. Thus, it cannot conclusively be said that it would become any worse, but the improvements are smaller in size than compared to Scenario 2. However, this way of reasoning is possibly incorrect, as some of the delay experienced by vehicles in Scenario 3 is then moved into a higher travel time, as the speed limit was reduced. As such, it is not conclusive that it is better for vehicles, in which case only Little's criterion was fulfilled. Kaldor-Hicks criterion was most likely fulfilled however, as besides the delay improvement for pedestrians, other factors such as security weighs it up.

The graph of S1 Combined, Figure 18, with the combined green and red delays was, as mentioned in the methodology, an attempt to recreate the current state of the traffic point through the use of the signal-colour distribution obtained from the video analysis. The appearance of the graph is seemingly realistic with high quantities at low delays followed by a de-escalation. However, since the settings made in Vissim only allowed green crossings for Scenario 1, there is a possibility that some pedestrians with a high delay would have lost patience and crossed before signal switch. Thus, many of the highest values would have been removed. On the other hand, when having crossings in Vissim without traffic signals, the pedestrians would to a greater extent find gaps in the traffic which in reality would not be comfortable in a safety perspective. Additionally, all pedestrians crossing red signals might not have the intention of doing so initially. Therefore, they generate some waiting time until they find larger gaps in between vehicles, incentivising them to cross anyway. As these factors counteract each other, the new combined average of 8.42 seconds delay is quite reasonable. This number is in a direct comparison to the total average delay from Method 2 in the video analysis, which value of 8.13 matched quite well. Thus, the results further confirm the credibility of both methods.

In accordance with the delimitations of the thesis, the traffic simulations were made with the simplification of using fixed time rather than centrally controlled VAP, as it is in reality. When doing simplifications like these, it can be important to evaluate the legitimacy of such an action. The perceived situation that occurred during the hour of observation was that the pedestrian traffic flow was high and relatively consistent in green signal demand. The green time seemed to always be queued, and applied as soon and as often as it was allowed. As such, it was deemed to be, for the current situation, not very far from what a setup with fixed time would have been. Another argument was that the thesis aim is not focused around traffic signal programming per say, but more on pedestrian delay analysis. VAP programming and experimentation would have required more time in planning, while perhaps not generating a result much different than that of fixed time. One strong point that possibly could have affected our results to a point of large difference would be the limited use of the push button. Outside of a regular green time demand, some larger red signal-phases were strictly due to the pedestrians not queuing for the green signal. This would have been the main difference. However, if one is to improve this crosswalk, our hopes would be that this issue is addressed in some way, thus eliminating this factor. The results seem realistic despite this simplification, confirming that the difference perhaps would not have been large.

Lastly, the amount of red crossings made is quite alarming, and could indicate that an improvement to the crossing is needed. By implementing the adjustments made in Scenario 2, we believe that the amount of red crossings will be significantly reduced. However, there are also many other potential actions that can be taken in order to reduce it. For example, increasing the knowledge of the pedestrians about the dangers as well as it being illegal. This could be done through campaigns and advertisements. The crossing could also more visually and audibly express danger when the signal is red, to discourage this behaviour. Social structures built up through the society is a large contributing factor to promote this behaviour. Thus, in a long term perspective, the structure has to be changed gradually. By for example thoroughly teaching children in kindergarten traffic safety at a young age, they should then be less adaptive to other people's unsafe behaviours, carrying out a societal change.

6.4 General Discussion

Through the literature research, it was concluded that for many elderly, the average walking speed was as low as 1.2 m/s or even lower. As we wanted to base our research and improvement on being including, and able to satisfy the needs of all types of pedestrians, we initially had our minds set on applying this to the work. However, this seemed to be incompatible with both site observations as well as the technical parts the thesis, namely video analysis and model simulation. The traffic signal would have become much too inefficient, and was clearly not set this way to begin with. During site observations, there was a very small amount of elderly or otherwise movement-impaired pedestrians, thus a faster more realistic value needed to be used.

For the video analysis methodology we selected the rough value of 1.4 m/s, which then was applied as the calculated value of two seconds to account for the travel time through each waiting box. The value is slightly lower than the average for regular pedestrians of 1.6 m/s, according to the literature study. The reason was that it is observed in reality that pedestrians are quite irregular in their movements, both by speed and by select path. The value of 1.6 m/s assumes walking in a straight line with an even walking speed. As such, the chosen value needed to be lower to account for slight detours, varied walking speed dependant on observations and other distractions as well as hindrance by other pedestrians. The chosen value also seemed to match well with manual observations as an average.

For the traffic simulations, the default values for pedestrian speed were quite low. In the PTV Vissim Manual, the speed distribution classes which were originally assigned, were described as male or female between age 30 to 50 walking onboard ships. The lower boundary for women was as low as 2.56 km/h, or about 0.71 m/s, which seems unrealistically low. Hence, we created a new custom speed distribution class with 1.2 in lower and 1.7 in upper boundary as was mentioned in the methodology. Through literature research, these boundaries seemed to match well with the values between some of the more elderly pedestrians to young fast-walking men.

Seeing how the walking speed both in research and through some of the standard speed distribution classes in Vissim are so variated, many thoughts as to why arose. One large reason could be the fact that the Swedish population is rather tall compared to many other places in the world. With longer legs comes larger steps, thus increasing the speed. Another could be based on the culture of the city or country, where perhaps children would be taught early on to walk fast or slow as a natural element of living. In larger cities, stress and delays could potentially be larger, requiring the individual to "catch up" and start developing a behaviour of walking faster than usual. As such, it could be quite important to be wary of which pedestrian speed to take into account while working with pedestrian related projects. A strong recommendation is to prioritize using local research from same or neighbouring countries, where pedestrian behaviours are more similar.

Walking speed is a natural limitation to catch up from the time losses pedestrians are exposed to. To have a possibility of doing so, they need to increase their speed by running. This might feel exhaustive and the probability of pedestrians doing this is quite low. It is less of a hindrance to slightly increase the speed while driving a vehicle for example. An average walking distance in the city of Gothenburg might be between zero to two kilometres, and it is very likely to come across more than one crosswalk during the trip route. The total delay during the trip route can thus be very high in comparison to the actual distance. This is one reason to why pedestrians should be more prioritised within the city. On the other hand, what happens if vehicles always have to give way to pedestrians? It will most likely lead to more vehicle acceleration and deceleration, which is negative for the environment and contributes to more noise pollution. Therefore, it is important to have this in mind while doing adjustments in the traffic signals. From an environmental perspective, a green wave for vehicles can be preferable. Unfortunately, a green wave prioritises vehicles, thus there is a risk that vehicle traffic increases which counteracts any of those environmental improvements.

Crosswalks with a green time distribution catered towards vehicle traffic are common and widespread. Especially when public transport in the form of trams and buses require it. This results in a scenario where road-users are disproportionately prioritised, as was a problem highlighted in the literature study. As previously mentioned, the pedestrians will avoid waiting if possible, including avoiding signals and crossing informally, which creates strong safety implications because most pedestrian accidents occur in this manner. Thus, reducing the delay will encourage signal compliance and willingness to cross at signalised intersections, making it easier to regulate crossings safely. So the bigger questions are whether the delays are even and fair between pedestrians and vehicles for our crossing at Artillerigatan, and what can be done to further increase knowledge about this and have network designers emphasise on it. It is possible that the total delay per road user would be reduced heavily with more pedestrian priority. This is because despite the vehicle and pedestrian traffic flows being roughly equal, the delays are not. As the trend of interest for pedestrian traffic continues to grow, existing issues can hopefully be addressed to a larger extent and sooner dealt with.

7. Conclusion and Recommendations

The purpose of the master thesis was to perform a multi-method analysis on pedestrian delays at a crosswalk on Artillerigatan in Gothenburg. From the result and discussion chapters of the thesis, certain conclusions and recommendations are summarized to evaluate the research.

The quantities of pedestrians were higher during the afternoon hour compared to the morning hour. Many pedestrians crossed prematurely, before the signal had switched to green. It is later confirmed through video analysis that about 66% cross at red signal, which is quite alarming. The use of push buttons was limited, hence why redesigning the signal system to fixed time during high traffic hours could be a good improvement.

The use of Flowity as a tool for video analysis has great potential, allowing for larger data sample sizes and acquire more complex data than what is easily done manually. The software is continuously developed to adapt to customer demands as well as rules and regulations such as GDPR. However, many of the statistical parameters obtained from the video analysis were unrealistically low. This is largely due to Flowity struggling with retaining IDs to specific pedestrians. Only about 27% of the sample size was able to be used. As such, the software needs more improvements to be reliable enough for this kind of analysis. The angle of the camera affects the detection, a high position is therefore recommended. It is also recommended to do video analysis in warmer weathers. Despite software limitations, a somewhat realistic result was obtained, using different methods. The average delay for pedestrians in Method 2 was 8.13 seconds. Based on the average red delay, the average green delay was in Method 3 calculated to 13.71 seconds.

The delay distribution in the traffic simulation results showed conclusively that a large quantity of delays were within the zero to two second interval, but there were also high values at the end of the spectra. The total average delay was 16.97 seconds for the real-world scenario. With the signal adjustments made in Scenario 2, involving lowered cycle time, the delays for pedestrians were significantly improved with 3.84 seconds reduction, fulfilling Pareto’s criterion. The share of high-delay trips was also reduced. The crossing fulfilled Little’s criterion with the more infrastructural change made in Scenario 3. At the cost of increased travel time for vehicles, the delays and security of pedestrians saw small improvements. As the adjustments seem reasonable based on criteria, Scenario 2 is a recommended suggestion for pedestrian traffic improvement.

In order for Gothenburg city to reach its goals regarding an increased share of trips on foot, pedestrians need more prioritisation. Annoyingly high delays must thus be reduced to prevent negative perception towards walking as transportation. The city can also see improvements in many other factors besides pedestrian delays. Research on pedestrian behaviour should further be emphasised, and localised from the city, country or neighbouring countries.

References

Anciaes, P. R. & Jones, P. (2017). Estimating preferences for different types of pedestrian crossing facilities. *Elsevier*, 223.

Aultman-Hall et al., L. (2009). *Assessing the Impact of Weather and Season on Pedestrian Traffic Volumes.*

Beca. (2009). *Reducing pedestrian delays at traffic signals.*

Bjerhem, J. (2019, March 20). Pedestrian data collection. (J. Greger, & L. Wrede, Interviewers)

Centre for Transport Studies. (2012). *Experiences from the Swedish Value of Time study.*

Erlandsson, A. (2019, May 2). Drönarbild över Artillerigatan. Gothenburg.

Federal Highway Administration. (2016). *Traffic Monitoring Guide.*

Fi, I. & Igazvölgyi, Z. (2014). Travel time delay at pedestrian crossings based on microsimulations. *Periodica Polytechnica Civil Engineering*, 48.

Göteborgs Stad. (2019a, May 14). *Resvaneundersökning 2017*. Retrieved from https://goteborg.se/wps/portal/start/gator-vagar-och-torg/gator-och-vagar/statistik-om-trafiken/resvaneundersokning/

Göteborgs Stad. (2019b, May 14). *Trafikutveckling*. Retrieved from https://goteborg.se/wps/portal/start/gator-vagar-och-torg/gator-och-vagar/statistik-om-trafiken/trafikutveckling

Göteborgs Stad. (2019c, May 14). *Gamlestadsskolan F-6, 7-9*. Retrieved from https://goteborg.se/wps/portal/start/forskola-och-utbildning/grundskola/valja-skola/hitta-forskoleklass

Herrstedt, L. (2012). *Nordic Human Factors Guideline Ganghastigheder.*

Karlsson, P. & Nilsson, M. (2017). *Kartläggning av trafiktekniska mätningar och hur kommuner använder dem.*

Kronborg, P. (2007). *Fotgängarvänliga trafiksignaler.*

Lund, B. l. (2006). *Blinkende fotgængersignaler.*

Nordén et al., M. (2018, May 29). *"Sänk hastigheten till 40 km/h i alla tätorter"*. Retrieved from https://www.svd.se/sank-hastigheten-till-40-km-h-i-alla-tatorter

NTF. (2019, May 14). *Hur fungerar trafiksignaler?* Retrieved from https://ntf.se/fragor-och-svar/trafikmiljo/opinionsgrupper/hur-fungerar-trafiksignaler/

Pettinger, T. (2017, November 28). *Kaldor-Hicks Efficiency*. Retrieved from https://www.economicshelp.org/blog/glossary/kaldor-hicks/

PTV Group. (2017). PTV Vissim First Steps Tutorial. Karlruhe, Germany.

PTV Group. (2018, September 24). PTV Vissim 11 User Manual. Karlruhe, Germany.

PTV Group. (2019, May 14). *PTV Vissim*. Retrieved from https://www.ptvgroup.com/en/solutions/products/ptv-vissim/

Roess, R. P. & Prassas, E. S. (2014). *The Highway Capacity Manual: A Conceptual and Research History* . Springer.

Satellitkarta.se. (2019). *Turistkarta Göteborg*. Retrieved from https://www.satellitkarta.se/eu/stgot.html

Shailes, K. (2019, May 14). *Compensation Principle of Kaldor, Hicks and Scitovsky*. Retrieved from http://www.economicsdiscussion.net/welfare-economics/compensation-principle-of-kaldor-hicks-and-scitovsky/

Städje, J. (2015, August 29). *Så håller Trafikkontoret koll på 11000 trafikljus*. Retrieved from https://techworld.idg.se/2.2524/1.635562/sa-haller-trafikkontoret-koll-pa-11-000-trafikljus/

Tedblad, R. & Brendelökken, P. (2019, February 21). Interview about Flowity. (J. Greger, & L. Wrede, Interviewers)

Trafikkontoret. (2018). *Göteborgs Stads fotgängarprogram 2018-2015.* Gothenburg.

Trafiksakerhet. (2019, May 14). *Trafiksignaler för fordon och gående*. Retrieved from http://www.trafiksakerhet.se/trafiksignaler.htm

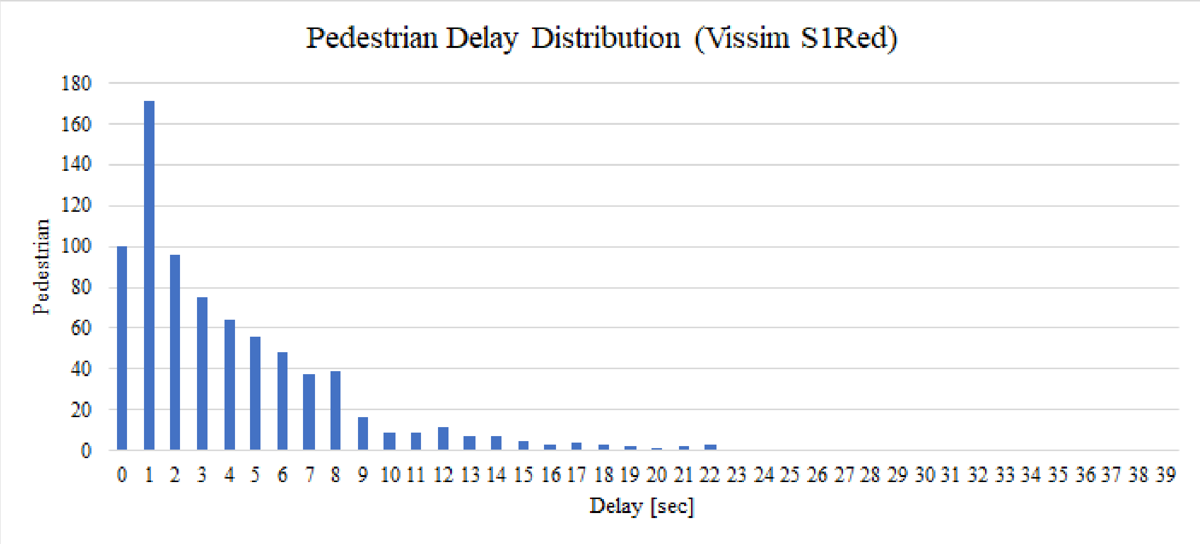
WSP. (2016). *Trafikanalyser; Makro-, meso och mikrosimulering.*

Västtrafik. (2019, February 5). *Reseplaneraren*. Retrieved from https://www.vasttrafik.se/reseplanering/reseplaneraren

ÅF Digital Solutions. (2019, May 14). *Detektera*. Retrieved from https://www.flowity.io/se/detect

Appendix I

Delay distribution and statistical parameters for the traffic simulation's Scenario 1 Red, with vehicle priority and no traffic signals.



Pedestrians	**Scenario 1 Red**
Avg. delay [s]	4.01
Med. [s]	2.70
Stdev. [s]	4.01
≥ 20 s delay [%]	6
≥ 25 s delay [%]	0